Çukurova Üniversitesi Mühendislik Fakültesi Dergisi, 39(2), ss. 535-544, Haziran 2024
Cukurova University Journal of the Faculty of Engineering, 39(2), pp. 535-544, June 2024

An ERP Based Industry 4.0 Maturity Model Proposal

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Geliş tarihi: 09.06.2024 Kabul tarihi: 27.06.2024

Atıf şekli/ How to cite: ELİBAL, K., ÖZCEYLAN, E., ÇETİNKAYA, C., (2024). An ERP Based Industry 4.0 Maturity Model Proposal. Cukurova University, Journal of the Faculty of Engineering, 39(2), 535-544.

Abstract

This study proposes an Enterprise Resource Planning (ERP) based Industry 4.0 maturity. The model aims to make the vast array of Industry 4.0 technologies comprehensible and actionable for Small and Medium Sized Enterprises (SMEs) by mapping them to specific ERP functions, thus enabling a more agile and tailored approach to digitalization. A comprehensive literature review revealed limited research on this integrated approach and highlighted the need for a model that supports quick assessments and adaptable implementation strategies. A sample application has been conducted in a manufacturing company and it has been seen that the model leverages ERP's modularity to address company-specific needs and includes rapid evaluation features that provides to the dynamic requirements of SMEs, enhancing their competitive edge in the digital landscape. Additionally, the findings serve as a valuable guide for ERP designers/vendors, providing insights into the integration of Industry 4.0 technologies that can enhance ERP system capabilities.

Keywords: Maturity model, Industry 4.0, Enterprise resource planning, ERP

ERP Tabanlı Endüstri 4.0 Olgunluk Modeli Önerisi

Öz

Bu çalışma Kurumsal Kaynak Planlaması (ERP) tabanlı bir Endüstri 4.0 olgunluk modeli önermektedir. Önerilen model, çok çeşitli Endüstri 4.0 teknolojilerini belirli ERP işlevleriyle eşleştirerek, bu teknolojileri Küçük ve Orta Ölçekli İşletmeler (KOBİ'ler) için anlaşılır ve uygulanabilir hale getirmeyi, böylece dijitalleşmeye daha çevik ve özel bir yaklaşım sağlamayı amaçlamaktadır. Yapılan kapsamlı literatür taraması ERP-Endüstri 4.0 entegrasyonu hakkında kısıtlı çalışmalar olduğunu göstermiş, hızlı ve çabuk adapte edilebilir bir değerlendirme modelinin gerekliliğini ortaya koymuştur. Geliştirilen model ile bir üretim şirketinde örnek bir uygulama yapılmış ve modelin, ERP'nin modülerliğinden yararlanarak şirkete özel ihtiyaçları karşıladığı ve KOBİ'lerin dinamik gereksinimlerini karşılayarak dijital ortamda rekabet güçlerini artıran hızlı değerlendirme özelliklerini içerdiği görülmüştür. Ek olarak bulgular, ERP

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tasarımcıları/tedarikçileri için değerli bir rehber görevi görmekte ve ERP sistem yeteneklerini geliştirebilecek Endüstri 4.0 teknolojilerinin entegrasyonuna ilişkin bilgiler sağlamaktadır.

Anahtar Kelimeler: Olgunluk modeli, Endüstri 4.0, Kurumsal kaynak planlaması, ERP

1. INTRODUCTION

Assessing the current situation in the context of Industry 4.0 and taking action plans according to this assessment is a crucial concept for an effective digital transformation which can made by maturity modelling concept. Not only the lack of consensus about Industry 4.0 concepts and definition [1-4], also the variety of proposed dimensions of Industry 4.0 maturity models [5] are causing confusion for the practitioners. Manufacturing organizations, especially Small and Medium Sized Companies (SMEDs) are facing difficulties in the selection and implementation of Industry 4.0 solutions [6]. Limitations in time, financial resources, and the availability of qualified practitioners are some of the constraints for SMEDs which they challenge during the digital transformation process [5].

