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Industrie 4.0 roadmap: Framework for digital transformation based on the concepts of capability maturity and alignment

Ahmad Issa[a,] *, Bumin Hatiboglu[a], Andreas Bildstein[a], Thomas Bauernhansl[a]

[a]*Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Nobelstr. 12, 70569 Stuttgart, Germany*

* Corresponding author. Tel.: +49-711-970-1779 ; fax: +49-711-685-51858. *E-mail address:* ahmad.issa@ipa.fraunhofer.de

Abstract

Adopting digital transformation and Industrie 4.0 concepts is increasingly important for manufacturing companies acting in dynamic and competitive markets. In practice, however, these organizations struggle with implementing those concepts because Industrie 4.0 is rather a concept than a ready-to-implement solution. Additionally, its complexity hinders the achievement of successfully implementing Industrie 4.0 systems that truly incorporate all organizational aspects and levels. This paper introduces a framework to evaluate and guide Industrie 4.0 implementations, which build upon insights from capability maturity and alignment. Based on this, organizations can develop their own "roadmap" to increase the success of their Industrie 4.0 adoption.

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Keywords: "Industrie 4.0 Roadmap; Capability Maturity; Business/IT Alignment;"

1. Introduction

The central challenge for manufacturing companies is to move from a cost-based to a highly value-added competitive advantage. In this context, adopting Industrie 4.0 should deliver the required added-value through helping companies to formulate the required adaptations with regards to excellence and flexibility with the purpose of capitalising on the increasing demand for more customised, personalised and higher-quality products. This requires a shift to adaptable, digitalised, interconnected and demand-driven manufacturing processes. This is characterised by the transformation of traditional manufacturing equipment and systems into cyber-physical systems, which are orchestrated with the help of IoT platforms, rather than having to integrate them in a time-consuming and costly process.

The term "Industrie 4.0" has received explicit attention since 2011, where a number of initiatives worldwide addressing the theme of digital transformation of industrial production have been created, for instance the "Plattform Industrie 4.0" in Germany, Industrial Internet Consortium in the US and the Industrial Value Chain Initiative in Japan. Numerous studies have put the value creation prospective of Industrie 4.0 over the next 5 years between 100 and 150 billion euros within Germany alone. However, realistically speaking, such figures of this scale would still seem to be far from the reality in the industrial sector [1]. During the evolution of digital transformation, its scope has expanded from focusing solely on the manufacturing processes to the overall organization, and hence to the complete supply chain. More importantly, the focus has shifted from purely focusing on the automation problem to a business and added-value problem.

Manufacturing companies that has started to apply Industrie 4.0 concepts and systems are found in various industrial sectors. Examples of such sectors include automotive, transportation, aerospace and heavy machinery. These industrial sectors have their unique characteristics and hence different journeys within and applications of digital transformation. Additionally, the strategic position of the manufacturing company within the supply/value chain (Tier 1, Tier 2, or OEM) is strongly influencing the perception of digital transformation [2]. However, regardless of these differences, manufacturing companies are still investing in the digitalization of their production for clear common business benefits and goals.

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1.1. Problems in implementing Industrie 4.0

In order to harvest the benefits of digital transformation, many manufacturing companies have started to implement Industrie 4.0 concepts. However, for achieving Industrie 4.0 production, it is essential to implement both the horizontal and vertical integration of the value network and the production inside the factory.

Currently, the only Industrie 4.0 concepts implemented in various manufacturing companies are based on pilot projects that resembles feasibility studies rather than full digital transformation. Unfortunately, these pilot projects cannot show the full potential of digital transformation because they ignore key aspects within the organization, such as its structure and culture [3]. Consequently, the transformation in such cases is usually evolutionary rather than radical in nature. Moreover, these projects frequently fail to enhance or mirror the actual manufacturing processes or fall short from meeting the promised benefits or the actual needs of the organizations. Therefore, real cases of actual transformation are still rare both within manufacturing companies and in Germany as a whole. Consequently, we see that manufacturing companies, especially SMEs, struggle with adopting and implementing Industrie 4.0 solutions. The main problem related to the Industrie 4.0 paradigm implementation in these companies lies in the lack of the awareness of the link between business and technological worlds on the strategic and tactical levels within the company, as well as the failure to meet the production needs [4] [5]. In reality, many companies are treating digital transformation projects as typical IT projects. In fact, there is a basic challenge of understanding the drivers behind Industrie 4.0 and digital transformation within the organization. This is crucial for organizations to properly allocate resources and focus on the most important aspects of this transformation. The failure to grasp the enormity of the challenge has led many companies to fail in their endeavor to embrace digital transformation, where on an average less than 20% of big companies are succeeding in their digital transformation efforts, let alone SMEs [6].

