# Business Case Evaluation Methodology (BCEM) for Factories Digitalization

A quantitive approach to digital transformation assessment in industry domains

Roberto Rocca, Giacomo Tavola, Filippo Boschi, Paola Fantini, Marco Taisch
Department of Management, Economics and Industrial Engineering
Politecnico di Milano
Via R. Lambruschini 4/b, 20156, Milano, Italy
email:{roberto.rocca, giacomo.tavola, filippo.boschi, paola.fantini, marco.taisch}@polimi.it

***Abstract*— In the last years, the fast evolution towards automation and digitalization of production systems is forcing companies in re-thinking their business strategies and models. To overcome manufacturers' conservatism, migration strategies and business case evaluations are required to assess, support and guide adoption of the next generation of smart production systems. This paper proposes a Business Case Evaluation Methodology (BCEM) to support companies that aim to migrate from legacy automation systems towards the Industry 4.0 paradigm. The aim of the proposed approach is to assess the profitability of the investment in advanced technologies for the decentralization of industrial automation control architectures, evaluating opportunities and mitigating the risks of migration from technical, operational, human and business perspectives. The methodology implements an iterative approach starting from the definition of the current business and operational status of the factory and the identification of business goals; progressing towards the identification and evaluation of possible migration paths; ending with the selection of the optimal one according to a cost-benefit analysis. The paper presents two exemplary applications in real industrial environments, developed in the scope of FAR-EDGE European Project.**

***Keywords-Industry 4.0; digital factories; migration strategy; business case evaluation; investment assessment.***

## I. INTRODUCTION

Due to volatile and fast moving markets, increasing competition, as well as more complex products and production processes, industrial companies are facing increasingly intricate challenges [1]. Among these, digital transformation represents one of the biggest challenge that a company has to face nowadays [2], since it represents not only a technical issue, but also a cultural shift. In fact, the change does not only affect processes, but they require a shift from the present company values toward a continuous improvement philosophy. Within the modern industrial environment, this transformation refers to the processes that lead to the adoption of the Industry 4.0 (I4.0) paradigm. Even if the term has existed for some time, only a few organizations can claim to have reached a mature implementation. I4.0 refers to the industrial exploitation of Cyber-Physical Systems (CPS) for the intelligent decentralization in the factory. The result is the so called "smart factory" where, Information and Communication Technology (ICT), Internet of Things (IoT), Customer-to-Machine (C2M), Customer-to-Customer (C2C), Machine-to-Machine (M2M) communications [3]–[5] are integrated with distributed sensing, processing and actuating capabilities. Altogether these technologies enable a new paradigm for production management, driven by a better situation awareness, built on collection and analysis of big data. For the companies, in order to compete on the market, it is crucial to be able to promptly address market challenges with leading strategies [6]. That implies the adoption of flexible, lean, fast, agile, efficient, systems with prompt and reactive decision-making process. In spite of the benefits, the important impact of the potential technological and organizational changes has prevented many companies from adopting a full I4.0 strategy or even systematically investing in I4.0 capabilities [1]. Two relevant common barriers are: (i) high investment costs due to a lack of I4.0 suitability of the existing production infrastructure and (ii) missing transparency or quantification of benefits [1]. Moreover, this change has to be driven by clear managerial leadership. Accordingly, there is a fundamental need for assisting companies in the transition to I4.0 technologies/practices, and guiding them for improving their capabilities in a standardized, objective, and repeatable way [7]. The intent of this paper is to present a Business Case Evaluation Methodology (BCEM) that gives support to the companies that intend to migrate towards factories digitalization, considering a holistic approach from the technical, operational, human and business perspective.

The rest of this paper is organized as follows. Section II describes the BCEM for factories digitalization assessment. Section III describes two methodology application cases developed within the FAR-EDGE European Project context. Finally, Section IV draws some final conclusions.

## II. BUSINESS CASE EVALUATION METHODOLOGY FOR FACTORIES DIGITALIZATION

The starting point of a migration path is commonly referred to as AS-IS situation, while the final goal is named TO-BE situation. Figure 1 shows the framework of the migration process and BCEM proposed in this paper.

