Studying Industry 4.0 Readiness Factors in Egypt Industry and Exploring Challenges of Implementation

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ABSTRACT

The digital transformation has become the core stone for a country economy development. Egypt is aiming to foster the industrial sector by modernizing the traditional industrial methodologies through Industry 4.0 evolution technologies. The majority of industrial firms are still in transition from Industry 2.0 to Industry 3.0, in particularly SMEs'. This study is aiming to assess the Industry 4.0 readiness level of Engineering Industries sector in Egypt by investigating the challenges and factors affecting on lack of digital transformation.

The first part explores the implications of Industry 4.0 applications proved by ten practical case studies using qualitative approach by semi-structured interviews. The second part assesses six readiness factors of Industry 4.0 implementation using quantitative descriptive analysis with survey questionnaires conducted with 362 participants from small, medium and large size companies.

The results show that, the most of case studies of Industry 4.0 have achieved significant improvement in transparency and decentralization decision making and improving of overall performance including productivity and quality increase and resources utilization from 10% to 20%, efficient waste management from 10% to 20% lower, improvement in quality and defect rate by 5% to 10%, and achieve 5% to 15% of energy saving and enhance the competitiveness and customers' satisfaction, in addition to achieving short term of ROI.

Also, the findings highlight the main challenges of the lack of implementation of Industry 4.0 applications are sorted as; "Cost and lack of financial support", "Lack of knowledge of Industry 4.0 technologies", "lack of employees' qualifications", "organization culture and lack of leadership, the least one is "threat of data security".

The study has proved the six readiness factors having significant relationship with readiness maturity level of companies for implementation of industry 4.0 applications,

including, (The maturity of ICT infrastructure, Employees' skills adaptability and competencies, corporate strategy, leadership and knowledge of importance of Industry 4.0 technologies, company motivations and internal or external pressures, digitization level of the operational areas, and maturity of ecosystem).

Keywords:
Digital Transformation; Industry 4.0; Readiness Factors; Challenges, Implications, Smart Manufacturing

دراسة عوامل جاهزية الصناعة المصرية لتطبيق تكنولوجيات الثورة الصناعية الرابعة Industry 4.0، وبحث التحديات التي تواجه تطبيقها.

الملخص :

قد أصبح التحول الرقمي حجر الأساس لتنمية اقتصاد الدولة. تهدف مصر إلى تعزيز القطاع الصناعي من خلال تحديث طرق الصناعة التقليدية من خلال تقنيات وتطبيقات الثورة الصناعية الرابعة Industry 4.0، ولا تزال غالبية الشركات الصناعية في مرحلة انتقالية من الثورة الصناعية ٢.٠ إلى الثورة الصناعية ٣.٠، ولا سيما الشركات الصغيرة والمتوسطة. وتهدف هذه الدراسة إلى تقييم مستوى جاهزية الصناعة ٤.٠ لقطاع الصناعات الهندسية في مصر للتحول الرقمي باستخدام تقنيات الثورة الصناعية الرابعة ٤.٠ من خلال دراسة التحديات والعوامل المؤثرة على التحول الرقمي والتصنيع الذكي.

يعرض الجزء الأول نتائج المترتبة على تطبيق تكنولوجيات التصنيع الذكي Industry 4.0، والتي أثبتت نجاحها من خلال دراسة عشر حالات عملية باستخدام النهج النوعي من خلال المقابلات شبه المنظمة مع قيادات عشرة شركات صناعية. ويقيم الجزء الثاني من البحث ستة عوامل لقياس جاهزية الشركات الصناعية لتطبيق تكنولوجيات التصنيع الذكي ٤.٠، باستخدام التحليل الوصفي الكمي مع استبيانات التي أجريت مع ٣٦٢ مشاركًا من الشركات الصغيرة والمتوسطة والكبيرة الحجم.

تظهر النتائج أن معظم الحالات العملية في تطبيق تكنولوجيات 4.0 قد حققت تحسنًا كبيرًا في عدة أبعاد، ومنها الشفافية واتخاذ القرارات اللامركزية، وتحسين الأداء العام بما في ذلك زيادة الإنتاجية والجودة من ١٠% إلى ٢٠%، وزيادة كفاءة استخدام الموارد من ١٠% إلى ٢٠%. وإدارة تخفيض الفاقد بنسبة ٢٠%، وتحسين الجودة وتقليل نسبة العيوب بنسبة ٥% إلى ١٠%، وتحقيق توفير في الطاقة بنسبة ٥% إلى ١٥% وتعزيز القدرة التنافسية ورضا العملاء، بالإضافة إلى تحقيق عائد على الاستثمار على المدى القصير.

كما تسلط النتائج الضوء على التحديات الرئيسية التي تواجه تنفيذ تطبيقات الثورة الصناعية الرابعة Industry 4.0، والتي تم تصنيفها على النحو التالي: "التكلفة العالية ونقص الدعم المالي"، "نقص المعرفة بتقنيات Industry 4.0 "، "نقص أليدي العاملة المدربة على التقنيات الحديثة"، "ثقافة المنظمة وعدم نضج القيادة، وأقلها هو "تهديد أمن البيانات."

أثبتت الدراسة البحثية أن عوامل الجاهزية الستة التي لها علاقة مباشرة بمستوى نضج وجاهزية الشركات لتنفيذ تطبيقات الثورة الصناعية الرابعة ٤.٠، تتضمن (مرتبة بأهميتها)؛ نضج البنية التحتية لتكنولوجيا المعلومات والاتصالات، ونضج مهارات الموظفين وكفاءاتهم للتعامل مع التقنيات الحديثة، واستراتيجية الشركة، والقيادة، ومعرفة أهمية تقنيات الصناعة الذكية ٤.٠ ، ودوافع الشركة والضغوط الداخلية أو الخارجية، ومستوى الرقمنة في المجالات التشغيلية في الشركة، ونضج النظام البيئي والأيكولوجي للصناعة في الدولة.