1.2. Research question and methodology outline

Given the importance and potential of digital transformation and Industrie 4.0 for manufacturing companies as well as their current struggle regarding its implementation, this study aims to: *"Develop an Industrie 4.0 roadmapping process for digital transformation in manufacturing companies that enables a step-wise approach towards implementation and deployment of its various aspects in order to maximize its success potential"*

In order to develop such a roadmap model, we have conducted a literature review as well as an empirical validation case study. The literature review was used to develop a "Digital Transformation Process" that is based on two main aspects: capability maturity and business-IT alignment.

Digital transformation maturity denotes the various "growth" stages that can be recognised for digital transformation within the organization. Business-IT alignment, conversely, is centred around the idea that the introduced new technologies within the organization should fit to its business strategy and objectives [7]. The overall process starts with a structured questionnaire. This method allows us to measure the maturity level (readiness level) of an individual organization. Using this readiness check enables us to describe an "as-is" situation of digital transformation in the organization, which the Industrie 4.0 roadmap is based on in order to bring the organization to a higher maturity level compared with the current status. A use case of one of the German companies that went through the whole roadmapping process will be presented in this paper.

1.3. Organization of the paper

The following section will present the construction of the proposed framework and its theoretical basis as well as the roadmapping process. In section 3, the application of the roadmapping process through a specific case study will be presented to illustrate its steps in real situations. Finally, section 4 concludes the paper with further research suggestions.

2. Theoretical framework

At the end of section 1.1, it was argued that the success of digital transformation and Industrie 4.0 implementation is hindered by the large scope of organizational changes that are involved. As a result, defining one big project to realize the full potential of digital transformation in a given organization is not feasible and will definitely end in management disappointment and failure.

Therefore, there is a need for adopting a different approach towards Industrie 4.0 and digital transformation, where various levels are considered, e.g. from basic to advanced levels. This paper proposes a step-wise approach based on capability maturity (explained in section 2.1). The idea behind this approach is that the implementation of Industrie 4.0 technologies and methodologies as well as organizational changes are required to move from one maturity level to the next one. The manufacturing company will only secure the full added value of higher maturity when both issues are addressed. In order to define this balance between technology implementation and organizational change, the concept of business-IT alignment and integration is used (detailed in section 2.2). These two concepts will form the basis for the proposed process, which will be explained in details in section 2.3.

2.1. Digital Transformation – maturity

Since both implementation and deployment success are parts of our research question, the main pillar of this paper's theoretical framework is based on the "capability maturity" concept. Usually, maturity is presented through outlining several growth stages that portray the potential development of the organization during a number of sequential periods. Therefore, the maturity is usually depicted through a matrix, where the horizontal dimension represents the time and the vertical dimension represents the performance/development level.

The origin of capability maturity in information systems goes back to Nolan's model [8], which represented the pattern (S curve) of adopting IT by organizations. Later, quality management adopted this growth model and the levels of growth were further broadened and provided as stages for organization development.

The Capability Maturity Model (CMM) has been the most recognized model within the area of information systems [9]. This model was designed in order to assess and evaluate the development of software systems and other related areas, such as project and human resources management and IT governance. The main assumption is that the performance of the organization would be correspondent to its maturity level.

This paper, however, uses the capability maturity concept but deviates from the traditional CMM in several aspects. In this research, the stages are defined as carrying out a particular project investment or not based on:

- ❖ Whether deploying the project within the organization follows an integrative, cross-departmental path;
- ❖ The extent to which the transformation can be extended outside the organization, i.e. including the partners within the value chain.