The figure frames the steps 2-3-4-5 under the concept of Blueprint migration [8]. Blueprint refers to an early plan that

 ISBN: 978-1-61208-736-8 

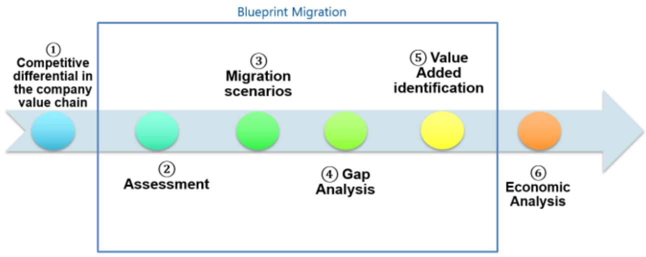


Figure 1. Business Case Evaluation Methodology framework

explains how something might be achieved. The comparison of the different strategies implies the comparison of several features, such as risks, migration design time, migration execution time, downtime, costs and effort [9].

In addition to the company managers involved in the assessment, the methodology requires a collaboration with OEMs and solution providers.

The procedure is described in the next sections, following a stepwise order.

### A. Step 1. Competitive differentials in the company value chain

The digital transformation should not be considered as a stand alone solution, but rather considered as a powerful lever to be integrated within the strategic processes of the enterprises. For this reason, the first step of the methodology aims to open the way toward digital transformation, trying to assess the potential benefits for the enterprise value creation and business model, taking into account the competitive landscape.

By identifying the relevant Key Performance Indicators (KPIs), applying the Strengths, Weaknesses, Opportunities and Threats (SWOT) analyses and an adaptation of the Porter's value chain model, different ways of designing the digital transformation can be analyzed.

In fact, the SWOT analysis [10][11], is very suitable since it guides the identification of business changing factors through a clear and meaningful way. It can be used effectively to build organizational and competitive strategy in a migration context.

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

Porter's model highlights the main activities (primary and secondary) that allow the company to create value and, although its original formulation requires to be revised in order to overcome the functional segments of the classic corporate structure, it is still valid [12][13].

Overall this first section set the strategic frame for developing the Blueprint Migration and performing the economic analysis.

### B. Step 2. Technical, Operational and Human assessment

The main goal of BCEM Step 2 is to clearly define the AS-IS situation in the technical, operational and human dimension. The three-dimensional structure has been adopted to offer a holistic perspective on the migration. To assess the various issues related to the three dimensions a maturity model has been developed and exploited within the context of FAR-EDGE EU project [8]. The maturity model rate from 1 to 5 the digital maturity or readiness of the considered aspect: the value 1 indicates a low or non-existent development, while 5 refers to a cutting edge implementation [14]–[18]. The assessment in Step 2 maps a first overview of the application context where the company is interested in reaching a higher maturity level. The final framework will be completed in Step 3 after the consulting of external experts.

### C. Step 3. Migration matrix and scenario definition

The tool for the holistic representation is the Migration Matrix [8] and it allows to map the AS-IS and the TO-BE scenarios. It is used as a tool to conceptualize and measure the readiness or maturity of the enterprise regarding some specific target state. In this way, it is possible to identify the AS-IS situation of overall dimension analyzed, enabling the possibility to define the starting point for the digital transformation. There could be more than one way to reach the desired result and the TO-BE scenario could not be unique. In fact, 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 Step 1. It can be referred to a mutually exclusive situation when more than one solution is considered to solve the same industrial problem (e.g., different technologies or resources are involved). On the other hand, the TO-BE scenarios can be referred to a mutually inclusive situation, when more than one solution is considered to solve different industrial problems. Once the scenarios are fully determined, then their description in the final Migration Matrix is portrayed. Initially, the rows are characterized, then for each one of these, the five maturity levels are specified. The final result implies one Migration Matrix for each scenario where it is depicted only one AS-IS status and one specific TO-BE status. The selected alternatives are then evaluated according to the business strategy, considering also outcome of BCEM Step 1.

### D. Step 4. Gap analysis

Gap analysis between AS-IS and TO-BE scenarios represents an outcome of the collaboration with solution providers. Required components, possible integrations and steps for application are the three main steps to carry on. Required components represent a detailed list of the additional components, operations, and new professional skills required for each scenario migration. Possible integration to the defined architectures has to be taken into account since they enable system flexibility and easier future updates: a non-quantitative data which should be considered when deciding which migration to choose. Then, the steps required for the implementation of each scenario include costs and time evaluation for the overall migration completion which are very relevant in the economic analysis. Steps for application provides general instructions for the implementation of the technology starting from the AS-IS status.

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### E. Step 5. Value added identification

The value added section aims to justify the efforts spent by the company on the use case implementation. The complete definition of the scenarios allows to foresee the quantitative and qualitative improvement of the system. Value added has a double meaning:

- KPI improvement. A quantitative and measurable increase of system performance with respect to the AS-IS situation.
- Unmeasurable advantage. A benefit derived from the new system which has a positive impact on one of the three migration dimensions (e.g., flexibility of a specific process). 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, the metrics needed for the KPIs improvement calculation are case specific.

