A Study on the Application Feasibility in the Steel Industry of Existing Maturity Models of Assessing Industry 4.0 Readiness

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Abstract

The steel industry is moving towards the implementation of Industry 4.0, in order to remain competitive in this globalized world, where cost reduction and greater interaction in the supply chain must be thought as a whole. This type of industry is usually done with different and complex processes, a part that manufactures steel and the other where the product is rolled. Due to this complexity and size there is a tendency to implement I4.0 in islands.
To assess whether a particular company has the ability to implement enabling technologies for I4.0 or at what level of implementation it is, aptitude assessment and maturity assessment models are applied. Another return that can be obtained from some maturity assessment models is to be a guiding tool for the strategic planning of the implementation of I4.0. Having this in consideration, the present work aims to present maturity assessment models for the implementation of industry 4.0 and to evaluate and start a debate about its applicability in the steel industry. With this aim, eight models applied in several industries were studied and verified if, and/or how, they could be applied in the steel industry, due to its particular characteristics.

Keywords
Industry 4.0; smart industry; steel industry; maturity model.

1. Introduction
From eighteenth to twentieth century the manufacturing industry had an important evolution, a fact that has a direct impact on the business models of the markets in which they operate (Yin,Y at all, 2017). In this period the industry has undergone several modifications, which have been given the name of Industrial Revolution. These revolutions have been called Industry 1.0, 2.0, 3.0 and 4.0. The end of one level and the beginning of another have been marked by great changes. And, according to companies, the gap between supply and demand was evolving and forcing the industry to develop from 1.0 to 4.0 (Yin,Y at all, 2017).
Industry 4.0 is described as the fourth industrial revolution. It starts in 2010, when Germany decides to draw up a plan for its socio-economic growth over the decade. This plan aims to guide the country's evolution in the areas identified as of strategic interest, in order to become a global reference country. This fourth revolution is

represented, mainly, by Cyber Physical System (CPS), Internet of Things (IoT) and, Cloud Computing, however, it also counts on intelligent devices and Business Process Management (BPM). While the Third Industrial Revolution also focused on the automation of machines and processes, Industry 4.0 focuses more on end-to-end digitization and the integration of digital industrial ecosystems, seeking fully integrated solutions. Basically, CPS consists of a system that starts to incorporate equipment, inventories, and production in a global network, being able to exchange information between them, send commands and control each of these components, independently.
This work presents some developed models for assessing the maturity of I4.0 in the industry, in order to verify its applicability in the steel industry.
After this introduction and framework to the work presented in this section 1, section 2 summarizes the models for assessing the digital maturity of companies for several economic sectors. In this section, a comparison between some of the existing models, from the other authors, is also presented. In section 3, the steel industry is described, and its characteristics are explained. The current reality of this sector in I4.0 is presented in this section 4. The central theme of this study is outlined in this section, where the feasibility of applying the existing maturity assessment models in the steel industry is discussed. Finally (section5) a conclusion to the study is made with a discussion on the analysis of the applicability of the existing models in the steel industry.

2. General maturity assessment models for I4.0

Maturity models are commonly used as a tool to conceptualize and measure the maturity of an organization or process relative to some specific target state.

The path to I4.0 is extremely important for the industry to remain competitive; it is important to understand the level of maturity of the implementation of I4.0 as well as the correct definition of the point of implementation of each industry in its business segment, and only then build a strategy or deployment plan.

To this end, many evaluation models to measure the level of maturity of the implementation of I4.0 were developed, each of them presenting different evaluation formats both in the way and in what is intended to be measured.
Some consider the implementation of a set of I4.0 technologies and the application of pre-defined growth models for each technology defined in the nine technological pillars, Information Security, Reality, Big Data and Analytics, Autonomous Robots, Simulations, Vertical Integration System, Horizontal Integration System, IoT and Additive Manufacturing (Storoli et al, 2018). Organizations may not yet have a coherent strategy or even a plan for the implementation of I4.0, while others use I4.0 only in specific areas of the organization, as independent islands. However, to unlock all the opportunities offered by integrated and smart production, efforts need to be extended to include services such as logistics and customer service in the I4.0 approach.

This work resumes some models for assessing the maturity of I4.0 implementation in manufacturing industries, and compares them in terms of their main characteristics.