الكلمات المفتاحية :

- جاهزية الصناعة - تكنولوجيا الثورة الصناعية الرابعة- تحديات التصنيع الذكي

1. Introduction

The Industry 4.0 revolution is technological paradigm including conglomerated technologies and methods of value chain organization that involves intelligent and smart products, smart factory (manufacturing processes), going through smart enterprise for creating an intelligent manufacturing environment in which all participants are interconnected and share information with each other with digital-twin concept. The Industry 4.0 is characterized by embedded and networked systems that eliminate the lines between the real and virtual factory, as represented by the Cyber-Physical-System (CPS) and the Internet of Things. So that, the Industry 4.0 evolution includes three primary activities representing end-to-end engineering across the value chain; 1) Digitization and integration of vertical and horizontal value chain, 2) Digitization of products and services, 3) Development of digital business models and customers access. [3], [12]

The primary motivators for the firms to implement Industry 4.0 are (a) Technological applications push and (b) Technological application pull. Advances in ICT, greater factory automation, digitalization of the organization, technologies of IoT, CPS, and other factors are driving the technology applications push. In terms of technology application pull, there is a market demand for shorter product development cycles, more personalization, flexible and agile manufacturing, and decentralized decision-making, among other things. [24]

The Smart Factory concept is relying on integrating the emerging technologies; (autonomous robots, IoT, AI/ML, Big data, Cloud Computing, Sensors, VR/AR, etc.) of the Industry 4.0 mechanism, in which the intelligent machines, tools, work pieces, and humans of the network-linked intelligent system communicate with each other for realizing self-organizing, self-optimizing, and high competitive production. [18]

1.1 Research Objectives

This research study is aiming to assess the readiness level of Industry 4.0 revolution in Engineering Industries sector in Egypt, by investigating the challenges and micro level factors affecting on implementation of Industry 4.0 within the industrial organizations. This study uses mix of qualitative and quantitative research methods for collecting data toward to descriptive analysis of the readiness factors. In addition, the research study explores the implications of Industry 4.0 technologies in the ten practical case studies.

1.2 Importance of Digital Transformation by Industry 4.0 Technologies

Industry 4.0 evolution has become a strategic pillar at most countries, therefore, Industry 4.0 has been novel topic for research in research institutes, universities, independent development organizations and companies as well. The main drivers for moving forward smart manufacturing include the globalization, cost advantage, proximity to customers, improving

quality, controlling the waste, efficient resources utilization, flexibility and improve transparency. [15]

There are three dimensions driving Industry 4.0 Technology; Industry 4.0 Infrastructure with interconnectivity and virtualization, Big Data Maturity between different business units to achieve vertical and horizontal integration and improve decision making, and Industry 4.0 Applications. Which, represents Industry 4.0 characterization of all technologies. [7]

1.3. Survey of Industry 4.0 Readiness Factors for Enterprises

The assessing the companies' readiness for adoption with Industry 4.0 technologies is difficult job and depends on internal factors and national factors and there are lot of barriers for implementation. Various research studies examine the readiness of Industry 4.0 of emerging countries like Malaysia, India, Indonesia, Turkey and South Africa from different perspectives. Some studies focused on macro level factors and some focused on micro-level factors inside the manufacturing firms.

The challenges of Industry 4.0 implementation include Technical, strategical, organizational, educational, economical, and other types, [4]. Some research studies focus on certain industrial firms like Soomro, et al., (2021) [13] surveyed the readiness of Industry 4.0 of 100 technology companies in Malaysia, towards to 7 key internal factors, (i) Market pressure, (ii) risk-taking, (iii) knowledge, (iv) management support, (v) competencies, (vi) motivation and (vii) freedom.

While, the knowledge and readiness of enterprises about Industry 4.0 smart applications implementation are varied based on the company size [26], the two research studies; Tortora, A. M., Pianese, C. (2021) [10] in Italy and Sriram, et al., (2021) [11] had examined the knowledge and readiness in MSMEs enterprises, and reported that, more than 50% of SMEs' are still have lack of awareness of potential benefits of Industry 4.0 technologies on the company efficiency and performance. Also, the studies reported the main obstacles of I4.0 implementation; 40% of participants consider the high cost of equipment and tools, while, 35% of them have difficulty to find the skilled workers, and ~30% have limited knowledge of technologies.

In addition, the research study had been done with participants in SMEs' and large organizations from America, Asia, Europe, it reported that 46% of companies who adopted Quality 4.0 were large enterprises, 41% Quality 4.0 organizational readiness were SMEs, around 45% of companies who have adopted Quality 4.0 were from the European continent. [23]. So that, there are 5 major reasons for weak of adopting quality 4.0 are: lack of resources lack of alignment with corporate strategy and goals, lack of understanding of the benefits high initial investment, lack of clarity on the need for quality 4.0, lack of confidence in existing quality management strategies and methods lack of assurance that quality 4.0 will deliver good results and improve decision making. [1]

Another research study presented the Industry 4.0 readiness from maturity model of Enterprise Information System like ERP system, data security, business processes, they analyzed 18 dimensions of IT related to Industry 4.0 readiness, including different technology dimensions like; "Digital Product, Digital Processes, Digital Control". In addition, it oversees the macro level of network readiness index (NRI) over the country. [2]

Concerning the required skills for Industry 4.0 implementation, one research study reported that Industry 4.0 requires greater skills than traditional manufacturing, and enterprises should take the lead in assisting employee up skilling and reskilling in order to keep jobs. Experiential training in the manufacturing business could help with Industry 4.0 skill development. In addition, the education system should have main contribution for aligning with the Industry 4.0 skills development and minimize the challenges in the manufacturing industry, [14]. While, Artificial Intelligence (AI) is a crucial technology in smart manufacturing applications, it faces lack of talent and skills for implementation in Malaysian factories [26]. Moreover, for reshaping 4^{th} industrial revolution,

Raj et al., (2019) [22] and Mangla et al., (2018) [17], had identified and analyzed 23 barriers to the adoption of Industry 4.0 across different economic contexts from interviews with 6 industry experts and established relationship between those barriers, with the assistance of the Grey-DEMATEL technique.

