INDUSTRY 4.0 – ASSESSMENT AND ROADMAP DEFINITION FOR AEROSPACE MANUFACTURING

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Introduction

An increasing order backlog for aircraft and stringent regulations makes a compelling business case for both OEMs and suppliers in the asset-heavy aerospace industry to deploy digital technologies and maximize asset utilization to unlock hidden value. However, before embarking on the Industry 4.0 journey, which encompasses digital technologies, a careful and thorough assessment of current capabilities and state of readiness is necessary. This review will conserve precious resources, time and costs that can otherwise be incurred while implementing randomly selected technologies that do not align with business objectives.

This paper describes a holistic framework based on the Acatech Industry 4.0 Maturity Index to help aerospace OEMs and suppliers assess their maturity, identify gaps and strategically prioritize and prepare their Industry 4.0 transformation roadmap.

Maturity Model

The Acatech Industry 4.0 maturity framework (acatech, 2018) is defined by four structural areas that make up a business, i.e., Resources, Information Systems, Organizational Structure and Organization Culture. Each of these structural areas comprises two dimensions and in turn, each of these dimensions is governed by a set of capabilities. The extent to which each capability is implemented determines the maturity stage of the relevant dimension. Each dimension needs to be investigated for every functional area, such as manufacturing, engineering and supply chain separately.

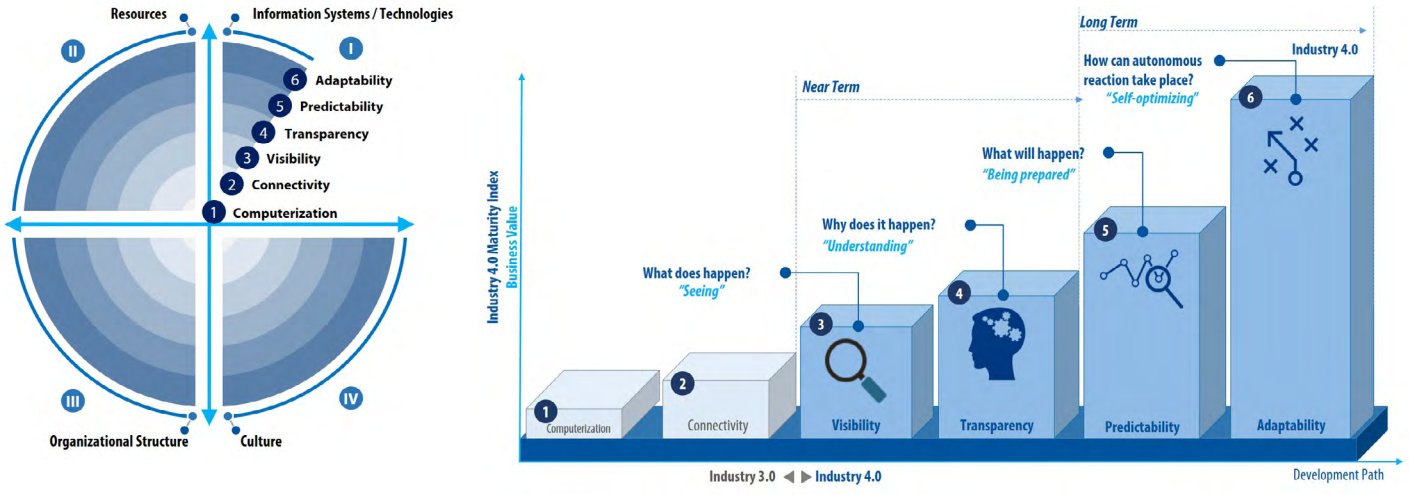

Figure 1: Industry 4.0 Maturity Stages

Industry 4.0 Maturity Stages

The Industry 4.0 maturity level of a company is measured on a six-stage scale. The following table (Infosys Limited, 2018) shows the capabilities required to attain each stage.

1	Computerization	Tasks are supported by computerized control and data processing systems relieving employees of repetitive manual tasks
2	Connectivity	Data processing systems are structured and linked, and core business processes are reflected in IT systems
3	Visibility	Companies have a digital shadow (real-time data) and the management takes data-based decisions
4	Transparency	Companies understand why events happen and knowledge is discovered through recognition
5	Predictability	Companies know what will happen to enable decisions to be made based on future scenarios
6	6. Adaptability	Companies react autonomously to conditions. The system controls itself autonomously and is fully viable

Industry 4.0 Maturity Model Structural Areas

The Acatech Industry framework (acatech, 2018) can be customized to meet the requirement of organizations from various industries by adding or removing the Industry 4.0 capabilities in each of the four structural areas. Considering unique features of different actors i.e. OEMs and suppliers in the aerospace industry, a tailored version of the Acatech maturity model with fundamental Industry 4.0 capabilities is shown in Figure 2.