Using these principles, we define four maturity levels:

1- **Level 1 – No Industrie 4.0 or only "ad-hoc"**: There is no person responsible for Industrie 4.0 or digital transformation and, most importantly, no vision has been formulated regarding those topics. Consequently, there are no well-defined processes or supporting systems.

2- **Level 2 – Departmental level (isolated silos)**: digital transformation is seen as a technical or production problem that is being handled on a departmental or shop floor level. Yet, there is no global vision in order to coordinate and synchronise these activities. In many cases, the IT or production/engineering departments are the first ones to look into digital transformation and Industrie 4.0 adoption.

3- **Level 3 – Organizational level (cross-departmental)**: Digital transformation is being handled as a business problem that needs an overall vision and integrative approach. All departments are involved in defining this vision and formulating the digital strategy.

4- **Level 4 – Inter-organizational level (cross value chain/supply chain partners)**: Digital transformation is seen here as a business issue that covers the overall value/supply chain. Consequently, defining the digital transformation/Industrie 4.0 vision and strategy should take into account the complexity and needs of the value/supply chain partners. The processes and use cases are defined in a way that goes beyond the organizational borders in order to enable collaboration with those partners. This will allow the transparency and intelligence required to enable the appropriate decision-making regarding production and/or products.

2.2. Digital Transformation – Alignment and Integration

The second pillar of this paper's theoretical framework is built on the "Business-IT alignment and Integration" principle. This concept has been around since the 1980s, where researchers and consultants have encouraged and promoted the adoption of an aligned approach to the deployment of new IT technologies in different organizations. This view has been iterated and highlighted later in the 2000s by Michael Porter [10] who stated that the use of Internet technologies makes the strategy even more relevant and essential rather than obsolete.

On the operational level, many scholars have argued that implementing and deploying new IT technologies should follow and accompany a sensible contemplation and attention to business processes and organizational structure (e.g. [11] [12] [13]). Therefore, they have encouraged an aligned approach of IT with strategies, business processes and organizational structures. One of the most famous models regarding Business-IT alignment is the "Strategic Alignment Model" [14], which was one of the first models to help organizations in reaping the benefits of new technologies. In this model, the authors have argued that both business and IT strategies, as well as business processes and infrastructure should have a "balance", in other words, they should be aligned via the strategic fit [15]. Another model was then developed without the explicit focus on this alignment, which has defined five main "business pillars", namely Strategy, Monitoring and control, Structure and processes, Human resources, and IT. It was argued that organizations in which the five pillars are in balance perform 30% better than the market on average.

The continuously increasing significance of digital technologies in manufacturing companies demands that they integrate the decision-making regarding adoption and deployment of these technologies with their collective processes at all levels within the organization. In this context, alignment of business with IT management cycles is not sufficient to harness the benefits of digital technologies; rather it should be combined with a multi-level integration of business and IT management. This integration aims to incorporate completely the capabilities of digital technologies with business strategies and expectations. This constitutes an interesting paradigm shift regarding the relation between business and IT strategies [16], where before the digital transformation era, it was expected that business strategy is defined first, followed by the IT strategy and then the alignment occurs [17]. Adopting this integrative approach enables the companies to focus on creating a desirable position within the digital ecosystem, which in turn allows them to explore and take advantage of these new technologies [18].

2.3. Industrie 4.0 Roadmap Process

In line with the theoretical framework, we argue that Industrie 4.0 investments should be carried out using an integrative approach that enables the alignment of business and IT. Such an integrative approach is usually called "roadmap" in the manufacturing sector, which is an overall plan for the deployment of new technologies, containing organizational change, that explains the main phases that needs to be taken [19]. This digital transformation roadmap is unique for every manufacturing company and requires the involvement of all organizational levels and decision makers. In this paper, we propose a process for creating this roadmap for individual manufacturing organizations, which helps them define a clear *focus* for their digitalization activities that is suitable to their maturity level. In addition, this process takes into account the alignment of various business areas and processes using a variety of tools. While this process can be used to generate concepts for new business models, it is better suited to the optimization of business processes and operations.

