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MAPPING AND VALIDATION OF INDUSTRY 4.0 FRAMEWORK IN STEEL INDUSTRIES

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Abstract

Globalization and resource scarcity have led to competition in production, forcing companies to meet higher expectations with fewer workers and fewer resources. A new industrial revolution, known as Industry 4.0, has been triggered by this situation. The industrial environment has undergone significant changes recently as a consequence of new technologies termed Industry 4.0 (I.4.0), particularly in the areas of manufacturing and digital technology. Despite several instances of I.4.0 implementation in businesses, this field of study is still in its adolescence and lacks thorough investigation. The purpose of this article is to apply the industry 4.0 framework to the manufacturing sector to validate and map the framework. The main aim is to provide assistance and decision support for the development and implementation of this software in the manufacturing industry that wishes to improve its current activities.

Index Terms—Industry 4.0, Framework, metal Industries, validation, mapping.

I. INTRODUCTION

For real-time decision-making in the expanding steel industry, a fully integrated production system is necessary. Lack of data flow between business systems, like ERP (Enterprise Resource Planning), and production activities, such as MES (Manufacturing Execution Systems), is the main issue facing the steel industry. Visibility of product quality, operational lead times, planning and scheduling, maintenance management, and equipment health are only a few requirements for the steel industry's manufacturing processes. The business has struggled with outdated systems and technology that are common in the steel industry. Modern technology deployments are referred to as "brownfields" since they take place in silos with no organization-wide uniformity. There are many different processes and uses in the steel industry, which results in a variety of sources for production statistics. Before being sent to other systems, real-time data is gathered and aggregated [1].

The research by the University of Johannesburg to define a Smart Manufacturing Entity and use 4IR to address the technical gaps in the steel sector. Study topics included the steel industry, economic advantages, technical challenges, the 4IR framework, 4IR tools, and 4IR advantages. The strategy for implementing 4IR in the steel company is the alignment of present technologies and needs with the objective of 4IR architecture that produces the advantages of Smart Manufacturing.

The steel role in the economic sector

The importance of steel to India's economy and future is captured in a study published by the NCAER (National Council of Applied Economic Research). As per its conclusions, India's steel sector has a vital role in the country's overall growth. In fact, it is the only commodity with a wide range of uses across several economic sectors.

It is utilized for packaging as well as for producing daily-use items and constructing homes, and automobiles. Industries including power generation, petrochemicals, and fertilizers that employ packaging, fabrication, and engineering are increasingly using special steels [2].

Economic Benefits of the steel industry

Another unavoidable reality is the enormous job prospects that steel factories provide, particularly in Tier III cities. Steel has a 1.4x production multiplier impact but a 6.8x employment multiplier effect. Further, India currently produces more than 100 MT of crude steel annually, surpassing Japan to occupy second place in the world. In India, steel today accounts for roughly 2% of GDP and directly and indirectly employs about 6 lakh people.
Additionally, India is a significant contributor to the world steel industry because of its strategic position, which is characterized by a long coastline for imports and exports. These figures alone demonstrate the significance of steel in pushing the nation's GDP over 7 percent Y-o-Y.

Technological challenges in the steel industry [3]

The second-largest steel production in the world is India. It presents a unique set of challenges, however. There are several difficulties the Indian steel sector must overcome, including a lack of technological adoption, fluctuating steel pricing, supply chain management issues, logistical issues, and transportation issues. The steel sector nevertheless faces several difficulties, despite the government's varied initiatives. We examine some of the main issues the Indian steel sector is now experiencing:

1. Demand prediction
2. Capital- and labor-intensive industry
3. Disruptions in raw material supply
4. Logistics-related challenges
5. Lack of technology adoption
6. Low per capita consumption
7. Increasing environmental concerns
8. Downtime and potential utilization

II. FOURTH INDUSTRIAL REVOLUTION

Modern Strategy: Germany started an action plan to outline how business procedures in the industrial sector would converge. In 2011, the strategy was known as the "High-Tech Strategy Action Plan 2020." As shown in Figure 1, the plan included combining technologies such as CPS, IoT, IIoT, Mobility, Cloud computing, AI (Artificial Intelligence), Big Data, and smart sensing. Thus, Industry 4.0 refers to the merged technologies.