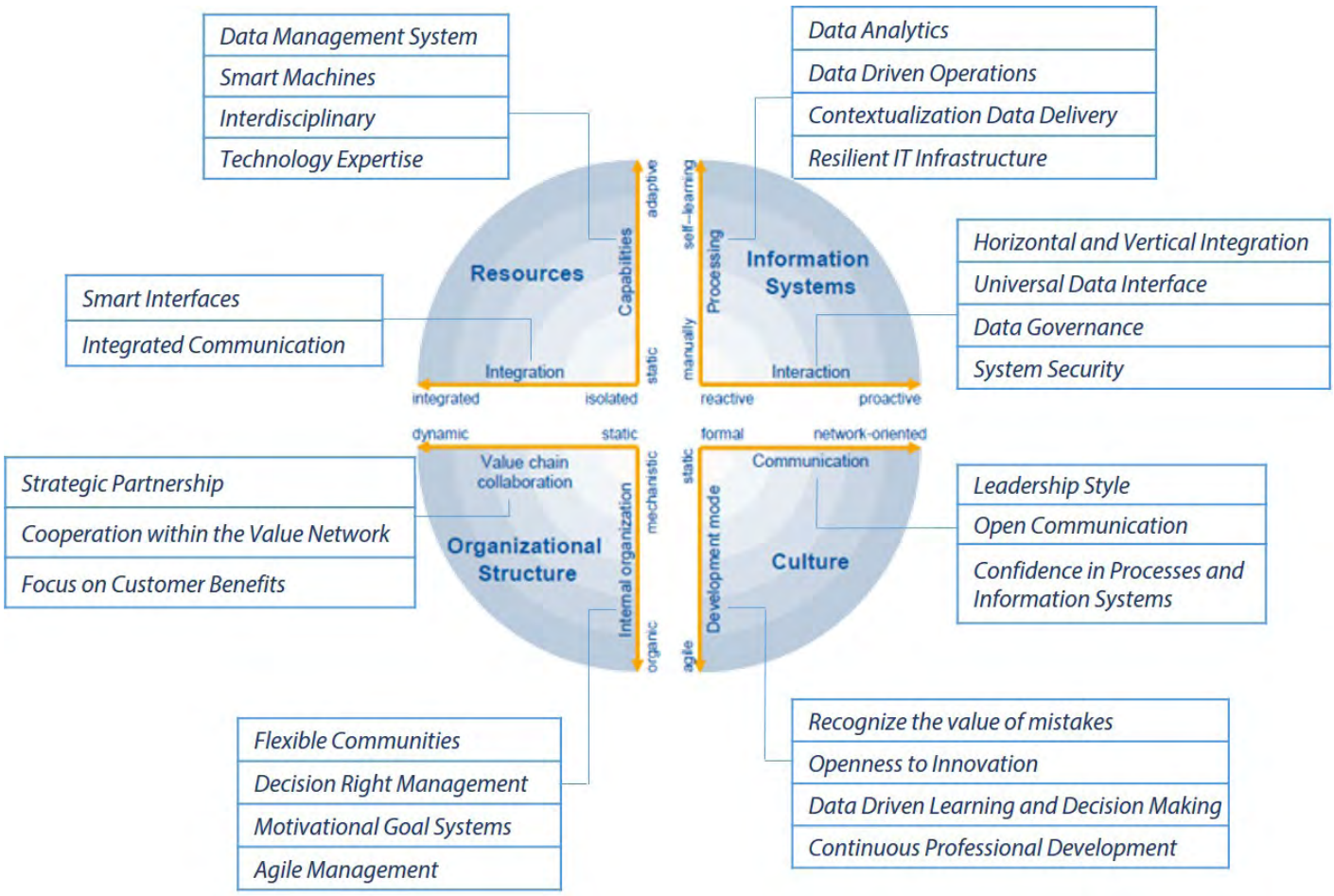

Figure 2: Capabilities of Industry 4.0 Maturity Framework

Application in Aerospace Industry

The Industry 4.0 assessment framework can be defined with six major steps, as shown in Figure 3. Each step has clearly defined objectives and output(s) that would help an aerospace manufacturer shape its Industry 4.0 transformation strategy. Active engagement of the stakeholders across hierarchical levels in each functional area is a vital part of the Industry 4.0 assessment methodology.