The following steps form the process that we propose for the development of an individual Industrie 4.0 roadmap.

1. **Task Force Setup**: While digitalization and Industrie 4.0 activities are often driven by the teams responsible for operations, large potentials beyond the shop floor may stay untapped. Successful roadmapping requires a holistic understanding of all information flows, processes and utilized tools within the company including interaction with the supply-chain. Similarly, awareness of the state of the art and current development in digitalization is required to realistically assess the potential implementation of use cases in regards to technical maturity, cost and alignment with available resources.
2. **Digitalization Assessment:** To assess the digital maturity of the company, we propose interviews with the task force members within their field of expertise based on already defined questionnaire. The questions have three main dimensions: Technology, Organisation and process. The interviews serve to clarify technology and media gaps in the aforementioned information flows, lack of documentation, missing information pathways or sources and the current degree of exploitation. The interviews may also assist in the critical reflection of difficulties and potentials as preparation of later phases of the roadmapping. The results are aggregated and discussed within the task force.
   Once the interviews are conducted, the task force compares the gathered information and answers for the questions with previously identified (normalized) answers. This back-office process identifies the normalized answer that closely resembles the real situation. Using these normalized answers, the maturity level for the company is calculated.
3. **Focus Definition**: High impact action fields are identified in alignment with the strategy and organizational structure of the company. The second task is the definition of measurable indicators for the later evaluation of the potential of the collected use cases in a decision matrix with two dimensions: ease of implementation and benefit. Each indicator is associated with two weights, representing its contribution to implementation effort ($w_{e)}$) and benefit (w_b) in relation to all N indicators. The weights are normalized so that the sum for each dimension equals *1* respectively. To ensure the conditional independence of the two dimensions, indicators that merge both dimensions, such as return on investment, are either broken down accordingly or omitted, so that either effort w_e or w_b equals *0* for each indicator.
   $$\sum_{n=1}^{N} w_b(n) = 1; \sum_{n=1}^{N} w_e(n) = 1 \text{ with}$$
   $$(w_b(n) = 0 \wedge w_e(n)) \vee (w_b(n) \neq 0 \wedge w_e(n))$$
   Equation 1: Conditions for indictor weights
4. **Use Case Idea Generation**: We propose to initiate the generation process on staff-level with workshops within in each identified action field including employees with differing tasks. This bottom-up approach typically yields more use cases addressing current problems and task force members who moderate these workshops need to ensure that the attendees think beyond the scope of current daily business. On the other hand, weaknesses of current business processes are often revealed, leading to ideas with imminent improvement impact. Acceptance of new digital tools by the employees is often critical for their success. Such early involvement of employees in the roadmapping process may therefore also improve utilization once implemented.
   As knowhow regarding digital technologies may differ between workshop attendees, technical solutions may not be expected as an outcome of the workshop. However, the documentation of use case ideas must cover the associated problems or improvement idea, a short description of the desired final application scenario and the quantified expected impact on the indicators for contributing an added-value. With this information, the task force may complement a technical and organizational solution concept and assess its impact on the indicators for implementation. In the final stage of this phase further use case ideas, which may span several action fields, may be added to the list by the task force.
5. **Use Case Impact Estimation:** To simplify the evaluation, we propose the setup of a classification matrix, where rows represent an indicator n and the columns represent descriptive, unambiguous categories c_n with an associated value $v(c_n)$. Each use case is then matched to the matrix and the estimated impact regarding implementation effort E and benefit B are calculated according to Equation 2. To clarify the earliest implementation date, dependencies between use cases and the maturity of required technologies are identified. In this context, dependency means that a use case requires prior implementation of one or more other use cases as information input. It also may prove beneficial to split complex use cases into sequenced use cases whenever possible, to simplify implementation and allow earlier benefit.
   $$B = \sum_{n=1}^{N} w_b(n)\, v(c_n) \text{ and } E = \sum_{n=1}^{N} w_e(n)\, v(c_n)$$
   Equation 2: Calculation of benefit B and effort E of each use case
6. **Use Case Selection:** Firstly, exclusion criteria, such as a maximal project budget or the roadmap's time horizon are identified. Use cases which match one of these criteria are excluded from further consideration. We propose to select use cases with a large ratio of benefit to implementation effort in line with the strong return-on-invest focus of most companies. Possible forerunners for these use cases have to be included, as these typically do not score highly in the evaluation. Further boundary conditions to limit the number of selected use cases are company specific. An example might be the overall available budget for projects.