### F. Step 6. Economic analysis

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. The unmeasurable advantages and disadvantages which cannot be translated in economic value are not part of Step 6. First, the KPIs improvement is translated into money and the results are addressed as Economic KPIs or Benefits. The Economic KPIs estimation is not always straightforward. Being the benefits computation use case dependent, it is impossible to provide a complete framework. Nevertheless, we can identify a common tool to be used as reference framework: the Total Cost of Ownership (TCO), that could be adopted for cost evaluation [19]. 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. A subdivision is made between upfront implementation costs and recurring costs.

The investment is evaluated on a fixed time interval with a Discounted Cash Flow approach and the specific case assumptions for the economic analysis have to be declared. The Net Present Value (NPV) is an economic index which measures the value acquired by the company associated with the investment. The Cash Flow (CF) of year $t$ is computed taking into consideration the differential analysis between the TO-BE and the AS-IS scenario. Moreover, the Profitability Index (PI) is considered. It is a relative index of profitability and it is defined as the discounted cash flow divided by the discounted investments. The Internal Rate of Return (IRR) is also considered in Step 6, since it represents the maximum risk for which the investment can be considered viable. 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. Of course, the best case is verified when the DPP is as short as possible. NPV, PI, IRR and DPP are indexes which defines the economic success of a project, and they are also a measure to compare more than one solution, as in the case of multiple scenario evaluations. The final decision to implement or not one or more of the defined project is the final point of the methodology. The migration process defines qualitative and quantitative reasons to guide decision-making activity.

## III. BCEM APPLICATION: TWO USE CASES WITHIN THE H2020 FAR-EDGE CONTEXT

The entire methodology has been developed and tested within the Horizon2020 FAR-EDGE European Project context, with the scope to perform an economic and technical analysis of the digital transformation process toward I4.0 technologies. The main goal of the project is to create a novel Reference Architecture (RA) for industrial automation, which leverages the benefits of edge computing, while using blockchain technologies for flexible, scalable and reliable configuration and orchestration of automation workflows and distributed data analytics [20]. The two BCEM application cases are represented by (i) a world's top white appliances manufacturer company and (ii) a leader company in the automotive sector. A summary of the two use cases applications, following the stepwise order that characterizes the methodology, are reported below.

### A. Use case 1. Durable goods company

#### 1) Step 1. Competitive differentials in the company value chain.

The business objectives of this company, which interest in re-shoring will allow the consolidation of production volumes in Europe, are on (i) improving quality, (ii) time to market, (iii) costs, as well as (iv) system architecture. Better and more efficient utilization of data generated at the shopfloor level can enhance both the capability of filtering defective parts and products and increase the productivity. The achievement of these objectives starts from the manufacturing field, where the investment in improving technologies can decrease the number of factory defects at the lowest cost. The FAR-EDGE technologies in this sense impact on automation, simulation and analytics, both on the technological process and on the company's organizational processes. As a starting point it has been applied a SWOT analysis in order to comprehend the strengths, weaknesses, opportunities and threats of the FAR-EDGE Architecture implementation within the company plant. FAR-EDGE projects with its innovative decentralized structure could enhance system flexibility, adaptability and reliability. The SWOT analysis and Porter's value chain 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. The technology development which should implement and maintain the new architecture enables the improved data management. The human resource management which is responsible for employees training and hiring digital skilled people. The primary activities, where the smooth and lean migration is focusing on, are out-bound logistics and services, nonetheless, production data should be collected from the operations in order to optimize the products dispatching. At this point, the KPIs were identified after having got a clear idea about the potential application field of the project: (i) sorter OEE, which improvement is computed as the ratio between the fully productive time and the planned production time; and (ii) sorter reconfigurability.

*2) Step 2. Technical, Operational and Human assessment.*

The AS-IS matrix has been developed on multiple levels, describing the technical, operational, and human aspects where the company should increase its readiness or digital maturity to reach a satisfactory solution leveraging on the FAR-EDGE platform. The use case described is almost a green field scenario: all or most of the technological content of the AS-IS system was not present. In this case, the starting maturity levels of the migration matrix are very low and the solution is built from the beginning.

*3) Step 3. Migration matrix and scenario definition.*

In the TO-BE system architecture, each smart object is managed by an independent Edge Node. Edge Nodes are of fundamental importance, since the information from the field can be managed and processed in each smart object in order to modify the dispatching policy accordingly. All the nodes communicate within a Distributed Ledger smart contract called Collaborative Sorting.