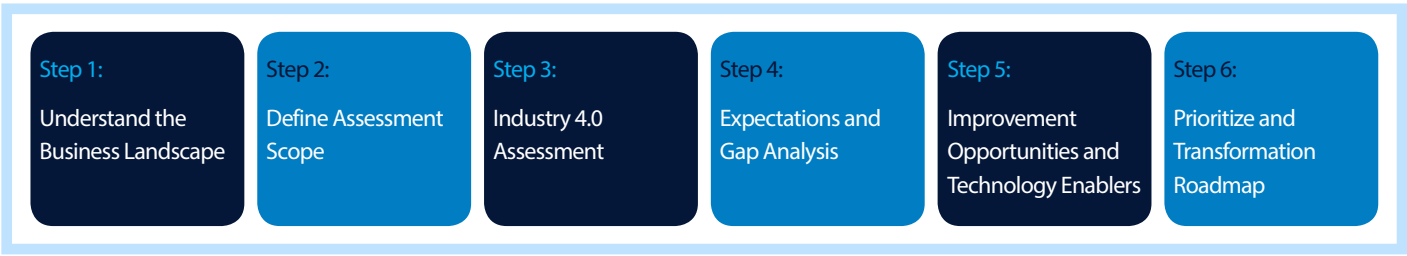

Figure 3: Simplified Industry 4.0 Assessment Framework

Step 1: Understand the Business Landscape

A good understanding of an aerospace manufacturer's business landscape is necessary to recognize its business direction. Understanding of external and internal business drivers and how they impact different areas of the organization would help clarify company vision and better align business and technology goals. Considering the aerospace industry dynamics, two key aspects are identified, namely the aerospace value chain and 4Ps (People, Process, Product and Plant), that would provide sufficient insights to assess maturity.

Aerospace industry value chain

Exploring the aerospace value chain will provide a comprehensive view of the key external factors that shape an aerospace manufacturer's business. It is recommended to look into the following three fundamental areas:

- **Place in the value chain**: The design and manufacturing of aerospace parts and sub-assemblies involve many companies and sometimes direct risk-sharing among participating companies. A clear understanding of the organization's place in the industry value chain would help identify customer(s) and key partners. It is necessary to understand the dynamics and requirements to be able to assess the effectiveness of collaboration with external partners and identify improvement opportunities with relevant technology enablers to ensure smooth partnerships
- **The value proposition**: Any business's goal is to meet the needs of its customers. Consequently, its value proposition, customer benefits and expectations form the foundation. In the case of aerospace manufacturers, based on their position in the industry value chain, the value proposition can take many forms such as reliability, performance, efficiency, risk or a combination of these. The organization needs to htave a clear picture of the value proposition, customer benefits and expectations for an accurate Industry 4.0 assessment
- **Stakeholder relationship**: The aerospace value chain is increasingly becoming dynamic and network-based, where risk-sharing partners pool their resources to develop and deliver products. To assess the effectiveness of collaboration, a good understanding of the external stakeholders' roles and interactions among them is essential

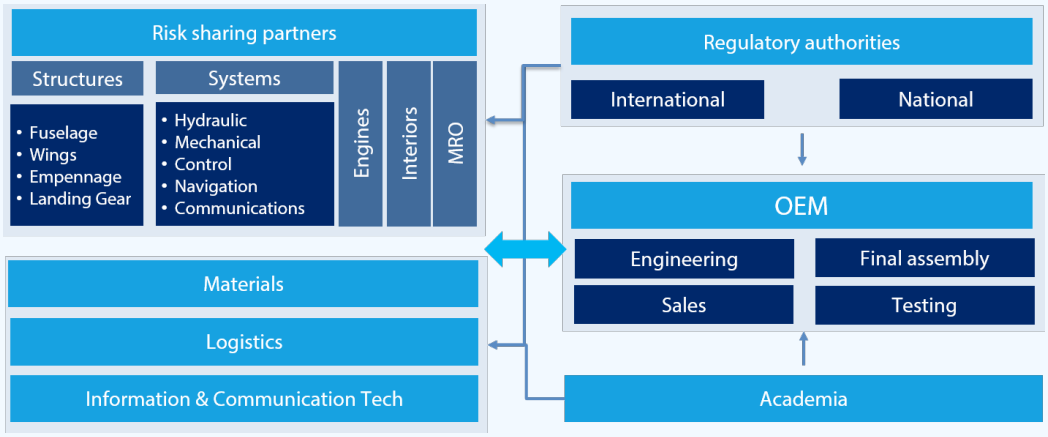

Figure 4: Typical Aerospace Industry Value Chain

People, Product, Process and Plant

While the aerospace industry value chain allows the analysis of external factors, the 4Ps framework provides a sharper picture of the organization's internal factors and driving forces that impact value creation -

- **People**: In the Acatech Industry 4.0 framework, people are at the core of the maturity assessment. Assessing Industry 4.0 capabilities such as interdisciplinary and flexible communities require a deep understanding of the necessary skills and organization structure of human resources
- **Product**: Aerospace manufacturing organizations exist in various forms ranging from manufacturing relatively simple products such as passenger seats to high-tech multidisciplinary products such as aircraft engines. The products or service objectives of aerospace manufactures also differ, e.g. fuselage parts and sub-assembly manufacturers have weight as their primary consideration, whereas engine manufacturers are concerned with efficiency and emission objectives, in addition to weight. It is crucial to have a thorough understanding of the organization's product portfolio to understand how resources coordinate to achieve the organization's objective
- **Process**: Aerospace parts and assembly manufacturing involve a diverse set of materials, manufacturing technologies and cross-functional processes. The processes and the respective technologies significantly differ from one manufacturer to another. Detailed mapping of all processes and steps involved in transforming the inputs into the final products would provide the evaluator with the required awareness of technological and operational constraints
- **Plant**: Finally, it is desirable to clearly articulate the organization's long-term and short-term objectives, everyday challenges and the capabilities of key resources involved in creating and delivering the final products