3. Application Example

The roadmapping process, introduced in the previous section, was applied -amongst others- to a manufacturer of medical equipment and consumables with a single production site and around 1700 employees. The products are disposable sterile medical supplies, which results in cleanroom requirements for the shop floor. No semi-finished components are sourced externally as the plant covers a vertical range of manufacture from supplied raw material like plastic granulate and cardboard to the packaged final product.

3.1. Applied Roadmap Process

Task Force Setup: The assembled task force consisted of the following members: Head of HR, head of maintenance, head of facility management, head of logistics management, head of IT, a line manager, an industrial engineer, a product manager (internal coordinator) and two external experts for digitalization and Industrie 4.0. The externals' duty was moderation of the process, assessment and consultancy concerning technical solutions.

Digitalization Assessment: The outcome of the assessment interviews was aggregated by the externals and presented to the task force and general management. As strengths were considered: the integration of supplier information into the software system and software development experience within the company for the in-house manufacturing execution system. As weaknesses were considered: low transparency of process parameters, high effort in maintenance and documentation of the clean room requirements, and low flexibility in production planning and product mix. The meeting was also utilized to establish a common understanding of Industrie 4.0 and digitalization within the task force, based on the state of the art.

Indicator	N	w_b	w_e	$v = 0$	$v = 1$	$v = 2$	$v = 3$
Work safety	1	0.33	0	No effect	Depiction / warning of danger	Extend / probability of danger is reduced	Danger is eliminated
Product Safety (quality)	2	0.26	0	No effect	Signals compliance deviation	Risk of compliance deviation is reduced	Eliminates risk for compliance deviation
Cost Savings	3	0.20	0	< 300 000 €	< 700 000 €	< 1 500 000 €	> 1 500 000 €
Company-wide Communication	4	0.1	0	No effect	All required information is received	Information received in real time	Direct feedback possible
On-Time Delivery	5	0.07	0	No effect	Visualizes deviation from target	Improved on-time delivery	Guarantees on-time delivery
Novelty (for Marketing)	6	0.04	0	Below industry standard	Industry standard	Innovative by industry standard	Objective innovation
Costs	7	0	0.5	>700 000 €	700 000 € - 400 000 €	399 999 € - 100 000 €	< 100 000 €
Technological maturity	8	0	0.5	Current research	Available in 2-3 years	Severe adaptions / prototype	Off-the-shelf solution

Table 1: The Classification Matrix

Focus Definition: The integration of value chain partners was excluded from the roadmapping due to legal regulations and diverse distribution channels, differing between almost all local markets and the existing, strong integration of suppliers. However, it was decided to generate basic ideas for digital products and services. The task force decided to focus mostly on operations and selected the following seven action fields as promising for Industrie 4.0 use cases: intralogistics, facility management, process management, documentation, management of equipment, company-wide information spread, and product improvement. In further discussions a set of six overall indicators for benefit and two indicators for the implementation effort were identified, which can be seen in columns 1-4 of Table 1.