Figure 1: Industry 4.0 Framework (Kagermann et al., 2013) [4]

An industry 4.0 framework connects people, processes, and objects in a smart manufacturing value chain by combining the technologies shown in Figure 2. Irrespective of the product or service, Industry 4.0 is positioned to support the standardization of business processes and data flow in production operations.

Industry 4.0 archetypes

The core strategy of I.4.0 is the integration of tools, procedures, people, and organizations. Industry 4.0 is thus characterized by three architectural aspects in terms of integration (Teuteberg & Oesterreich, 2016; Stock et al., 2016):[5]

a) Vertical Integration

The IT landscape of a business contains information at many levels. Each level's information is used for a variety of purposes, such as production operations, business 20 activities, or integration needs. The data needed for the manufacturing process is specified at each stage. However, depending on the needs, the level of intricacy and granularity varies. The administration and control of data and processes between interconnected levels are made possible by vertical integration. Vertical integration also makes it possible to adopt processes and make decisions following established business norms. Vertical integration helps to integrate the whole manufacturing value chain, from supply chain operations through production-related plant equipment up to the ERP.

b) End-to-end engineering

Before being included in industrial production activities, a product needs careful preparation and execution. Data that is pertinent to the product is produced at every stage, from concept development through product end of life. The management of data flow from the conception of the product through design, logistics, execution, service, consumer, and the end of the product's life is known as end-to-end integration. End-to-end integration requires the synchronization of business processes and master data pertinent to the product to sustain quality. If a warranty or service item is necessary, information on the manufacturing requirements and standards of a product must be readily accessible.

An organization's design, production, and service divisions are all included in end-to-end engineering. Data is gathered and incorporated into each appropriate step of the product's life cycle as it progresses, helping the company handle any issues that could develop with the production or customer service operations.

c) Horizontal Integration

The management of various supply chains is necessary for the execution of industrial operations. The beginning of the supply chain is the raw material provider, followed by the operations, the logistics of the product, and finally the consumer. The function of horizontal integration is to view and manage supply networks. Horizontal integration may provide information about the wait times for raw materials, manufacturing operations stock on hand, and warehouse stock levels. One of the advantages of horizontal integration is the goal of controlling and maintaining the supply of raw materials concerning industrial demand.

III. DIMENSIONS FOR INDUSTRY 4.0

We were able to determine the fundamental abilities being taught in learning factories all across the globe by examining the different Learning [9]. The courses that are taught in learning factories are listed in research by Abele et al. and Kreimeier et al. [6-7]. The competencies learned in learning factories were converted into these courses. The first level of the framework is comprised of these skills. Since learning factories are exemplars of SMEs, additional research investigation enabled the identification of groupings of components commonly present in learning factories and SMEs.

The following definitions were developed throughout the study for the components of a learning factory that were discovered via analyses of the different learning factories, such as Objects, System nodes, software, and Technology [8]. Dimensions for the framework were categorized using these sets of components [9]

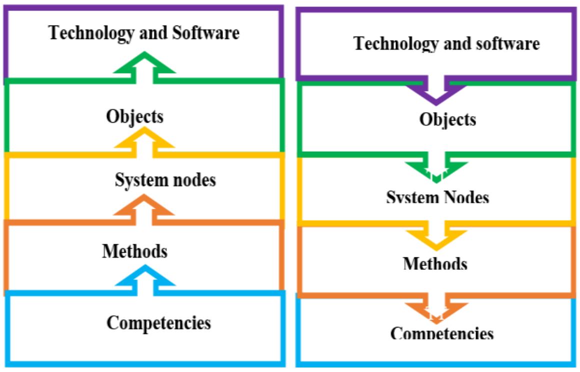
Dimension for Industry 4.0 framework

1) **Competencies**: Competency is understood to be the growth of a specific, industry-related skill that may be taught using a variety of applications.
2) **Methods**: is described as being made up of several items and system nodes that together perform a purpose.
3) **System nodes**: are user instances that may be modified or changed in some way to fulfil a need or perform a task as part of a system operation. The culmination of smaller items is called system nodes.
4) **Objects**: these are the smallest physical components that may contribute to, improve, or change a process function but can't, by itself, perform a process function.
5) **Technologies and software:** The prerequisites for objects and system nodes to operate successfully are referred to as software and technologies.