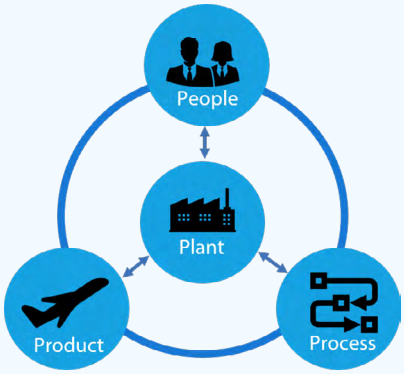

Figure 5: 4Ps Framework

Step 2: Define Assessment Scope

The previous step provides a good understanding of the external and internal environment of the organization. The next step in the assessment process is to identify the key stakeholders and functional areas, e.g., manufacturing, engineering. As aerospace manufacturers differ significantly from one another, the products or services they deliver shape their organization's structure and processes. Therefore, it is vital to identify the functional areas and the key stakeholders for each functional area, which may vary significantly for OEMs and suppliers.

Second, to have a comprehensive and accurate Industry 4.0 assessment, it is necessary to involve people from multiple hierarchical levels, i.e., both operational and managerial level, some stakeholders would be able to provide a better picture of certain capabilities to the assessor e.g., employees on the shop floor would be able to answer more correctly on user-interface with production machines than employees at the managerial level.

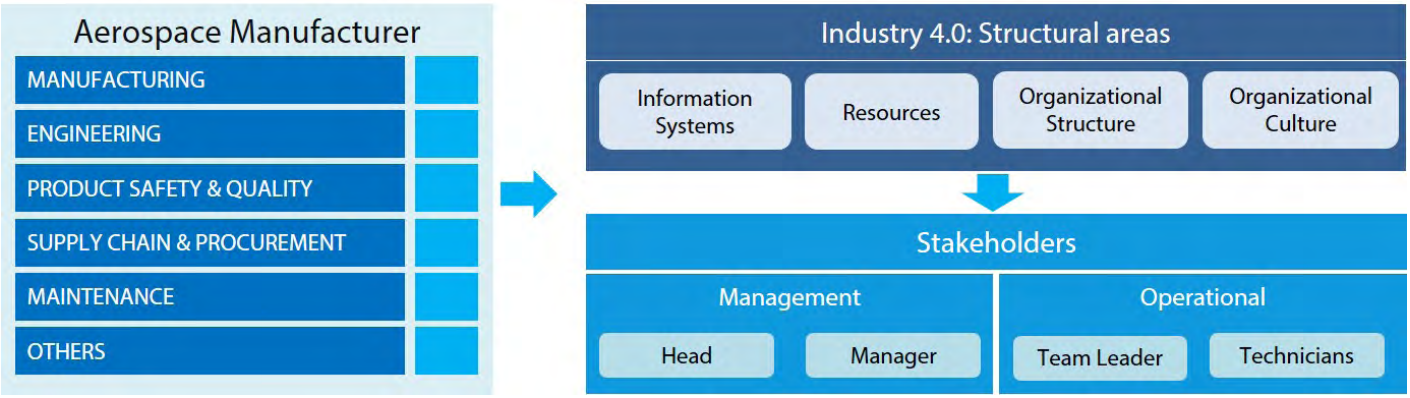

Figure 6: Aerospace Manufacturing - Key Stakeholders and Assessment Areas

Step 3: Industry 4.0 Assessment

The Industry 4.0 assessment can begin after having a deep understanding of the aerospace manufacturer's environment and a defined assessment scope with identified stakeholders. The assessment of Industry 4.0 capabilities involves:

- Data collection
- Data consolidation and mapping

Data collection

There are multiple ways to collect data on the existing maturity of Industry 4.0 capabilities. One such approach involves validating a set of statements tailored to each stakeholder of the functional area being assessed. Each statement can be validated by the appropriate hierarchical level of the functional area on a graduated scale, e.g., 0 to 5, with 0 being not deployed/achieved and 5 being fully deployed/achieved.