Use Case Idea Generation: For each action field a workshop of three hours was conducted. Each workshop was moderated by the internal task force coordinator to ensure a standardized approach and employees with extensive experience in the field, including the respective task force members. Initially, participants briefly described their main duties, current problems and ideas for improvement in an abstract, non-technical way. Then a brainstorming was organized to generate ideas for use cases. Due to the time constraint, not all 55 ideas generated in those workshops could be detailed. Therefore, an ad-hoc prioritization by the attendees was carried out to focus on more promising ideas. The prioritization approach was limited to the impact on benefit, since most attendees were only able to estimate this dimension confidently. Each idea was categorized in reference to all ideas generated in the particular workshop by popular vote for each benefit indicator. Vote options were: *low / medium / high impact*. Discussions of the result were not allowed due to the time constraint. This resulted in 37 sufficiently documented use cases. After the completion of the workshops, the task force reviewed all the use case descriptions. In this process, the task force reduced the total amount of use cases to 28 by merging similar ideas. Concepts for technical solutions were drafted and dependencies between the use cases identified. Based on the solution, the required internal experts and possible external partners were proposed.

Use Case Impact Estimation: Next, the classification matrix (Table 1) was developed in alignment with the expected ranges of impact on each indicator. The labour cost were estimated at 1 000 € per day and added to the estimated hardware costs. Each use case idea was matched to the scheme for every indicator and the weighted sum was calculated. The evaluation was then finally summarized in a scatter plot of all 28 uses cases based on benefit and implementation effort (see Figure 1).

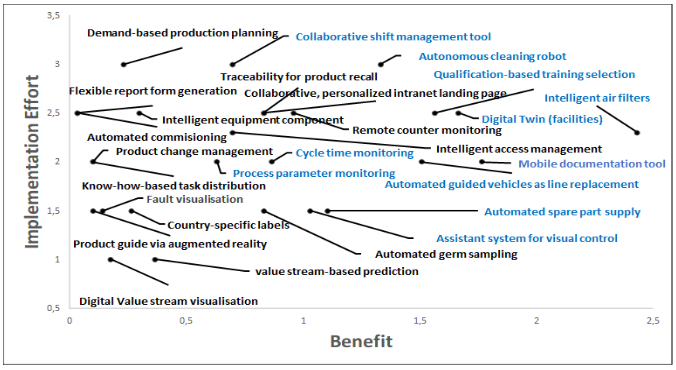

Figure 1: Decision Matrix with all 28 use cases; final selection marked in blue

Use Case Selection: The task force decided to set a benefit value greater 1 as primary selection criteria for the roadmap, regardless of the implementation effort. Eight use cases fit this requirement. In the second selection round, the technical dependencies of these selected use cases were reviewed and two forerunner use cases were added to the selection. Finally one easy to implement "quick win" with a relative high impact was added, resulting in eleven uses cases for the final roadmap.

3.2. Validation of the results

Customer View: Once the results are presented to the company, a final discussion with the interviewees involved in the digital assessment was conducted. The main outcome of this discussion was that the results were aligned with the company's own perspective regarding the digital transformation activities. Another interesting outcome of these discussions was also that the maturity level was of little or no value to the companies, especially SMEs. This is because the focus definition and idea generation processes helped them to identify better where they should focus and act. Another raised point from the discussion was that a simple benchmarking with similar companies, i.e. similar size or industrial sector, would be very useful to the digital transformation efforts. However, this would be available only when the methodology is applied to more companies and more data is collected.

Enabler View: The results were also shared with an expert target group in order to get their feedback regarding the identified ICT enabling technologies and platforms as well as their feedback on the interview questions and the strategic focus definition of the company.

4. Conclusions and Recommendations

Industrie 4.0 and digital transformation in the production area are relatively new concepts that are still being addressed on a feasibility projects level. ICT developers and business consultants are dominating the narrative regarding how companies' journey should be while undergoing such crucial transformation. With the proposed framework, we believe that we have provided a practical process based on a sound theoretical framework for manufacturing companies that are implementing (or planning to implement) Industrie 4.0 concepts. This process is based on the concepts of maturity and business-IT alignment and integration. We showed how individual organizations could utilize the proposed process in order to assess their current position and use that as a starting point to build their roadmap for the future.

As we are at an early stage of a relatively new topic, there are many important areas for future investigation. For instance, further manufacturing organizations from different branches need to be assessed in their journey in implementing Industrie 4.0 concepts using the proposed process, so it can be further improved and validated. In addition, further research on the organizational change and human factors with digital transformation would be very productive, both for practical and theoretical purposes.

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