Chonsawat et al (2020) developed their model for assessing the maturity of the application of I4.0 in Small and Medium Enterprises (SMEs) and applied it in two manufacturing companies in Thailand. The objective was to identify the gaps between current Small and Medium Enterprises and those with a higher level of implementation of I4.0. The model also serves as a guide for improving their production efficiency.

The authors classified the factors used to assess an organization's readiness into five dimensions and 43 sub-dimensions. Figure 1 shows the five main dimensions, including Manufacturing and Operations, People Capability, Technology-Driven Processes, Digital Support, and Business and Organization Strategies.

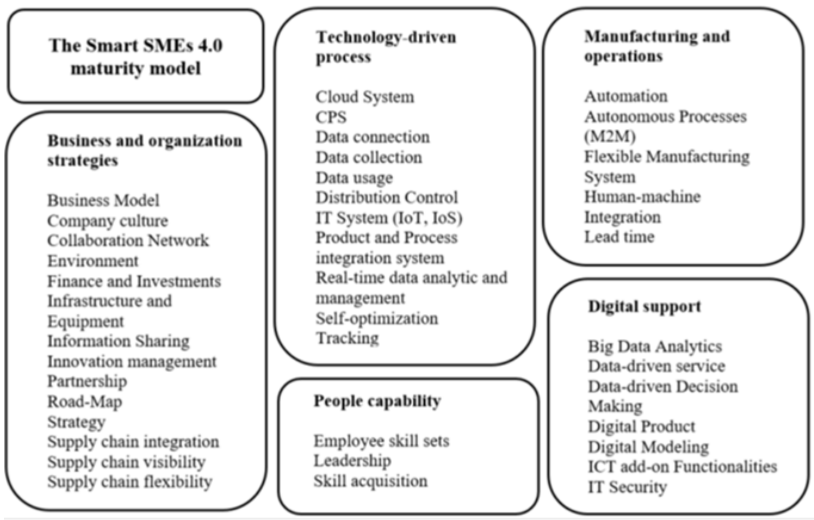

Figure 1. The five dimensions and forty-three sub-dimensions defined to assess the readiness of companies for Industry 4.0. (Chonsawat, et al.2020)

The authors created a set of questionnaires and sent them by e-mail to the companies participating in the case studies.

The results contain two parts, the first being the evaluation by score of the main dimensions. The highest score shows the most significant factors that require improvement before attempting the I4.0 transformation.
The second part of the results presents the organization's degree of readiness to implement I4.0, where companies choose the level that best defines their capabilities in the five main levels and their characteristics.
The results show that the model can assess an organization's current level of readiness and improve its potential.
Continuing with the need to understand the theme of Industrial Revolutions and how I4.0 can impact the aforementioned conjunctural, environmental, social and economic changes, Storolli, W.G. et al (2018) present a study to define their degree of maturity in the Brazilian auto parts environment using the OPM3/Likert 3 single-criteria method and the multi-criteria method Preference Ranking Organization METHod for the Enrichment of Evaluations – Promethee.

The dimensions defined in their model were Manufacturing, Commercial, ICT, R&D and Administration. The maturity items were IoT (Internet of Things); IoS (Internet of Services); IoD (Internet of Data): comprehend Big Data and Big Data Analytics, Cyber Securit; CPS (Cyber-Physical System); Smart Factory; Intelligent sensing; Traceability; Predictive Maintenance; AGV (Automatic); AR (Augmented Reality), and the levels were Initial – when not using or less than 25% of the tools linked to the I4.0 concept; In implementation – when using 25 to less than 50% of the tools linked to the I4.0 concept; Intermediate – when using 50 to less than 75% of the tools linked to the I4.0 concept; Final implementation phase – when 75 to less than 100% of the tools linked to the I4.0 concept are used; Implemented – 100% of the tools linked to the I4.0 concept are used.

Trotta, D. et al. (2019), after reviewing different maturity assessment models, followed the steps to build a model applied to SMEs as the following: Problem Definition, Comparison of existing maturity models, Concept assessment, Determination of the model development strategy, Implementation and Evaluation.

-Phase 1. The "problem definition" begins with the clarification of the researchers' objectives and serves to better frame the subsequent analyses. Four SMEs operating in the manufacturing sector undergoing I4.0 implementation were interviewed. The results of the interviews confirmed the crucial role played by employees and the need for the company to assess more than just technological maturity.