In addition, there is difference of barriers and policies between developed and developing countries in this regard. The most five critical influencing factors on the implementation of Industry 4.0 in Indian firms are ‘lack of standards, regulations, and forms of certification, followed by the ‘lack of internal digital training, ‘lack of infrastructure, ‘lack of clarity regarding the economic benefit, and ‘lack of a digital strategy alongside resource scarcity.

Some research studies focus on exploring the barriers and drivers of Industry 4.0 technologies implementation in SME’s, like [15], [20]. [22], and [12], while, another study had shown that larger companies seem to be more Industry 4.0 ready than SME’s, while, SME’s are struggling with adapting and implementing of I4.0 technologies and even some SME’s are not confident with Industry 4.0 technologies outcomes. [9]

1.4. The impact of adoption industry 4.0 applications

The impacts of adoption the Industry 4.0 applications (Smart Manufacturing) have numerous on economic, sustainability and social.

The economic impacts of smart manufacturing are effectively on Production, Services, Final Products, Customers satisfaction, Workers and Government Economic Policy, as shown in figure 1.

Fig. 1. Positive Impacts of Smart Manufacturing

Those positive results shall be achieved through de-centralization and monitoring the production by intelligent system, skilled workforce, higher resources utilization, innovative processes, customized products and maintaining supply chain efficiently, in addition to a great impact on production bottleneck analysis. [18], [5]

While, Industry 4.0 (Smart Manufacturing) has two key pillars: integration and interoperability. In particular, the vertical integration achieves great implications in shop floor performance including; productivity, quality, transparency, agility, decision making, waste management, energy saving and horizontal integration over different agents around manufacturing can gain implications on customer satisfaction, suppliers' relationship and company competitiveness. [8]

L. Bayoni et al., (2019) [16] emphasizes how Industry 4.0 knowledge and technology are transforming business operations of HRM (Human Resource Management) and SCM (Supply Chain Management). All the potential benefits are toward to

more effective production system that combines low cost with customized goods and services. This change pushes towards improvements in educational institutions by replacing the conventional programs with a new educational model based on competency development and collaborative learning. Therefore, organizations must move themselves into a socio-cyber-technical perspective and providing solutions for technical human–machine interface. Furthermore, Industry 4.0 cover the implications for SCM in three dimensions; education and qualification (human competences), collaboration and integration. Meanwhile, Industry 5.0 comes up with concept of return to "Human Centered" by prioritizing the well-being of employees and technological breakthrough. Therefore, it should be invested a lot for enhancing workforce digital skillsets, in particularly of limited numbers of qualified and experienced professional in I4.0 technologies and 5G competencies [28}.

In addition, Industry 4.0 technologies and processes such as real time data monitoring, CyberPhysical System, big data analytics, Artificial Intelligence and Digital Twins have great sustainability indicators by delivering machines and plants in competitive terms of efficiency, costs, flexibility, transparency, production quality, energy saving and green environmental. These KPIs have been examined in ceramic industry in Italy. [8]. Moreover, Iqra et al. (2023) [6] and Rabab et al., (2019) [18] indicate that the establishment of the Smart Factories with

Industry 4.0 innovations and applications of Smart Devices (collaborating robots, machines, sensors, etc.) and Smart Work-pieces will be essential to achieve sustainable development, competitive, flexible, customized production.

H. Shatnawi (2024) [27] reported that the Artificial Intelligence is playing a crucial role in automobile industry for enhancing smart manufacturing efficiency in mechanical systems by utilizing AI robots, reduces energy consumption, optimizes heat exchange and reduces manufacturing expenses with boosting the productivity to achieve sustainability.

2. Methodology

2.1 The Research Method

The research study uses set of methodical approaches to make examination of readiness factors of industry digitalization (Industry 4.0) and address the challenges of implementation. This research is divided into two main parts and uses mix of qualitative and quantitative approaches to explore the implications of Industry 4.0 implementation in certain case studies and assess the various readiness factors in the organizations of engineering industries sector as follows:

- The first part explores the main challenges faced during the implementation journey and explore the implications of Implementation Industry 4.0 applications in practical case studies using qualitative approach by semi-structured interviews. The

participants were top management or digital transformation executives from ten medium or large manufacturing enterprises.

The study implementation factors include; level of implementation of Industry 4.0 applications across the organization; Main challenges faced during the implementation; Vertical Implications in shop floor on performance including; productivity, quality, transparency, agility, decision making, waste management, energy saving; and Horizontal Implications in customer satisfaction, suppliers' relationship and company competitiveness.

- The second part examines the readiness factors of Industry 4.0 implementation (industry digitization) using quantitative analysis with surveyed questionnaires. The examined readiness factors are corporate strategy and leadership, knowledge level and awareness of importance of Industry 4.0, digitization and automation of the operational areas, Employees' skills adaptability and competencies, the maturity of ICT infrastructure, the internal or external pressures and motivation factors within the organization and finally examines maturity of eco-system. The survey uses 5-point Likert scale to construct the research instrument of this part. The Study applied descriptive statistical analysis using SSPS tools to assess the readiness factors, in addition to applying linear regression analysis by (AMOS) to examine the statistically significant effect of the six readiness factors.

2.2 Sources of data

The research study relies on the primary data sources. For the first part of case studies, the data is collected by semi-structured interviews questions, with participants of professionals or management staff for exploring the implications of implemented Industry 4.0 applications. In the second part of research, the data is collected through the survey questionnaires.