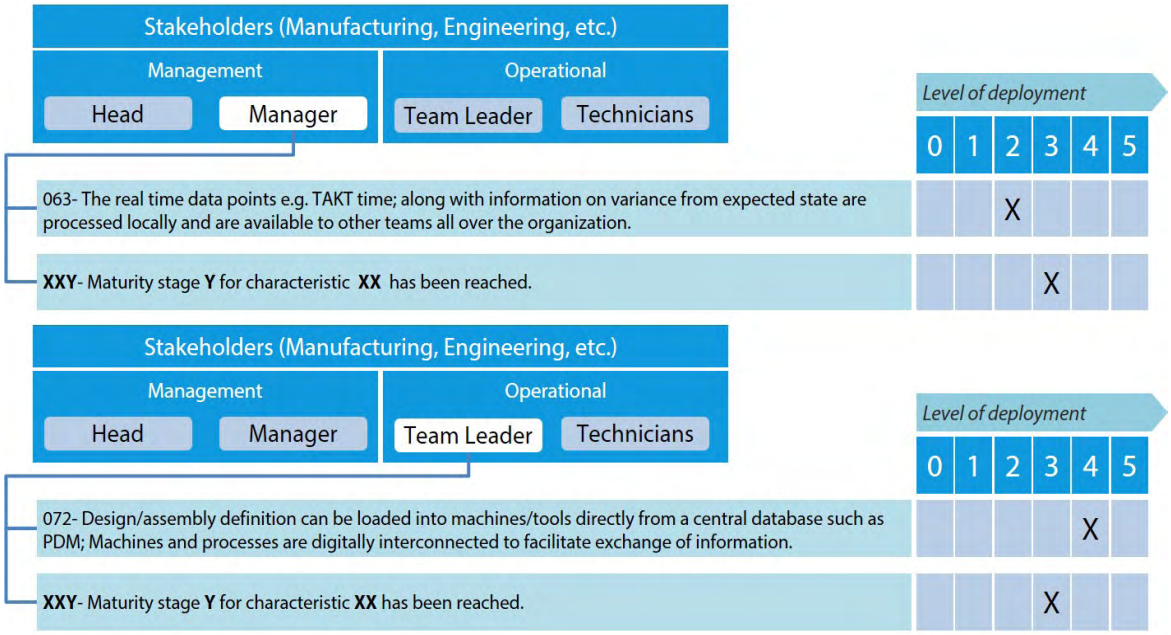

Figure 7: Data Collection for Manufacturing Stakeholders

The average of the collected scores from different stakeholders (hierarchical level) for each capability gives the overall maturity of the corresponding capability.

$$M_{jk} = \sum \frac{S_{i\ jk}}{i}$$

M_{jk} = Maturity score for industry 4.0 stage j of capability k

S_i = Score of stakeholder i

Data Consolidation and Mapping

Next, the collected scores for each capability and each functional area are consolidated as follows,

$$M_k = \sum \frac{M_{j\ k}}{j}$$

M_k = Maturity score of capability k

S_i = Score of stakeholder i

Depending on the context, instead of a simple average a weighted average may also be used.

			Computerization				...	Adaptability			
		I4.0 Capabilities	ME	SCP	...	ENG	...	ME	SCP	...	ENG
Resources	Digital capabilities	Smart machines	4	5	...	5	...	0	0	...	0
		Data management system	4	5	...	5	...	0	0	...	0
		Interdisciplinary	4	5	...	5	...	0	0	...	0
		IT technology expertise	4	5	...	5	...	0	0	...	0
Information System	Information processing	Data analytics	4	5	...	5	...	0	0	...	0
		Data driven operations	4	5	...	5	...	0	0	...	0
		Data delivery	4	5	...	5	...	0	0	...	0
		Resilient IT Infrastructure	4	5	...	5	...	0	0	...	0

ME: Manufacturing / SCP: Supply chain & Procurement / ENG: Engineering

Figure 8: Illustration - Consolidation of Scores for Each Functional Area

Likewise, the average scores for each dimension/principle and each structural area give the final maturity of each Industry 4.0 dimensions and structural areas.

Figure 9: Illustrative Mapping of Industry 4.0 Maturity by Functional Area

Step 4: Expectations and Gap Analysis

The next step consists of understanding the expectations of each functional area. Different aerospace manufacturers may have different Industry 4.0 target maturity expectations for each of the functional areas. A good understanding of how much value each increment in the maturity stage would generate for the aerospace manufacturer is required to determine the Industry 4.0 target maturity expectations. When setting targets, aerospace manufacturers must also investigate new products and services that are possible as a result of reaching a higher Industry 4.0 maturity stage.

Employees at the managerial level, such as business managers or head of each functional area, have the visibility and are thus best placed to gauge the Industry 4.0 maturity expectations.

A similar method, as used in the previous step, can be employed to understand the aerospace manufacturer's target maturity level across different functions. The following table illustrates the target maturity expectation for Data Analytics capability for various functional areas.

Maturity Stage	Capability - Data Analytics	ME	ENG	…	SCP
Computerization	Standard reports - data is collected and cleaned to transform in standard reports.	Y	Y	…	Y
Connectivity	Adhoc reports - analyze multidimensional data interactively from multiple perspectives.	Y	Y	…	Y
Visibility	Monitoring - KPIs and insights from data are available across the enterprise in real-time.	Y	Y	…	Y
Transparency	Forecasting - data extrapolation and analysis to understand correlation between key parameters.	Y	Y	…	Y
Predictability	Predictive - ability to predict behavior and patterns across the value chain and personalized KPIs.	Y	Y	…	Y
Adaptability	Prescriptive - actionable insights and fully autonomous system.	N	N	…	N
Target Maturity		4	4	…	4

Table 1: Expectations Assessment - Industry 4.0 Target Maturity

Likewise, these expectations are aggregated and mapped together with actual Industry 4.0 maturity levels for each of the functional areas.