A recent literature review which is conducted by Elibal and Özceylan [5] showed that in 57 academic publications 341 different dimension have been proposed to assess the readiness of digitalization. This variety arise some questions such as; i) to which dimension should be focused, ii) what are the value-focused dimensions, iii) what kind of practices of Industry 4.0 leverage the digitalization of an organization in an agile way. Current maturity models may be insufficient for making fast evaluations and plans to answer these questions while agility is the most important factor for organizations; especially for SMEs because of their limited resources. To overcome this problem, an ERP based Industry 4.0 maturity model will be proposed in this study.

ERP applications are going to be assumed as the core functions of an organization and Industry 4.0 concepts are going to be described via mapping these ERP functions. Thus, it is expected that; (i) Industry 4.0 concepts will be come down to an understandable level for the assessment participants, (ii) an agile assessment and planning will be possible which is more applicable especially for SMEs, (iii) modularity of ERP will provide the modularity of the model, (iv) company/case specific assessments may be possible.

A literature review which has been conducted at Scopus and IEEE Xplore databases with the search query mentioned in Table 1 (at 13-05-2024) showed that there are very limited studies about the reviewed concept and this result leveraged the motivation of this paper. Among 11 publications found, only the study of Basl and Novakova [7] proposed an ERP 4.0 maturity model.

Table 1. Search query for ERP based maturity model publications

(TITLE-ABS-KEY (erp) AND TITLE-ABS-KEY (maturity) AND (TITLE-ABS-KEY ("industry 4.0") OR TITLE-ABS-KEY ("manufacturing 4.0")) OR TITLE-ABS-KEY ("smart manufacturing") OR TITLE-ABS-KEY ("smart factory") OR TITLE-ABS-KEY ("factory 4.0") OR TITLE-ABS-KEY ("industrie 4.0") OR TITLE-ABS-KEY ("fourth industrial"))

Basl and Novakova [7] proposed four dimensions as mentioned below;

- The overall model of providing ERP services aiming at cloud
- Integrated technology trends 4.0 aiming at IoT, digital twin, blockchain, etc.
- Improved core functionality of ERP like planning and decision support
- Increasing levels of automation and robotization of business processes supported by ERP

While the study of Basl and Novakova [7] provides valuable insights into ERP-based Industry 4.0, it offers a foundational understanding of how modern ERP systems can integrate advanced Industry 4.0 technologies. Their work outlines essential trends and offers a preliminary framework for evaluating ERP 4.0 maturity. This approach is instrumental in

understanding the evolution of ERP systems in the context of Industry 4.0, highlighting the increasing importance of cloud computing, IoT, AI, and automation in modern enterprise systems. However, it remains a general framework. The model lacks specificity in its practical implications and does not provide detailed guidance on how to integrate specific technologies with various ERP functions. This limitation poses challenges for businesses, especially SMEs, in implementing effective digital transformation strategies.

This paper aims to build a comprehensive ERP-based Industry 4.0 maturity model designed to facilitate digital transformation in SMEs by integrating core ERP functions with advanced Industry 4.0 technologies. The model aims to make the vast array of Industry 4.0 technologies comprehensible and actionable for SMEs, enabling a more agile and tailored approach to digitalization. Some practical expected benefits from the proposed model can be summarized as below;