-Phase 2. “Comparison of existing maturity models” deals with the study of previous maturity models.

- Phase 3. "Model development strategy" spreads from the analysis of the models to support the development of the new.
-Phase 4. "Concept evaluation" is necessary to verify the quality of the created model and to fix any deficiencies. In the case of this work, the scale was tested in four Italian SMEs operating in the manufacturing sector.
-Phase 5. "Implementation" is the actual transfer of the model from theory to the assessment of the maturity of companies.

-Phase 6 "Evaluation" is the moment when the model is finally evaluated and accepted or eventually rejected.
These authors defined five dimensions in their model which are Strategy, Technology, Production, Products and People.

Items in each dimension are presented as a Likert scale ranging from 1 to 5, where 1 is "not implemented/not present" and 5 "fully implemented/present".
The survey data was then analyzed and a radar chart designed to help professionals visually understand their maturity. The five key dimensions of the maturity model defined were Strategy, Technology, Production, Products and People.

Trotta, D. and Garengo, P. (2019) highlighted in their research article the difficulties encountered by SMEs in assessing their maturity level of I4.0 using tools designed for large companies. On the other hand, publications investigating I4.0 from a managerial perspective are increasing. However, contributions in engineering and computer science surpass documents with a managerial perspective. The model created by them allows companies to check their degree of maturity and plan actions to improve their maturity.

Schumacher et al (2016) describe the results of developing a maturity model and a related tool to systematically assess the state of development of manufacturing companies in relation to the I4.0 vision. According to the authors, the developed maturity model meets both a scientific perspective and a practical effect, which is its applicability. The scientific purpose is to obtain solid data on the current state of manufacturing companies and their I4.0 strategies, to extract potential success factors. The practical objective of this work is to enable a company to rigorously assess its own maturity regarding I4.0 and reflect on the need to adapt current strategies.

The development of the proposed model included three distinct phases. An initial phase to deepen understanding of the I4.0 domain, a development phase to design and architect the model framework, as well as a practical application tool and, an implementation phase to validate the resulting tool as applied in real life. The first steps contained an assessment of the domain complexities and a gap analysis of the existing maturity models applicable to assess the maturity of I4.0. Semi-structured interviews were conducted with practitioners and researchers which helped to determine the underlying problems and validate the research effort as a solution to the problem.

3. The characteristics of the steel industry

As the main alternative technological options in the steel industry for the production of steel, there are integrated and semi-integrated plants. The integrated plants consist of the transformation of iron ore into steel and this one into final products (rolled). The semi-integrated plants start their process in the steel shop, using ferrous scrap as a basic input. After the steel is manufactured, the product is rolled, similarly to what happens in integrated mills. These two technological options, in fact, contemplate a wide variety of equipment solutions. Every steel mill has at least a melt shop and casting plant, when they are slab manufacturers, and some also have sintering or pelletizing, blast furnace and ladle metallurgy. Others have subsequent lamination processes.

The difference between an integrated and a semi-integrated plant is the fact that the first has the so-called reduction stage, where the iron ore is transformed into primary iron, Germano (1998).
Thus, the reduction step consists of transforming the iron ore into the so-called primary iron. This can be pig iron, DRI (direct-reduced iron - DRI) or HBI (hot-briquetted iron - HBI), using blast furnaces (coke and charcoal) and direct reduction installations. Primary iron, in one of its three forms, is then used in the refining stage (steel manufacturing). In the case of semi-integrated plants, the process begins at this stage. Refining contains three basic equipment (melt shop, casting and ladle metallurgy), the first two being mandatory.

In the steel plant, the steel itself is produced, e ither from pig iron (basic oxygen steel plant) or ferrous scrap and sponge iron (electric steel plant).

Once produced, the steel needs to be solidified (ingot cast). There are two alternative methods: conventional casting (using ingot molds) and continuous casting. The latter was also developed in the mid-1950s, presenting numerous advantages compared to conventional casting, Germano (1998).

Continuous casting allows higher semi-finished/liquid steel yield, being more compact (eliminating ingot molds, pit furnaces and primary rolling mill) and providing better quality to the final product.