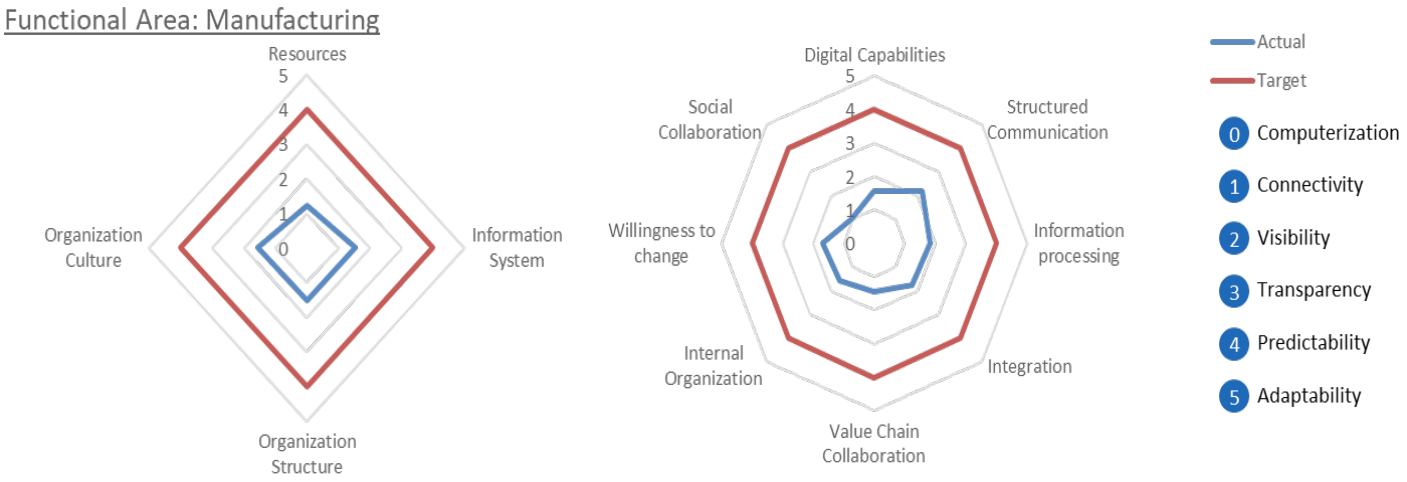

Figure 10: Illustrative Mapping of Industry 4.0 Target vs. Maturity by Functional Area

The output of this step should identify the lagging Industry 4.0 capabilities that need upgrading.

Step 5: Improvement Opportunities and Technology Enablers

This step consists of carefully analyzing the gaps between the actual and target Industry 4.0 maturity for each of the capabilities and the functional areas. The main objective of this step must be to identify the relevant technology enablers and corresponding digital projects that would help close the gap between the actual and the target Industry 4.0 maturity, acknowledged in the previous step.

Several frameworks exist to help evaluate the relevancy of different technologies. One of them is the Technology Enabler relevancy framework as presented in Figure 11.