2.3 Sampling

While the total population of engineering industries sector is about working 4200 enterprises, the research study is investigating the micro readiness factors. It uses convenience samples with the survey questionnaires with 362 participants from the target companies (large, medium and small). The number of samples is based on 95% confidence level and confidence interval 5%. Those participants with more than 5 years' industrial experience are from various positions; including top management executives, middle management and first line management.

2.4 Research Hypotheses and Theoretical Framework

From the theoretical framework, based on hypothesis and proved research questions by previous studies on other countries and observations of manufacturing experts, this research is examining certain hypotheses and research questions to address the main readiness factors and challenges for the Industry 4.0 implementation in Egypt industry, and verify the validity of the formulated theory.

This study examines the following hypotheses:

H1: Organization culture and leadership are the main drivers for readiness of manufacturing firms to digital transformation with Industry 4.0 technologies.

H2: The advanced digital technologies in operational and production areas are affecting on company readiness level for digital transformation with Industry 4.0 technologies

H3: Labors digital skills availability significantly influence on Industry 4.0 successful adoption and readiness level. [19]

H4: The maturity of ICT enables infrastructure with IT process automation is one of the main readiness factors for Industry 4.0 deployment

H5: Internal and external pressures and perceptions of higher drivers have positive effect on encouraging the digital transformation by Industry 4.0 technologies in the factories. [15] H6: Ecosystem affects significantly positive on widen implementation of Industry 4.0 solutions (ecosystem includes service providers, digital transformation experts, Industry 4.0 COEs',..). The theoretical framework of Industry 4.0 Readiness is illustrated in figure 2.

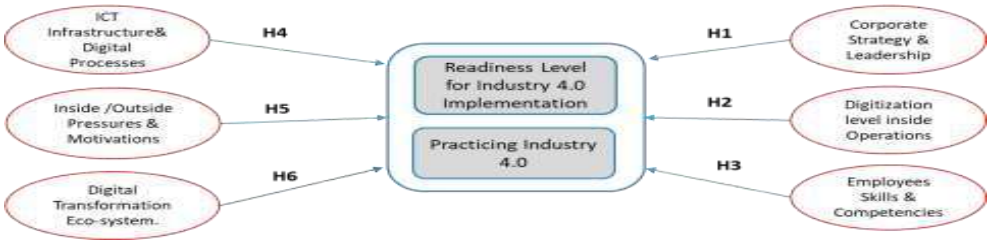


Fig. 2. Framework of Industry 4.0 Readiness in Egypt Industry Sector

3. Data Analysis

3.1 Part one: Qualitative Analysis for Case Studies of Industry 4.0

This part investigates the different implications dimensions in the ten case studies and their future plan for Industry 4.0 implementation. The analysis of collected data related to the performance indicators of the study dimensions are shown in table 1.

Tab. 1: Case Studies Analysis

Implications Dimensions	Performance Indicators	Results
Current Implementation	Smart machines, or Smart manufacturing over shop-floor	most have implemented Industry 4.0 applications over smart machines or smart manufacturing
	Smart Warehouse implementation	Only 2 cases have implemented smart warehouse
	Employees knowledge & engagement in the change	30% co's engaged employees in implementation 40% co's , their employees basic knowledgable of digital transformation
	Self finance or financing support	All self financed, no financial support
	Solution provider (local or multinational)	50% use local, 50% use multinational suppliers
Challenges during the implementation		90% facing from lack of skilled workers, 40% have workers resistance, 20% have concern of Cybersecurity issue, 20% no professional solution providers, 10% lack of top management support
Increase efficiency	Productivity Increase %?	10% to 20% increase productivity
	Decrease down time	10% to 20% lower
Increasing transparency & manufacturing agility	Decentralization and quick decision making	Most of them have achieved significantly quick decision making & decentralization
	Reliable information on time & improve transparency	All have better remote monitoring & controlling processes, 70% got better transparency
	Better efficiency of integration with R&D and supply chain	Some achieved better integration between R&D, production and Supply chain

Quality Enhancement & minimize the waste	Improving the products quality & decrease defect rate?	5% to 10% improve quality
	Minimizing waste of time& materials	10% to 20% less of waste time or materials
	Decrease stock turn over %?	~ 20% to 30% less stock turnover
	Increase competitiveness and meet international standards	improve competitiveness of 60% of case studies
Cost and Time Saving in the long term	Shorten time of release new product to market	From 10% to 20% faster release new products & faster product change over
	Achieve utitities saving (energy, water)	5% to 15% energy saving according to industry
	Predictive: Simulation of different scenarios	helping significantly for predective maintenance, less m/c's failure, decrease down time by ~30%
	Ease of collaboration within the internal sectors and external partners	Little effect, while no smart integration till now , only one case has horisantal / vertical integration
	Integration with local suppliers	Weak effect, due to the most of feeding suppliers have lack of ICT infrastructure
Improved Customer Satisfaction	How achieve quick response for customer inquiry or complain?	40% □ got better response to customers
	Enhancing proximity to customers, easier collect suggestions	30% better customer loyality due to fast response
Future Perspectives of Industry 4.0	How the companies will cope digital technologies	Most need to upgrade employees digital skills and İnvest more in ICT
	The expected mplementation in the next 3 years	70% have plans for extending Industry 4.0 smart applications accross the organization

The observations from above analysis indicate that the implementation of digital transformation using Industry 4.0 applications achieves significant improvement in transparency and quick and decentralization decision making and improving of overall performance including productivity and quality increase and resources utilization from 10% to 20%, efficient waste management

from 5% to 15%, and enhance the company competitiveness. In addition, based on the case studies, the return of investment is always from one to two years. In some cases, the shortage of financial support led to slowdown of Industry 4.0 implementation. In addition, there is no integration with suppliers due to the most of feeding suppliers have lack of ICT infrastructure.