Ladle metallurgy (or secondary metallurgy) is about the interconnection of steel manufacturing with the casting machines, allowing a fine adjustment of temperature and chemical composition, essential characteristics to noble steels. Thus, the greater the proportion of steels treated in ladle metallurgy, the better the production mix should be. In electric steel plants, the use of ladle metallurgy allows a substantial gain in the reduction of running time, increasing the plant's productivity. With the adoption of this type of equipment, the steel shop changes its way of operating. Without ladle metallurgy, the steel shop performs two functions: first, it melts the scrap with the alloys needed to produce each type of steel; second, it promotes refining, that is, "fine tuning" to achieve the ideal properties of steel. With ladle metallurgy, the steel shop ends up performing only the first job.

The main secondary metallurgy equipment is ladle furnace (for electric steelmaking) and vacuum degassing (for basic oxygen steelmaking).

After solidification of the steel, the next process is rolling, where the steel is transformed into the final product, that is, into rebars, wire rod, profiles, rails, hot rolled coils, cold rolled coils, galvanized sheets, metal, stainless steel sheets.

4. The I4.0 in Steelmaking

Large industrial companies prioritize digital technologies to increase the efficiency of the production process and improve business management, in particular Digital Automation with sensors for process control, CNI (2018).
Companies are starting to move to incorporate digital technologies beyond the production process, that is, technologies applied in product development and in products and business models. The investment plans present a distribution among the types of digital technologies that is less concentrated than the current distribution of the use of technologies.

Digital automation with sensors for process control is the most used technology by companies. Second, there are Integrated Engineering Systems for Product Development and Manufacturing, CNI (2018).

Digital automation with sensors with identification of products and operating conditions, flexible lines, is still little used, followed closely by the collection, processing and analysis of large amounts of data (big data) of the company and Monitoring and remote control of production with systems of the MES and SCADA type.

Broadly speaking, the IoT, fast and secure communication network technologies (networks), AI, Big Data, Cloud Computing and Smart, connected production will be relevant for most basic inputs. However, by 2027 none of them are likely to be revolutionized in terms of technology or business model. The only likely exception is that a greater possibility of disintermediation is considered, which would put independent distributors of steel products at risk, CNI (2018).

It is very likely, therefore, that the predominant competitive strategy in the system is the recurrent adoption of incremental innovations, since several products are commodities and radical innovations are infrequent in these sectors, which have a lower research intensity than manufacturing in general.

In general terms, the world steel industry as well as in Brazil follows the same trends. Brazilian steelmakers have a low degree of productive diversification but have been undergoing updates which allow them to remain viable businesses.

A study conducted by CNI, called Industry 2027 (Indústria 2027. CNI, 2018), identified eight Technological Clusters – among them are the IoT, AI, Nanotechnology and Advanced Materials –, innovations whose effects on the economy and society are a path of no return. Figure 2 presents these Technological Clusters.

The evaluation of the eight Technological Clusters identified the key technologies that, introduced commercially in up to ten years, can initiate changes in Production Systems, altering business models, competition patterns and the current configuration of companies' leadership positions. In this time horizon, these technologies can constitute threats and opportunities for established or new companies, as well as imply the emergence of new market segments.

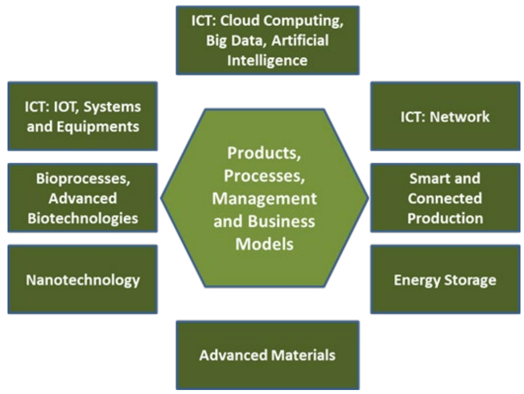

Figure 2. The Technological Clusters which comprise a set of key technologies grouped by technological proximity and knowledge bases involved. (Source: Indústria 2027: CNI, 2018)

The steelmakers' perception is that the current diffusion of Technological Clusters in the Brazilian steel industry is incipient and its challenges at the national level include:
• A structured and organized treatment of the topic.
• Building an ecosystem that facilitates the implementation of these technologies.
• The break with technological dependence on other countries.
• The increase in investment in these technologies, considered to be easily adaptable to the national reality.
In Brazil, the current steel production development presents initiatives to implement I4.0 through its Technological Clusters, mainly in the areas of reduction, steelworks and rolling mills. Manufacturing systems are complex systems, involving a large number of interconnected equipment and many interconnected processes working together (Lin, S-W et al, 2019).