Initial Dimension of the Framework [9]

Figure 2(a) shows how the dimensions were arranged such that it reads as follows from the bottom up: It is possible to teach certain competencies using specific system nodes, which contain specific objects and are made possible by specific software and technologies [9]

Figure 2(b) shows the following in ascending order: Which tools, programmes, and materials may be used with certain system nodes to produce particular teaching strategies that enable the teaching of particular skills in a learning factory. As a certain technique would represent the planned implementation in an SME and no competencies are imparted, it may stop at the methods dimension.[9]



(a) (b)

Figure 2: Initial dimensions for framework [9]

Final Dimension of the Framework [9]

The research showed a few of the many advantages that may be realized by implementing Industry 4.0, and as was noted in the conclusion section, it can be viewed as an operational improvement tool. After that, I.4.0 creates packages out of existing technology, software, objects, and procedures. This allows the framework to capture such packages and make them accessible by adding a new dimension, I.4.0 applications, between the competencies and techniques dimensions. As seen in Figure 3, this new dimension served as a connection between the competencies taught dimension and the other dimensions.

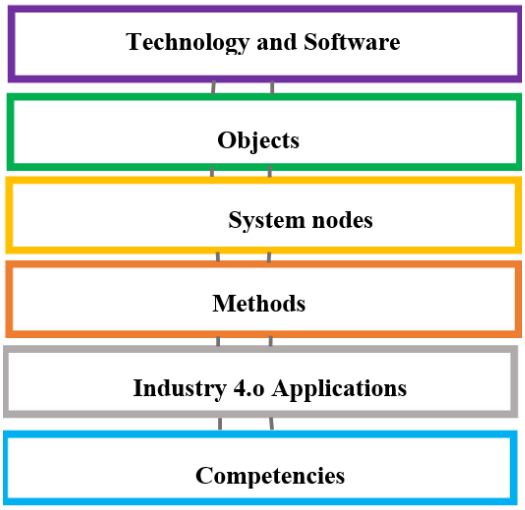


Figure 3: Final dimensions for framework [9]

Dimensions and Elements Industry 4.0

The components for the I.4.0 applications dimension were mostly given by a study project by the Fraunhofer Institute [10][11] about classifications of I.4.0. He made Industry 4.0 more distinct and easier to understand. Industry 4.0 was divided into layers that are pertinent in a learning factory and SME setting and match the framework's six dimensions. Industry 4.0 components were present in every dimension, offering concrete standards for implementation. Six Dimension and their corresponding elements are given below.

Dimensions	Elements
Competencies	design for assembly low-cost implementation design for manufacture visual management ergonomic design systems thinking lean tools smart logistics
Industry 4.0 applications	collaborative work human movement optimization digital factory big data analytics smart manufacturing intelligent transport smart products real-time work visualization
Methods	Real-time work-data visualization Efficient resource management Product memory KPI tracking Additive/reductive manufacture Synchronized material supply Real-time KPI tracking SES (Self-execution system) Simulation Standardization SWS (Smart work sequencing)

	Automation Workplace organisation
System nodes	commissioning warehouse rework Transport system Manufacturing Machining E-Kanban Kanban Assembly station Palletisation station Product design station
Objects	Barcode scanner Wi-Fi routers Transfer skid Conveyor (Automated/ mechanical) Supermarket Smart conveyor Computer PLC (“Programmable logic controllers”) 3D printers Microcontrollers Smart transfer trolley Mechanical transfer trolley Heavy machinery: Lathe, CNC etc. Robots: light mobile Robots: Stationary
Technologies/ Software	3G/4G/LTE Sensors Bluetooth Trace and track Barcode Augmented reality Wi-Fi Ethernet Advanced materials NFC (Near field communication) Smart labels Hardware specific software 3D printing Cloud computing OSS: “Open-source software”