- The model's modularity allows for rapid evaluation and adaptable implementation strategies tailored to the specific needs of SMEs. This flexibility is crucial for SMEs, which often face constraints in time, financial resources, and availability of qualified practitioners. While organizations use ERP systems according to their needs, improving current modules of ERP in the context of Industry 4.0 provide a value-focused enhancement. Modularity of the model will enable SMEs to adopt and integrate Industry 4.0 technologies incrementally, reducing the complexity and cost associated with large-scale implementations. By breaking down the the model into manageable modules, SMEs can prioritize their most critical needs and implement solutions that provide the most immediate benefits. For example, a SME might start by integrating IoT capabilities into its inventory management module to gain real-time visibility into stock levels and reduce waste. Once this module is successfully implemented and provides benefits, the company can then focus on other modules, such as AI-driven predictive maintenance or advanced data analytics for decision support. A Human Resources (HR) module may not be used in the organization so the digitalization in this area may be supposed to be not crucial. This step-by-step approach allows SMEs to spread out costs over time and reduce the risk of disruption to their operations. Moreover, modularity of the proposed model ensures that the ERP system can be easily customized to fit the unique processes and workflows of each SME. This customization is particularly valuable because it allows the ERP system to grow and evolve alongside the business, adapting to new challenges and opportunities without requiring a complete overhaul. As a result, SMEs can achieve a more scalable and sustainable digital transformation.
- The proposed model provide valuable insights for ERP designers and vendors, guiding the development of new ERP solutions that are better aligned with the evolving needs of modern businesses. This can lead to the creation of ERP systems that fully leverage Industry 4.0 technologies, offering enhanced functionality and competitive advantages.

In order to propose an ERP based Industry 4.0 maturity model that mainly aims to provide expected benefits mentioned above, in section 2 the literature review about ERP and Industry 4.0 will be investigated. In section 3, a draft of proposed model will be presented. A sample application will be presented in section 4, and finally conclusions and future research suggestions will be done.

2. LITERATURE REVIEW

As the aim of this paper is to propose an ERP based Industry 4.0 maturity model, to understand the relationship between these concepts, a literature review has been conducted at Scopus Database (13-05-2024) with the search query mentioned in Table 2. Among 307 publications found, 34 of them are investigated in order to identify which Industry 4.0 technologies are used in ERP systems. Highlighted technologies are summarized in Table 3.

Table 2. Search query for ERP-Industry 4.0 related publications

(TITLE-ABS-KEY (erp) AND TITLE-ABS-KEY ("industry 4.0") OR TITLE-ABS-KEY ("manufacturing 4.0") OR TITLE-ABS-KEY ("smart manufacturing") OR TITLE-ABS-KEY ("smart factory") OR TITLE-ABS-KEY ("factory 4.0") OR TITLE-ABS-KEY ("industrie 4.0") OR TITLE-ABS-KEY ("fourth industrial") OR TITLE-ABS-KEY ("4th industrial")) AND (LIMIT-TO (LANGUAGE , "English"))

Table 3. Highligted Industry 4.0 technologies in ERP

Publications	Industry 4.0 technologies in ERP
[8]	Information integration
[9]	Connection of machines, real time monitoring, planning decisions
[10]	Tablet computers and mobile phones, big data analytics, virtual application, integration with social networks
[11]	Cloud computing, IoT
[12]	Autonomous robot integration
[13]	RFID
[14]	Mobile devices, cloud computing, big data, IoT, digital production and additive manufacturing, AI, ML, virtual assistance
[15]	CPS, IoT, actutators, sensors, big data
[16]	RFID
[17]	Mobility, integration, smart devices, big data, data analytics, cloud
[18]	Cognitive technologies, big data, IoT, cloud computing, VR and AR, corporate portal, wireless mobil solutions, electronic data interchange (EDI)
[19]	Cloud ERP
[20]	Big data, cloud computing, AI, IoT
[21]	IoT
[22]	IoT, sensors, CPS, big data, cloud computing
[23]	Cloud ERP
[24]	RFID
[25]	Blockchain
[26]	Sensor, real time process monitoring
[27]	Big data, system integration, cloud, and automatic identification and data capture.
[28]	IoT
[29]	Real time data
[30]	IoT
[31]	Cloud Database
[32]	Augmented reality
[33]	IoT, RFID, real time analyses, social media analyses
[34]	Cloud Database
[35]	IoT, real time data, ML, AI
[36]	Cloud computing, IoT
[37]	IoT, big data, mobil devices, cloud computing
[38]	Big data, cloud technologies
[39]	Automated warehouse
[40]	Machine interconnection
[41]	Digital twin

Table 3 provides an overview of various publications related to the application of Industry 4.0 technologies within Enterprise Resource Planning (ERP) systems, spanning from 2012 to 2024. The listed technologies include Cloud Computing, IoT (Internet of Things), Big Data, AI (Artificial Intelligence), and RFID (Radio Frequency Identification), among others. These technologies are integrated into ERP systems to enhance capabilities such as real-time data processing, mobile computing, and sensor-based monitoring, aiming to improve automation, connectivity, and decision-making processes in business environments. Each publication focuses on different aspects of these integrations, highlighting advancements in ERP functionality through the adoption of Industry 4.0 technologies. Via the gained insights from Table 3, a draft model will be proposed in section 3.