A steel mill has a long and complex end-to-end production process that consists of many sub-processes, including sintering, pig iron making (blast furnace), melt shop (converter), continuous casting, hot rolling, cold rolling, heat treatment and coating processes.

Each of these sub-processes operates dozens of various pieces of equipment in a complex production process. Furthermore, these processes run at various paces that range from a continuous process at an early stage (e.g. iron making) to a discrete process at a later stage (e.g. cutting into strips). From end to end of the production process, there are material, energy, information and value flowing through these sub-processes.

In addition, steel plants have an extensive useful life and some companies even complete a century of operation. Perhaps the best-known example is the U.S. Steel, founded in 1901. Even having lost its leading role in the sector, in 2016 the company was still the 24th largest steelmaker in the world (WSA, 2017).

According to Martins (2019) and Tropia (2017) it is possible to verify studies on the challenges of implementing I4.0 in the steel sector, as well as the main changes in terms of relations in the production chain, general organization of the company and organization of production. As a result, it can be concluded that expectations are optimistic regarding productivity, process integration and access to information on operations. However, there are worrisome issues regarding labor consequences, information security and new workforce profiles (Martins, 2019). This is the most common discourse regarding the effects of implementing I4.0 in the Brazilian scenario.

5. Discussion of the applicability analysis and Conclusion

The work presented here aimed the analysis of the feasibility of applying existing maturity assessment models in the steel industry.

The steel industry is considered a capital-intensive segment, in other words, that demand a large amount of capital for its operation. Another important feature is that this industry can be found all over the world and inserted in a global market. Developments to reduce costs and increase competitiveness are always in the portfolio of projects in this industry segment.

In Brazil we can find several players, with different ages, some with Brazilian nationality and others with international owners, but all players inserted in the global market. For this reason, every player has to be up to date in terms of productivity, cost, business model, product, especially considering the different technologies used in terms of manufacturing and implementation date.

With the objective of competitiveness, this industry needs to undergo modernization in some of the processes, with increased automation, digitization with sensors for process control, capture and analysis of process data, better connection between processes and, if possible, connection with suppliers and customers (supply chain).

The I4.0 is a way to get expected results like above mentioned, with its different enabling technologies.
As this kind of industry is the continuous process industry, the impacts of the implementation of I4.0 technologies should focus on improvements in the production process and the digital prioritize to increase the efficiency of the production process and improve business management. The implementation I4.0 through its Technological Clusters should be happen in the areas of reduction, steelworks and rolling mills and the main changes in terms of relations in the production chain, general organization of the company and organization of production.

Considering all these characteristics and the models presented in this work, the first conclusion is that there is applicability for assessment models in this industry, because used some dimensions which can be applied in this industry.

Taking in account the I4.0 implementation will be in the processes (and in islands), the dimensions to be considered in the assessment models are those related to technology rather than those related to the business model, commercial or supplier.

Digitization dimension is considered the base to enable technologies I4.0 implantation. From this dimension met, even in isolated processes, the Manufacturing dimension (Production and Operations), with all technological maturity items, can be implemented. Both are the main dimensions in this industry. Of course, the Strategy dimension must be considered, once that it will take some time for all these technologies to become truly accessible. But the steel industry can prioritize critical, since high value to deploy all services can be a barrier of I4.0.

Other dimensions could be applied but not I this time, because its dimension are related with suppliers or customers and, how this kind of industry is very big, involving many suppliers and customers, it is hard to have whole supply chain with I4.0 implemented. This work shows that the assessment models can be applied in steel industry, since to evaluate the stage of I4.0 implementation as to have the role to guide this implementation. The dimensions have to be defined in correct way as well as maturity levels. It is worth mentioning that the proposal presented represents an initial investigation of maturity assessment models for the implementation of I4.0 and its applicability in the steel industry.

Finally, recommendations for future work basically consist of: promoting more detailed modelling studies and proposing a model structure more suitable for the industry segment proposed here for study.

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