Table1: Dimension of Industry 4.0 framework with their elements

IV. INDUSTRY 4.0 FRAMEWORK [12]

Greenfield design

To include Industry 4.0 applications into a brand new, soon-to-be-built plant, a user may request a greenfield design of an Industry, in which case the design would be carried out in line with the framework from the competencies dimension up to the software/technologies dimension. The user would then choose the most important skills and knowledge that the learning factory should emphasize or highlight. After settling on a set of essential skills, the user should examine the tree diagrams, which show how those abilities relate to the other dimensions. Figure 4 is a branching diagram depicting one possible path to proficiency using lean tools. The figure's dimensions are shown at the figure's top. In this particular instance, the user will follow the supplied coloring scheme and work from the left side of the tree diagram to the right side. Once the user can create a left-to-right route using just blue, green, and/or orange pieces, a skill may be taught or utilized in the learning factory. This is accomplished through the selected Industry 4.0 application. When a branch's color is red, it means that the choice is not viable. These errors show that the user is not competent in that particular subset of the competence and hence cannot use the tool for implementation or instruction.

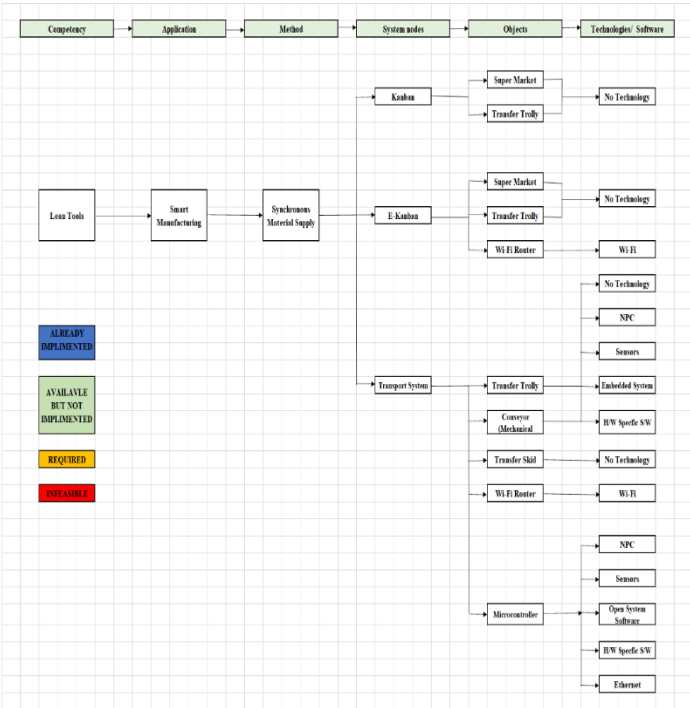


Figure 4: Industry 4.0 Green Field Design [12]

Brownfield design

If a factory already exists but the user needs guidance in making decisions about its reconstruction to accommodate Industry 4.0 features, a redesign is required. Similar to the greenfield design example, the user starts in Figure 4 on the right side of the tree diagram and works their way to the left, adding colors in the manner explained above. With this method, the user will have an easier time figuring out what resources are currently available to them and what they may be put toward. It has already been established that the user requires a smooth transition from the realm of technologies/software to the realm of business. the relevant Industry Only green, blue, and/or orange elements are used in 4.0 applications and skill dimensions. 4.0 implementation and required skills. Working through to the competencies dimension is necessary to realize the ultimate goal of this framework application, which is to improve present operations and/or the skillsets taught via the designing and deployment of Industry 4.0 applications.