3.2 Part two: Quantitative Analysis for Case Studies of Industry 4.0

This study is aiming to examine and analyze the knowledge and overall readiness factors toward the Industry 4.0 (Smart Manufacturing) in engineering industries sector in Egypt. It uses quantitative questionnaire with 49 questions, sent to 362 participants to analyze six independent variables and examine significance relationship with the dependent variable. The research variables are listed.

Independent Variables (X):

- Corporate strategy and Leadership, knowledge and awareness of importance of Industry 4.0.
- How the extend of the digitalization and automation in operational areas in the company
- Employees' skills and competencies to use the advanced digital technologies
- The level of maturity of ICT (Information and Communication Technologies) infrastructure

- Internal and external pressures and motivations to encourage the implementation of smart manufacturing in the company processes.
- Maturity of Eco-system for enabling Industry digital transformation *Dependent Variable (Y):*
- Readiness Maturity Level of the company for digital transformation with Industry 4.0 Technologies (Smart Manufacturing).

3.2.1 Demographic Analysis

The study was targeting seniors' levels and managers with more than five years' experience, including 15.5% of respondents have 5-10 years' experience, 38% of respondents with 10-20 years' experience and 46.5% of respondents with more than 20 years' experience.

The survey includes different manufacturing focus Areas; the majority of the study samples were from Electronics/Electrical Industry with 38.7%, 2nd from home appliances companies with 20.5%, then other respondents from several industries including Cables and wire harness, automotive, Metal and steel, plastic and engineering and feeding industries with percentage from 4% to 8% for each. While, number of employees and company revenue identify the company size, the survey samples include 14% small companies, ~15% medium companies and ~71% large companies with more than 200 million bounds and more than 200 employees.

3.2.2 Challenges of Industry 4.0 Technologies implementation in the Industrial Sector in Egypt

This study asked the participants to identify the main two challenging aspects for lack of implementation of Industry 4.0 technologies in their organization. The responses indicate that the main challenges as shown in figure 3 sorted descending as important as first one is "Cost and lack of financial support" with 60% of participants, second one is "Lack of knowledge of Industry 4.0 technologies" with 52%, third one is lack of employees' qualifications and digital skills with 40%, fourth one is organization culture and lack of support of top management and leadership with 35%, the last one is threat of data security with 16%.

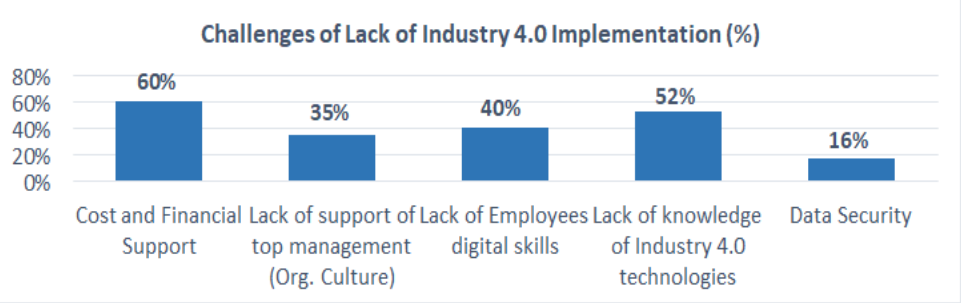


Fig. 3: Challenges of Industry 4.0 Implementation

The above data indicates that the main challenges are sorted descending according to most important; the first one is "Cost and lack of financial support" with 60% of participants, second one is "Lack of knowledge of Industry 4.0 technologies" with 52%, third one is lack of employees' qualifications and digital

skills with 40%, fourth one is organization culture and lack of support of top management and leadership with 35%, the last one is threat of data security with 16%.

3.2.3 The Reliability and Validity Test

To determine the validity and reliability of the study, tool Alpha Cronbach's coefficient is used to measure the stability of the study dimensions, as shown in table (2) with the statistics results.

Table 2: Alpha Cronbach's coefficient for the study dimensions (variables)

Reliability Statistics		
Dimensions	**Cronbach's Alpha**	**No. of Items**
X (Readiness factors)	**.892**	**39**
Y (Readiness Level)	**.835**	**2**
All dimensions	**.893**	**41**

According to above table, the Alpha Cronbach's coefficient is greater than 60% for all study dimensions, in addition, the Alpha Cronbach's coefficient for the dimensions as a whole is equal to (0.893), therefore, it can be relied on the measuring tool of the study dimensions and it confirms that the questionnaire measures and all study dimensions are clear to the researchers and there is no ambiguity and if the researcher applies the questionnaire a second time to the same sample will give almost the same results.

3.2.4 Confirmatory Factor Analysis for the Study Dimensions

This type of analysis is used to test hypotheses about the existence or absence of a relationship between the elements of each dimension, as well as evaluate the ability of the model to express the data set and the results were as follows: using AMOS.

The study has performed the confirmatory factor analysis of the independent variables (the readiness factors of Industry 4.0 technologies implementation) using AMOS software. The figure 4 shows the relationship between the elements of different variables.