*4) Step 4. Gap analysis.*

It was possible to identify in this use case a unique migration scenario because of the specificity of the industrial problem and two main areas can be identified among the FAR-EDGE components utilized for the accomplishment of such a result: (i) Cyber Physical System: all the smart objects are represented and configured on the Distributed Ledger; and (ii) Simulation Services: its goal is to suggest an optimized sorting policy exploiting real-time data from the field. Simulation services include local monitoring and control of the real-time situation through the Edge Nodes. Collaborative Sorting recognizes the change in the state of the system and adapts the dispatching rule accordingly.

The gap analysis has also highlighted additional tasks and competences required for managing and maintaining the systems.

*5) Step 5. Value added identification.*

The final consultation with the experts estimates a possible growth of the KPIs identified in Step 1. The Sorter OEE will increase by 5% and the sorter reconfigurability will improve significantly. A situation dependent analysis is part of the next section of the methodology. For what concerns 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 M2M collaboration in the operational dimension. For the human dimension, the number of stressful emergency breakdown situations is reduced and the reconfiguration of the system is not manual any more. On the other hand, the IT system becomes more complex and requires that different groups of employees are trained to acquire new technical skills.

*6) Step 6. Economic analysis.*

Accordingly to the last step of BCEM, the economic appraisal is then performed. First of all, 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.

Finally, the Discounted Cash Flow appraisal is calculated. In this case, the TO-BE scenario implies a favorable economic perspective. Alongside a consistent initial investment, the NPV is significantly positive after 10 years. 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.

*B. Use case 2. Automotive sector company*

*1) Step 1. Competitive differentials in the company value chain.*

The second project use case is represented by a leader company in the automotive sector. This use case exploits ERP, MES and SCADA to collect data from the sensors on the field. The digital knowledge is widespread and is part of the group strategy, in fact, they already participated to research projects related to I4.0. The mass customization causes a high complexity of the assembly systems, it provides a strategic advantage to target niche markets and meeting diverse customer needs in a timely fashion. In such a system operations standardization, production scheduling optimization, as well as scrap reduction are of fundamental importance. It is adapting to the new environment by a changed organizational structure, larger involvement of the end customer, smaller and less complex development projects and closer partner collaboration.

The qualitative analysis underlined the possibility to implement two main target KPIs for the project:

- Tools adaptation time: automatic reconfiguration of the nutrunners could decrease the setup time.
- Rework rate: a second effect would be the facilitation of the operators’ job by relieving the stress of the repetitive operation of setting the right tool’s parameters. This would imply an overall reduction of the rework rate due to human errors.

 ISBN: 978-1-61208-736-8 

*2) Step 2. Technical, Operational and Human assessment.*

Thanks to the collaboration with company experts and technical solution providers, AS-IS scenario has been mapped. In particular, the assessment highlighted that the scheduling activities are not supported by simulation services and the products are chosen from the large buffer upstream the finishing lines in a "first in first out" order. This provokes delayed deliveries due to non-optimized sequencing. The high number of degree of freedom of the assembly line has to be tackled with flexible interchangeability of the operations through the station. Currently, the tools along the lines are set up manually and for this reason, could lead to erroneous parameters imposition. In this case an automatic tool able to auto reconfigure according to the activity that has to perform could dramatically reduce setup time required by the operator to tune the parameters and at the same time guarantee a standardized replicability of the single operation excluding the human error factor.

From a human competencies point of view, it can be underlined a lack of competences in the Edge computing and distributed Ledger technologies. This gap is justified by the fact that such technologies are very advanced and in some cases never used in the manufacturing world. FAR-EDGE project will have to fill this gap and guide the use cases until the achieved result.

The AS-IS matrix identifies the usual characterization of the current situation from the technical, operational and human perspectives. The migration starting point is a brownfield scenario [8]: smart objects and sensor, as well as data management already exist in the shopfloor. Summarizing, the MES is in charge of automating and distributing the order processing throughout all the shopfloor. Work performance and production performance are monitored exploiting the Factory Control System (FCS) and ERP. A CAD system is present and it is fed manually with production data but it is not able to optimize the buffer policy. The tools reconfiguration is made manually by the operator to which is not required any digital knowledge, while the skills for I4.0 belong mainly to IT department experts.

*3) Step 3. Migration matrix and scenario definition.*

The FAR-EDGE project can provide three powerful tools for several improvements in this mass customization use cases:

- Simulation services embedded in the platform could partially solve the tardy delivery problem by suggesting improved truck sequencing.
- Data Analytics could measure the assembly time of each product and produce statistics for improved decision making based on simulation.
- Automation could enable tools with Plug'n'Produce technology able to auto reconfigure the parameters avoiding assembly time losses and products unable to pass the final quality check.