3. ERP BASED INDUSTRY 4.0 MATURITY MODEL

In this section ERP based Industry 4.0 model will be presented. The proposed model includes 13 sub-dimensions under six main dimensions which are also the common modules of an ERP system; planning and manufacturing, customer relationship management, warehouse management, procurement, human resources, finance and accounting [42-44], as in illustrated in Figure 1.

Figure 1. Dimensions of the proposed model

For each dimension Level 1 and Level 5 statements had been defined. As in shown in Table 4, participants will be asked to select a level between 1 and 5 according to the statements. It is possible that some of the ERP modules may not be used in the organization or the mentioned concept may not be relevant, so the "not relevant" options may be selected in this situation.

Table 4. Level definitions of the proposed model

ERP Module	Dimension	Level-1	Level-5
Planning and Manufacturing	M2M communication	No M2M communication	Highly integrated M2M communication
	Data collection and monitoring	Manual input into ERP	Real time data collection and monitoring via IoT, sensors, data capture, etc.
	Scheduling	Manuel scheduling via data in ERP	AI based scheduling with real time data
Customer relationship management	Customer communication	Manual analytics via ERP	Highly integrated customer portal, social media listening, etc.
	Demand analysis	Manual analysis via data in ERP	AI based demand prediction
Warehouse management	Communicable raw materials, semi-parts	No communication	Highly integrated communication via IoT, RFID, etc.
	Warehouse stock monitoring	Manual monitoring in ERP	Real time monitoring via sensors, data capture, etc.
Procurement	Supplier communication	Manual data in ERP	Highly integrated supplier portal, social media listening, etc.
	Supplier analytics	Manual analytics via ERP	AI based supplier analytics via real time data, social media listening, etc.
Human Resources	Performance analytics	Manual analytics via ERP	AI based performance analytics via real time data, data capture, etc.
	Employee education	Manual analytics via ERP	AI based education predictions, electronic and online education environmnet with AR, VR
Finance and Accounting	Customer-supplier accounting	Manual analytics via ERP	AI based tracing and risk analyses
	Cost-budget tracing	Manual analytics via ERP	AI based cost and budget analyses with real time data, predictive insights

Table 4 outlines a comprehensive overview of different ERP modules, highlighting the transition from basic (Level-1) to advanced (Level-5) levels of integration and functionality. Each dimension within these modules is described with its Level-1 and Level-5 states, providing a clear picture of how operations can evolve with technological advancements.

In the Planning and Manufacturing dimension, M2M communication at Level-1 involves no interaction between machines, while at Level-5, machines are highly integrated, sharing data in real-time to optimize production. Data collection and monitoring evolve from manual input into ERP systems to real-time data gathering using IoT, sensors, and data capture technologies. Scheduling progresses from manual, ERP-based methods to AI-driven, real-time scheduling, enhancing efficiency and responsiveness.

The Customer Relationship Management (CRM) dimension shows a shift from manual customer communication and data analysis within ERP systems at Level-1 to highly integrated customer portals and social media listening tools at Level-5. This integration allows for better customer engagement and more accurate demand analysis through AI-based predictions.

In Warehouse Management, communicable raw materials and semi-parts move from no communication at Level-1 to real-time tracking and integration via IoT and RFID technologies at Level-Warehouse stock monitoring advances from manual checks to real-time monitoring using sensors and automated data capture, ensuring more accurate and efficient inventory management.

The Procurement dimension highlights improvements in supplier communication and analytics. At Level-1, supplier interactions and analytics are manually handled within ERP systems, whereas at Level-5, these processes are enhanced through highly integrated supplier portals and AI-based analytics, utilizing real-time data and social media listening for better decision-making.