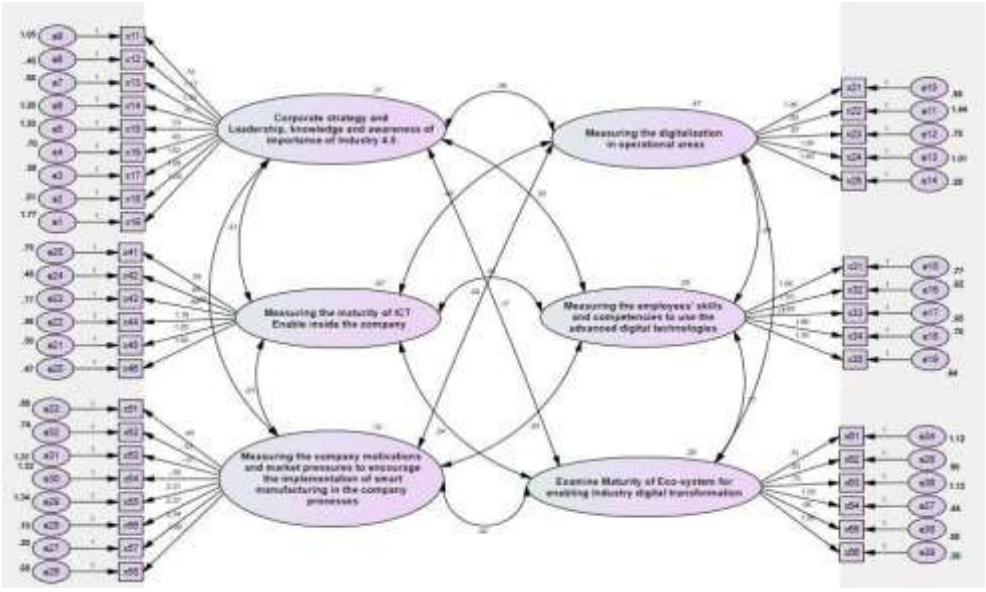


Fig. 4 the confirmatory factor analysis of independent variables

The Table 3 shows the quality indicators of the model fit summary by applying confirmatory analysis after deleting the elements with highest percentage of errors.

Tab. 3 The quality indicator the model

Measure	Estimate
CMIN	186.28
DF	62
CMIN/DF	3.005
GFI	.936
CFI	.933
IFI	.934
TLI	.901
RMR	.062
RMSEA	.075

3.2.5 Results of Descriptive Statistics Analysis

From Table 3, The value of the ratio (CMIN/DF) reached (3.00), which is equal to (3), which confirms the validity of the measurement model and its good match to the data of the research sample.

The value of all other goodness of fit indicators (GFI, CFI, AGFI, TLI, NFI) falls in the ideal range, i.e. greater than (0.90), this indicates that the quality of the model is ideal. The value of the RMSEA is (0.075), is a value in acceptable range. The RMSEA index is considered the most important indicator of the quality of conformity for the model acceptance or rejection.

Table 4: Descriptive Statistics and relative importance for elements of the Readiness Factors

	Readiness Factors Dimensions		Str. Deviation	Correlation Coefficient / Importance Level
V (1): Organization Culture and Leadership and knowledge of Industry 4.0				
1-	Knowledge and awareness of Industry 4.0 technologies [25]	3.41	1.124	0.600 / High
2-	Support of top management [9]	3.69	0.978	0.750 / High
3-	Middle and senior management knowledge of Industry 4.0 technology advantages [25], [3]	3.08	1.157	0.700 / High
4-	Decentralization of decision making [5]	3.17	1.227	0.550 / Low
5-	Processes continuous improvement with digital technologies	2.60	1.185	0.610 / Moderate
6-	Positive attitude of employees towards to digitization [2]	3.59	1.015	0.605 / Moderate
7-	Digitization is one of main pillars of corporate strategy [13]	2.67	1.172	0.620 / Moderate
8-	Agile system implementation [3]	3.53	1.122	0.652 / Moderate
9-	Encourage innovation and creativity	3.34	1.467	0.550 / low
	Organization and Leadership	3.2201	0.657	**0.627**
V(2): Level of Digitization and Automation Operational Areas				
1-	Level of automation of the machines and production automation and using robots [19]	3.38	1.193	0.645 / High
2-	Use of IT system for machines data collection and analysis	2.74	1.346	0.690 / Moderate
3-	Transparency and interoperability across company [20]	3.81	1.067	0.710 / High
4-	External Integration as backward with suppliers and as forward with customers [20]	2.92	1.216	0.723 / Low
5-	Always invest long-term in new digital solutions	3.55	1.096	0.782 / High
	Level of Digitization and Automation	3.2818	0.839	**0.7104**
V(3): Adapting employees skills with new digital technologies				
1-	Employees technical skills to adapt with digital technologies	2.99	1.018	0.645 / Moderate

2-	Engineers and middle management Knowledge with Industry 4.0 technologies [23]	3.36	1.109	0.753 / High
3-	Provided upskills programs for employees to deal with advanced digital technologies [25]	3.49	1.184	0.780 / High
4-	Dedicated team for digital transformation	2.89	1.276	0.804 / High
5-	Emotional competence of employees and awareness of Industry 4.0 Benefits [23]	2.71	1.041	0.747 / High
	Adapting Employees Skills	3.088	0.844	**0.746**
V(4): Maturity of ICT Enabled in the company				
1-	Availability of fast fixed broadband network connection	3.96	1.012	0.648 / Moderate
2-	Available ICT specialists	4.08	0.947	0.778 / High
3-	Level of using ERP or SCM systems [2]	4.08	1.153	0.743 / High
4-	Remote access to company IT system [12]	3.60	1.330	0.853 / High
5-	Regular update of IT infrastructure with the latest tech [12]	3.70	1.125	0.844 / High
6-	Applied standards and regulations for IT security [12]	3.95	1.159	0.626 / Moderate
	Maturity of ICT Enabled	3.896	0.882	**0.750**
V(5): Company motivation and market pressures				
1-	Internal or external pressures to work on Industry 4.0 [13]	3.70	0.954	0.554 / Moderate
2-	Necessarily improvement to tackle lack of performance	4.21	0.881	0.582 / High
3-	Problem of Transparency and interoperability [13]	2.59	1.148	0.593 / Low
4-	Employees resistance for the change [4]	2.78	1.156	0.503 / Low
5-	ROI period from adoption of Industry 4.0 applications,		1.404	0.658 / Moderate
6-	Productivity increase encourages Industry 4.0 implement		.875	0.670 / High
7-	Decrease of waste (materials or energy or time) motivates Industry 4.0 implement [13]	4.16	0.919	0.637 / High
8-	High cost factor and availability of financial support [4]		0.896	0.600 / High
	Pressures and Motivations Factor (Avg.)		.52457	**0.600**
V(6): Maturity of Eco-system for enabling Industry digital transformation				
1-	The engineering education programs adaptation with Industry 4.0 emerging technologies [9]	2.71	1.127	0.654 / High