The greatest change made with respect to the AS-IS architecture is the introduction of the Cloud and the Ledger infrastructure. These new items are able to enhance automation services control, namely Plug'n'Produce technology. At Cloud level cohabits the ERP and FCS technology, in this way it is possible to exploit all their functionality in a coexistence of the legacy ISA95 and FAR-EDGE architecture. The Distributed Ledger technology is exploited to create the so-called "intelligent product": every product is registered in the distributed ledger, after every activity, the ledger is updated in the nearest peer node, and then in all the other peer nodes of the network. In this way, the product carries along the assembly line the information regarding operations performed and equipment installed.

*4) Step 4. Gap analysis.*

A FAR-EDGE Gateway is required in order for the Handheld scanner, the One Spindle Nutrunner and the Edge Display to communicate with the Distributed Ledger. A FAR-EDGE adapter has two connectors and is developed using the edge automation services. It adds Plug'n'Produce support to the nutrunner by attaching the nutrunner to one port and the work cell gateway to the other. The purpose is to encapsulate the open protocol and translate to and from the FAR-EDGE interface and thus, simplify configuration.

From a practical perspective, few physical activities will change with respect to the AS-IS situation. The operator is no more in charge of setting the parameters of the tool, he would just have to scan the product on the assembly line, plug-in the nutrunner and perform the activities in the order provided on the display. The complex IT system serves the purpose of a remarkable simplification of the production operations and quality. The human dimension requires a little step forward in the comprehension and mastery of the I4.0 tools. Maintenance and IT department have to develop an expertise to be able to sustain and provide assistance for the new architecture components. Furthermore, the operators along the assembly line have to possess basic knowledge of digital technology to fully exploit the potential of the tools automatic reconfiguration.

*5) Step 5. Value added identification.*

Once defined clearly the technology that could be implemented in the project, a final impact on the measurable and unmeasurable advantages and disadvantages has been considered. The tools adaptation time will decrease by 98%. This high percentage is justified by the transition from a manual operator activity, to an automatic configuration that would just require the time to plug in the tool and scan the product. It has been estimated that the rework rate will decrease by an uncertain quantity. The reduction is due to the decrease in human error in setting the tools parameter in any reconfiguration. Due to the high level of uncertainty related to this KPI, it has been decided to exclude it from the analysis, in order to maintain as consistent as possible hypothesis. The unmeasurable effects on the system are a dramatic increase in flexibility and replicability of the processes in the exact same way. The price of this impact is a complication of the IT architecture and a slight increase in energy consumption.

*6) Step 6. Economic analysis.*

The tool adaptation time imply a cost which will be critically reduced in case of implementation. A 98% reduction on the initial value is foreseen. This operation is performed in non-planned production time, thus it does not affect the throughput of the system. The DPP of the investment occurs in the eighth year and the IRR value was computed, with a result of 14,2%. Being the IRR greater than the discount rate has been used (10%), it can be stated that both PI and IRR indexes confirm a positive investment analysis for the project.

## IV. Conclusions

The paper presents a holistic methodology for business case evaluation related to digital transformation. Even if the smart technologies implementation is becoming a main trend in the manufacturing world, the path toward I4.0 is not smooth. The final objective was to provide factories struggling for the achievement of a digital transformation with a useful guide tool to define, select, monitor and reach a successful scenario. The entire methodology has been applied to FAR-EDGE project use cases. The analysis has to consider a holistic approach from the technical, operational and human perspective. The migration has been analyzed under these three dimensions, assessing how to implement the new technologies and how does they impact on revenues, KPI and business models. Nevertheless, the revolution that the new computing paradigms are introducing involves the employees firstly and their way to adapt to this kind of changes in operations. The jobs are changing thanks to the digital transformation, the people and the operations have to be harmonized to the technical renewal so to reach a perfect and deep evolution. In general, the more flexible and open to future innovation a company is, the more it will be probable that they will lead, instead of following, in the market challenge. A very challenging task is to clearly identify the impact of the most recent technologies to a specific application, so to adapt and bend their functionalities for the purpose suggested by the firm's goal. In this light, the future work could be the utilization of the method presented to build a wide database. The more migration matrices related to value added there will be, the more the methodology would be usable and precise in foreseeing the final transformation results.

## Acknowledgment

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723094. In any case, the present work cannot be considered as an official position of the supporting organization, but it reports just the point of view of the authors.

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 ISBN: 978-1-61208-736-8