Figure 5 is a tree diagram depicting the steps we will take to implement our vision of Industry 4.0. We'll begin at the left and work our way to the right. Again, the items are colored according to the given color-coding key. The user may construct the industry 4.0 application in the same way they would construct any other framework application once a direct line can be formed from the application to the technologies/software associated with the application.

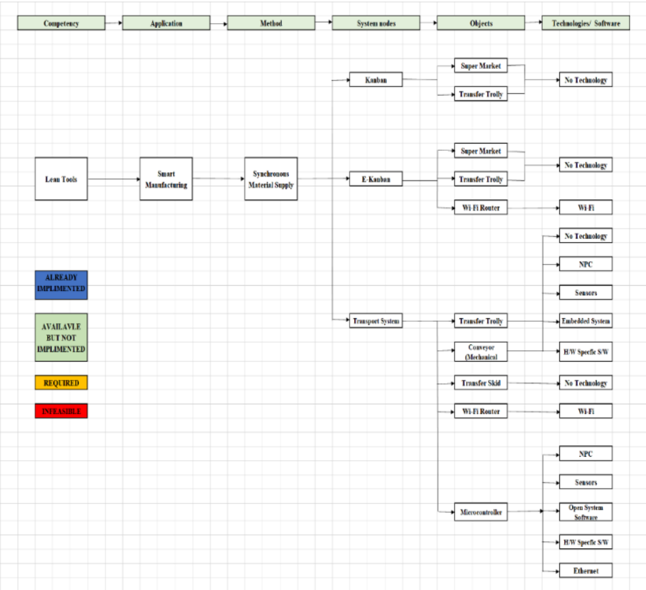


Figure 5: Industry 4.0 Brownfield design[12]

V. MAPPING AND VALIDATION OF INDUSTRY 4.0 WITH THE METAL INDUSTRY

(Gopani Metal Industry (GMI)

We secured approval from Gopani metal industry Pvt. Ltd. to verify and check the framework shown in Figure 4. GMI Manufactures and delivers Cold Rolled Closed Annealed strip coils and sheets, it is among the best steel companies in India. Their worth is enhanced by their high-quality design, reliable production, and punctual shipping. Oil and gas, vehicle, consumer appliance, electrical component, and equipment manufacturers are who the firm mainly serves with its goods and services. Products made in this factory are Cold Rolled Steel, Hot Rolled Pickled Steel, as well as Hot Rolled Skin, Passed Steel.

Figure 6.1: Gopani Metal Industries

Figure 6.2: Hot and Cold Rolled Pickled

In the factory mapping phase, the management team chose three capabilities to test which was part of the industry planning process. The competencies decided were:

- visual management,
- lean tools,
- low-cost implementations.

Following the standards and the framework shown in Figures 4 and 5, The learning factory's foundation was developed backwards, beginning with the skills that would be taught there. This framework's implementation would make it possible to identify the bare minimum of methods, system nodes, and software/technologies needed to properly implement the targeted capabilities and would also demonstrate which Industry 4.0 applications may best be exhibited in doing so. The established framework's competence maps were compared to the resources already available within the department to determine whether overlapping additions would be necessary to properly apply all skills. The factory didn't have a comprehensive, cohesive structure at the time this use case was executed; it just had a few isolated components. Using these categories, we sorted every conceivable technique, system node, item, and piece of technology/software that pertained to each of the three domains.:

- implemented already,
- available but not yet put into practice,
- required, or
- impracticable.

One of the abilities is showing off cheap implementations, therefore things deemed unworkable for the industry were often written off based on how long they would take to develop and how much money they would cost. See an excerpt from the framework used to evaluate Gopani Industries' lean tool utilization.

By categorizing each branch of the framework for each skill individually and calculating the remaining likely branches, we were able to determine the bare minimum of extra components required for the proper execution of all three competencies. These three abilities may be strengthened by using the following Industry 4.0 apps:

- smart work sequencing,
- smart manufacturing,
- work data visualization.

It was also determined where the most overlap occurs between the procedures corresponding to these Industry 4.0 applications and the appropriate skills. Table 2 displays the GOI-approved strategies for implementing Industry 4.0, together with the accompanying competencies to be taught and examples of how those strategies might be used to highlight the potential of this technology.