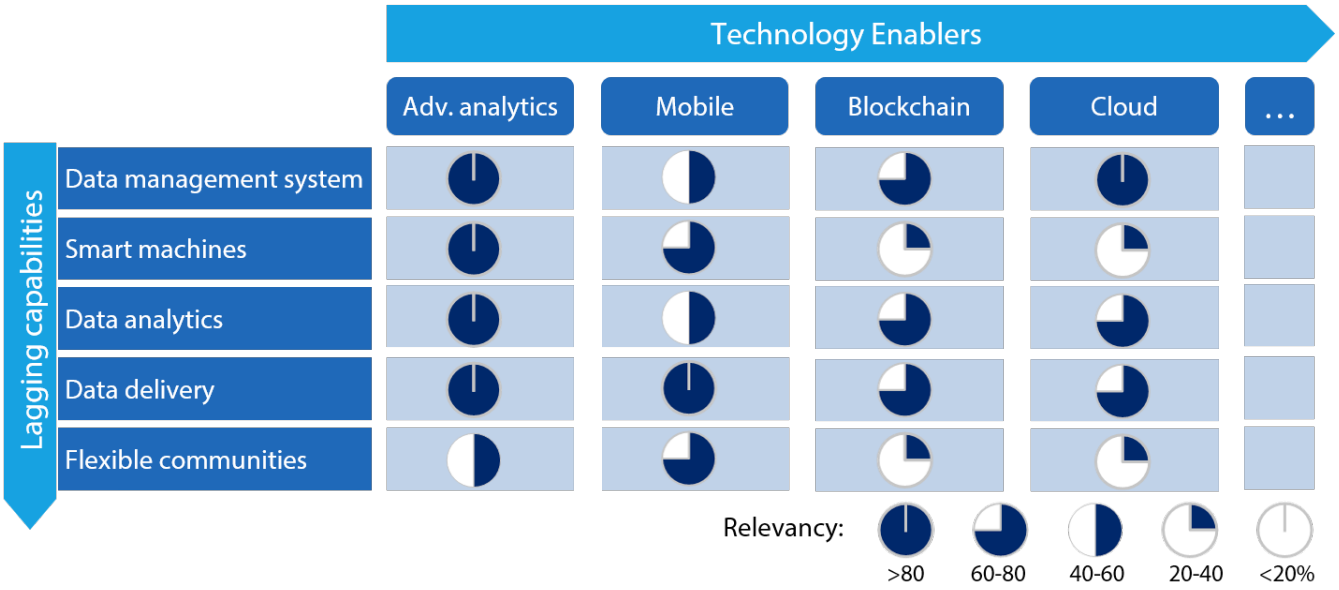

Figure 11: Technology Enabler Relevancy - (may vary from organization to organization)

The Technology Enabler relevancy framework will help select the technology enablers that are best aligned with both technology and business objectives.

These technology enablers should be analyzed for each capability that requires enhancement in each functional area. This step would help define the list of digital projects that would help reduce or eliminate the gap between actual and target Industry 4.0 maturity for each functional area.

Step 6: Prioritize Digital Projects and Transformation Roadmap

The last step consists of prioritizing digital projects and developing a strategic road map for Industry 4.0 transformation. At this stage, the aerospace manufacturer has a fair understanding of what must be done to achieve the target Industry 4.0 maturity, and this step helps in transforming that knowledge into actionable strategy.

Prioritize Digital Projects

Depending on the context and size of the organization, less or more complex methodologies can be adopted to prioritize the digital project identified in the previous step. The least complicated method consists of selecting the projects based on the additional value that each project would create for the organization, i.e., projects with high value creation would have high implementation priority and vice versa.

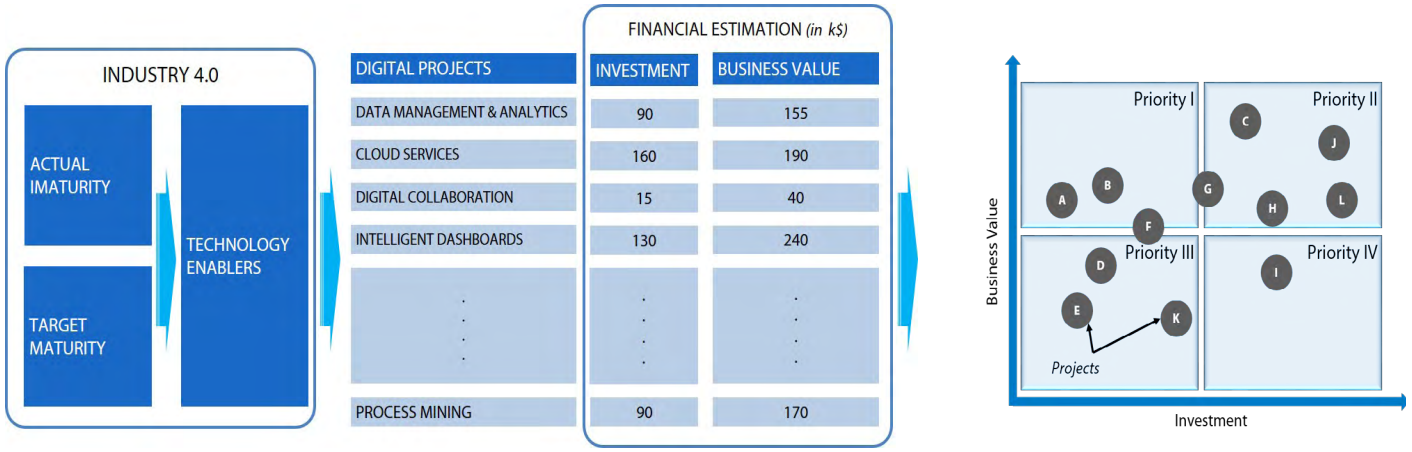

Figure 12: Prioritization of Digital Projects

However, it is strongly recommended to use a well-balanced multi-dimensional approach, integrating both financial and non-financial criteria to prioritize the digital projects. This would prevent a short-term outlook and promote projects that are better aligned with the organization's medium and long-term vision as well as sustainability goals.

Further, certain capabilities may require the simultaneous execution of interdependent projects. This requires combining the projects in project portfolios. Further, when implementing changes in a multi-dimensional environment with high uncertainty, risk is an important dimension that cannot be neglected. These multiple constraints and dependencies can be effectively managed by employing an integer programming model (Cevikcan & Ustundag, 2018) for determining an optimal project portfolio for Industry 4.0 transformation.