2-	The vocational education programs adaptation with Industry 4.0 emerging technologies [9]	2.27	1.072	0.715 / Moderate
3-	Quality of broadband connectivity Infrastructure [9]	2.91	1.140	0.600 / High
4-	Available of Experts specialized in of Industry 4.0 [4]	2.66	1.049	0.667 / High
5-	Available of Qualified local service providers for Industry 4.0 solutions or training providers [12]	2.68	.934	0.612 / Moderate
6-	Available of Centers of Excellence (COEs') & Digital innovation hubs for Industry 4.0 [13]	2.65	.806	0.618 / Moderate
	Maturity eco-system (Avg.)	2.6450	0.659	**0.644 / Moderate**

From above table, the majority of the mean values of elements of each readiness factor are between 2.6 – 4.0 (Average higher than 3.0), it indicates the agreement with most of elements. While, the values of standard deviation are small percentage (0.8 to 1.4), it indicates the discerption is low. While, correlation coefficients are ranged from 0.5 to 0.85, the importance of the study elements are varying from high importance (higher 0.7), moderate (0.5-0.7) to low importance (0.3 to 0.5).

The readiness factors sorted according to the significant relation with the implementation of industry 4.0 applications are; 1-The maturity of ICT infrastructure including IT networking, ERP/SCM systems, has a significant relation with readiness maturity level of Industry digital transformation. this study found that all large organizations are ICT matured, while small size companies have limited resources of ICT capabilities, 2- corporate strategy and leadership and knowledge of importance of Industry 4.0 technologies are affecting significantly on digital transformation with Industry 4.0 technologies, in particular of top

management support, culture, attitude and acceptance of employees toward digital transformation changes. 3- Employees' skills adaptability and competencies; the study indicates that the necessarily of continuous technical upskilling the employees with new digital technologies, in addition to increasing knowledge of engineers and middle management with smart manufacturing technologies. This enhances the employees emotional and eliminates the employees' resistance, 4- Company motivations and the internal or external market pressures are drivers to improve the competency of the products or company efficiency or transparency issue, or high waste, these issues could encourage to speed up the industry digitization into the company, 5- Digitization of the operational areas, considering production automation and robots and digital interoperability across production areas have highly impact on enabling the Industry 4.0 applications, 6- Maturity of ecosystem; the study revealed that the important elements of eco-system affecting on digitization are the engineering education programs, not-competent vocational studies, the shortage of local experts, consultants, local service providers.

3.2.6 Dependent Variable Descriptive Statistical Analysis (Y):

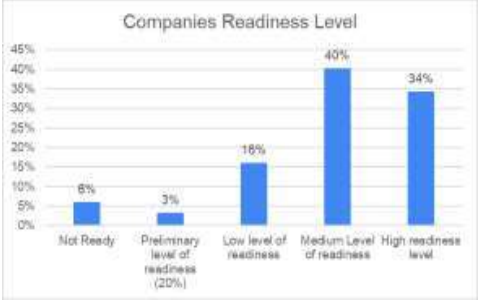
The dependent variable (Readiness Maturity Level of the company for digital transformation with Industry 4.0 Technologies) is examined by two questionnaire elements.

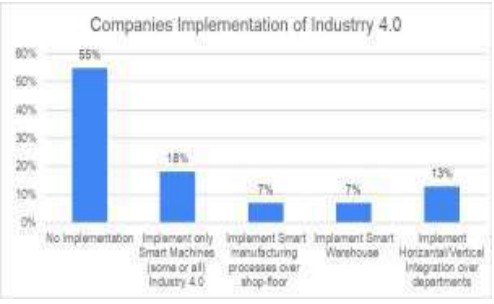
The first element: How is the company readiness level to implement Industry 4.0 technologies.

The frequency responses shown in figure 5 indicate that 25% of the companies are not ready, in preliminary level or low level of readiness, while, 74% are having medium level or high level of readiness for implementation of Industry 4.0, most of high readiness level companies are large companies, while, most of small companies have preliminary or low readiness level, and medium size companies have low or medium readiness level.

The second one: "how the implementation level of Industry 4.0 technologies across the company". According to statistical analysis shown in figure 6, it indicates that 55% with no implementation of Industry 4.0 technologies, 18% with limited implementation on one or some machines, 7% with implementation across manufacturing shop floor, 7% with implementation of smart warehouse and 13% are achieving vertical smart integration across the company departments or forward integration with customers' side, but there is almost no backward integration with feeding industries.

Fig. 5: Companies Readiness Level **Fig. 6:** Company Implementation of Industry 4.0





3.2.7 Test the hypotheses

To test the six hypotheses, this study applied linear regression analysis by (AMOS) to examine the statistically significant effect of the dimensions of the six independent variables (representing the readiness factors of Industry 4.0 technologies implementation) on the dependent variable (maturity readiness level of the company for digital transformation with Industry 4.0 Technologies (Smart Manufacturing)). The estimation linear regression model by (AMOS) which illustrates inter correlation between the variables is shown in figure 7:

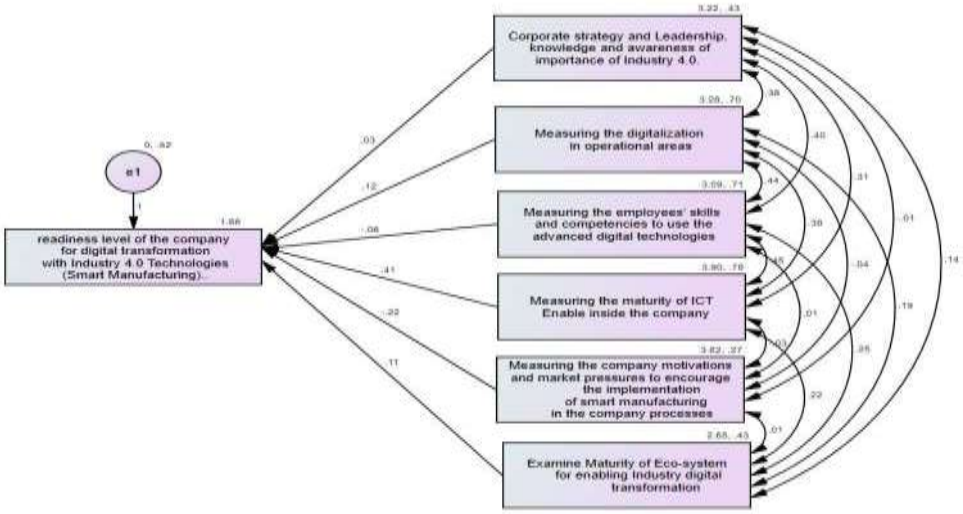


Fig. 7: Linear Regression Model by (AMOS)

However, we don't study the effect of interrelation between the readiness factors, it might be examined in future work. Table

5 shows the results of regression analysis and presents the significant relationship of each independent variable with the dependent variable.

Tab. 5 Regression Analysis Results

Regression Weights					
Dimension	**Estimate**	**S.E.**	**C.R.**	**P- value**	**R^2**
Intercepts	1.661	.357	4.647	.0001	.886
Y <--- X1	.026	.095	3.273	.005	
Y <--- X2	.124	.067	2.848	.005	
Y <--- X3	.060	.074	3.121	.007	
Y <--- X4	.407	.057	4.178	.000	
Y <--- X5	.225	.074	3.056	.002	
Y <--- X6	.114	.066	2.732	.003	

From the previous table:

- The critical ratio (C.R.) of the dimensions of the independent variables is greater than the value (+1.96), in addition, the level of significance (P-Value) is less than 0.01 for all the variables which indicates that these variables have positive statistical significance on dependent variable. However, (C.R.) coefficients of X1, X3, X4, X5 are greater than (+3.0), it means those variables have strong significant relation with dependent variable (Y), while, (C.R.) values of X2, X6 are

lower than (3.0), it indicates that they have moderate significant relation with (Y).

- R-square is equal (88.6%), this is the percentage of the effect of independent variables on dependent variable (Maturity readiness level of the company for digitization with Industry 4.0 Technologies) and the rest of the percentage is due to random error.

According to the above results of descriptive statistical analysis and regression analysis for surveyed questionnaires, this research study is supporting significantly the predefined hypotheses as follows:

H1: The findings indicate that the organization culture, leadership and awareness of importance of Industry 4.0 technologies have strong positive significant relationship with readiness maturity level of the company for digitization with Industry 4.0 technologies.

H2: The findings indicate that most of industrial firms are in early stage in fully digitization and connectivity but lack of digital technologies has a moderate relationship with the company readiness maturity level for implementation of Industry 4.0 technologies.

H3: The findings indicate that the labors' skills and competence of senior engineers' and middle management have positive strong significant relationship with maturity readiness level of the

company, in addition, the upskilling programs are crucial for enabling smart manufacturing.

H4: The research findings indicate that the ICT enable, including good infrastructure and IT process automation has positive strong significant relationship with company readiness level for implementation of Industry 4.0 technologies. While, most of large organizations have good ICT infrastructure and process automation with ERP, SCM and CRM applications with continuous upgrade, the successful case studies of Industry 4.0 have been implemented in large organizations.

H5: The research findings indicate that the external pressures from market competition or customers' retention, and internal pressures from low performance or high waste, and potential of increasing efficiency and quick ROI with Industry 4.0 implementation have positive significant relationship with company readiness level and they encourage the implementation of Industry 4.0 technologies.

H6: The research findings indicate that the maturity ecosystem of enable digital transformation in Egypt has positive moderate relationship with company readiness level and low impact on the slowdown of Industry 4.0 applications implementation.

4. Conclusion

This research study has achieved its objectives to examine the readiness factors and highlighted the main challenges of implementation of Industry 4.0 applications in Engineering

Industries Sector in Egypt, consequences, the study provides the recommendations to fill the gap and improve the readiness maturity index of Industry 4.0 technologies implementation in Egypt.

This research study has two parts related to each other. In the 1st part, it used the qualitative approach with semi-structure interview questionnaires to explore the implications of Industry 4.0 implementation in ten successful case studies. The research observations refer to:

- Most of case studies have focused on the applications over smart machines or manufacturing shop floor, only one case study has achieved smart integration between its departments. The medium enterprises relied on local service providers for implementation due to cost, while large enterprises relied on international service providers. In addition, shortage of skilled workers and shortage of local professional training providers are main challenges during the implementation.
- The most of case studies have achieved significant improvement in transparency and decentralization decision making and improving of overall performance in productivity and quality, resources utilization and enhance the competitiveness and customers' satisfaction.

The second part of this research study has discussed the main challenges which are affecting on the implementation of Industry 4.0 applications in Egypt and examined the impact of six readiness factors of Industry 4.0 digital transformation on

maturity level of companies' readiness for Industry 4.0 implementation. The ranked readiness factors according to their significant relation with industry 4.0 implementation are; The maturity of ICT infrastructure, corporate strategy and leadership and knowledge of Industry 4.0 technologies, Employees' skills adaptability and competencies, Company motivations and the internal or external market pressures, Digitization and automation of the operational areas, Maturity of eco-system.

In Egypt industrial sector, the adoption of Industry 4.0 technologies is still in early stages, while, most of implementations focus only on smart applications over production shop floor or limited case studies of smart warehouses implementation in large companies and few implementations in medium companies and almost no implementation in small companies.

The other emerging markets especially high population countries can benefit from the results and consider the recommendations of this research study, while most of them are having the same challenges according to other research studies.

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