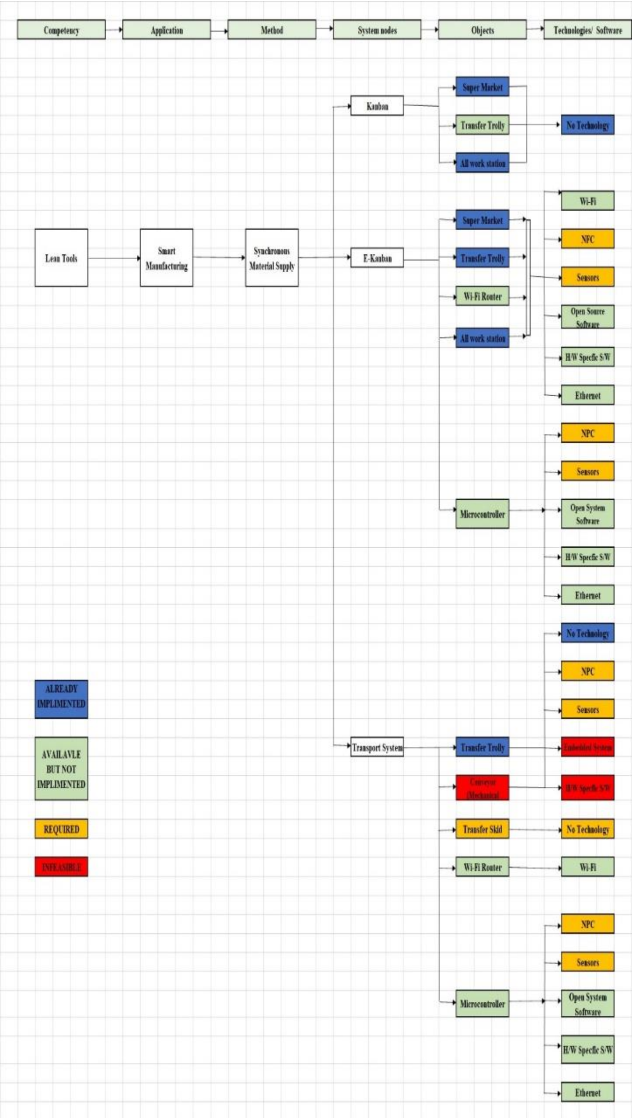


Figure 7: Mapping of Gopani Metal Industry with Framework developed

Competency	Industry 4.0 application	Method
Lean tools	Smart Manufacturing	Synchronized material supply
Visual management	Real-time work visualization	Smart work sequencing (commissioning) standardization
Low-cost implementation	Smart Manufacturing	standardization Synchronized material supply smart work sequencing

Table 2: Methods to be implemented, with respective Industry 4.0 application and target competency

Many potential paths toward an industry 4.0 learning factory were suggested by the framework's Brownfield design application on the GMI. In Figure 7, we see a visualization of one of these likely regions. This representation is a comprehensive input-output flow diagram, outlining the prerequisites for each Industry 4.0 application and the ensuing suitable procedures.

VI. CONCLUSION

Lean tools, visual management, and low-cost deployments are highlighted by the Global Manufacturing Index, along with the benefits of Industry 4.0. The E-kanban systems were able to effectively execute these competencies. Time savings and the elimination of wastes like human mistakes and unnecessary steps constitute the "lean" part of the equation. With these methods, just the needed amount is harvested at the right time. To complete the architecture, the microcontroller system, various sensors, and both hardware-specific and open-source software may be included. To make the heavy metal industry fully compatible with Industry 4.0, a variety of robots may be employed.

The above-mentioned competencies were successfully implemented, and not only did this result in significant improvements to the assembly and production processes, but it also laid the groundwork for a wide variety of further enhancements and developments. These approaches provided us with a head start in demonstrating the required capabilities via the GNI. Similarly, it can be applied to other manufacturing Industries.

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