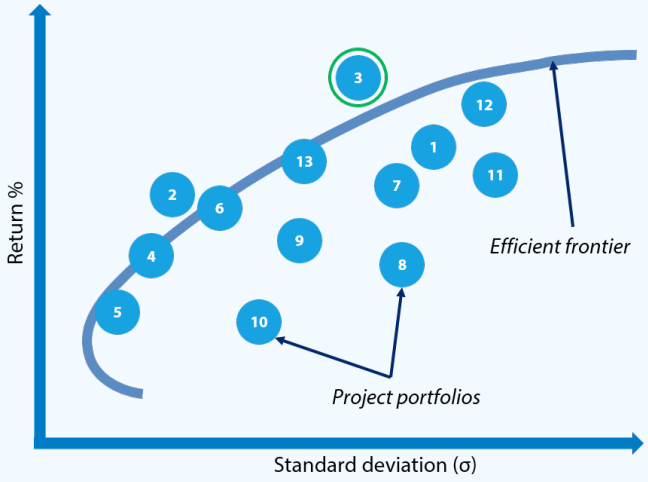

Figure 13: Portfolio Model - Prioritization of Digital Projects

Transformation Roadmap

Developing the Industry 4.0 transformation roadmap for selected projects is the next and the final step. It consists of defining and scheduling milestones for projects in selected portfolios.

A typical transformation road map with three project portfolios containing nine projects is shown in Figure 14.

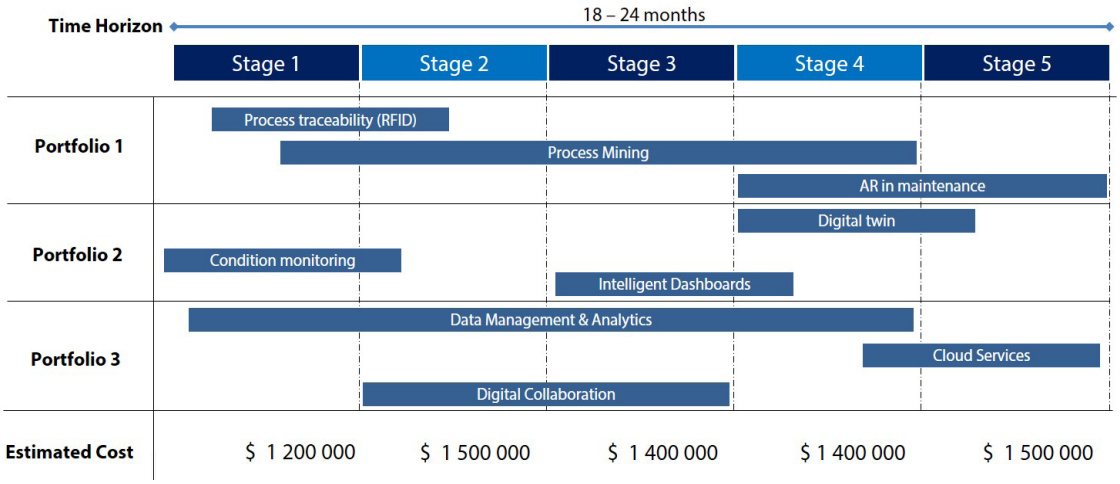

Figure 14: An Illustration of Transformation Roadmap for Industry 4.0

Conclusion

The framework presented in this paper would help aerospace manufacturing organizations to understand their current Industry 4.0 maturity, the target maturity to be achieved, and help identify the missing Industry 4.0 capabilities. It would serve as a compass to set the Industry 4.0 direction.

Further, Industry 4.0 is an evolutionary process and requires regular assessment of the organization's capabilities and implementation of new capabilities. It is crucial to measure benefits and reassess the new Industry 4.0 maturity against the changes in the business environment.

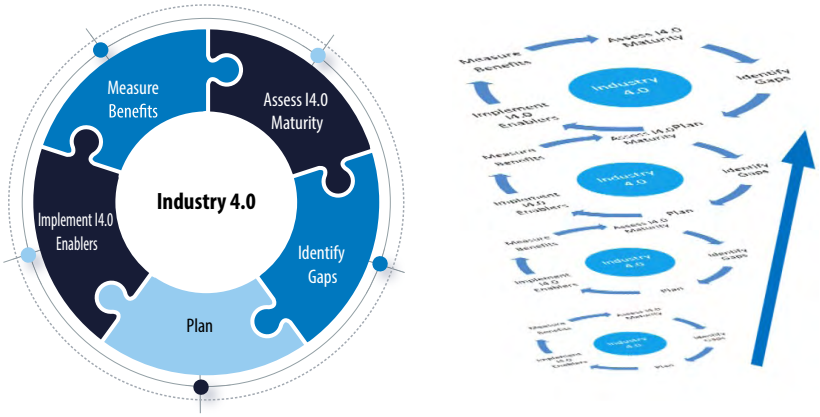

Figure 15: Industry 4.0 Iterative & Evolutionary Process

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