Human Resources demonstrates a transition from manual performance analytics and employee education tracking to AI-based systems that provide real-time data and predictive insights. At Level-5, performance analytics leverage real-time data capture, while employee education benefits from AI-driven predictions and advanced training environments utilizing AR and VR technologies.

Finally, the Finance and Accounting dimension shows how customer-supplier accounting and cost-budget tracing evolve from manual analytics in ERP systems to AI-based tracing, risk analyses, and real-time budget assessments. This shift enables more accurate financial management and predictive insights, ultimately improving overall financial health and decision-making processes.

4. APPLICATION

The proposed draft model has been applied to an automotive sub-contractor, BCS Metal Co., which is located in Gaziantep/Türkiye. The company mainly produces bus, midi-bus, truck and trailer chassis and has an ERP system with the modules of production and planning, customer and supplier management, warehouse management, human resources and finance-accounting. The model has been presented to the executive of the company and the level assignments from 1-5 has been done for each sub-dimension as in shown in Table 5.

Table 5. Level assignments of the company

ERP Module	Dimension	Level	Not Relevant
Planning and Manufacturing	M2M	1	
	Data collection	3	
	Scheduling	2	
Customer relationship	Customer	3	
	Demand analysis	1	
Warehouse management	Communicable		-
	Warehouse stock	2	
Procurement	Supplier	1	
	Supplier analytics	1	
Human Resources	Performance	2	
	Employee	1	
Finance and Accounting	Customer-	2	
	Cost-budget	3	

The company declared that "communicable raw materials, semi-parts" dimension is not relevant with their needs and business, so the radar chart of the model has been constructed with 12 dimensions as shown in Figure 2.

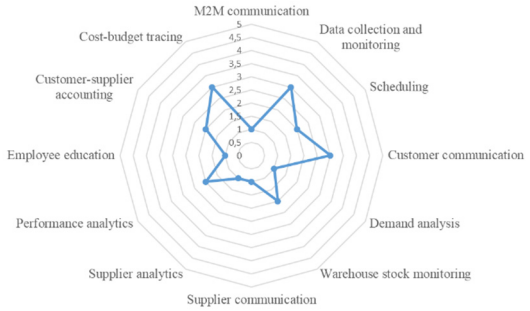

Figure 1. Maturity radar chart

The results obtained by applying the model to BCS Metal Co. can be used as a basic guide to create the company's digital transformation roadmap. The maturity levels determined for each ERP module clearly reveal the company's current status and development needs. These results can determine which areas the company needs to make improvements, enabling more effective use of resources. Targets should be set, especially for dimensions at low levels, and improvements in these areas should be prioritized. In addition, the flexibility and modular structure provided by the model allows the company to manage the digital transformation process step by step and in accordance with the specific needs of the company. In this way, the steps to be taken towards digitalization become clear and strategic plans can be created to increase the competitiveness of the company.

5. CONCLUSION

In this paper, an ERP based Industry 4.0 model has been proposed and a sample application has been conducted. Motivation of the study is developing a maturity model that provides a structured framework for assessing and advancing digital transformation in SMEs by integrating core ERP functions with Industry 4.0 technologies. This approach not only makes Industry 4.0 concepts more accessible and actionable for SMEs but also supports agile and tailored digitalization strategies that address specific organizational needs and constraints. Organizations may use the model according to the modules of applied own ERP system. Not only for organizations, the model also may be used as a guide for ERP designer and/or vendor to adapt the system according to the Industry 4.0 technologies.

Sample application showed us an organization can assess the own situation of the digitalization according to the ERP modules used. The model appears to have the potential to clearly determine the steps companies will take towards digitalization according to their needs.

Rapid technological developments and the increasing needs of organizations increase the diversity of both ERP modules and Industry 4.0 technologies day by day. This study should be considered as an initial study, and the development of the dimensions (according to ERP modules) and maturity statements (according to Industry 4.0 technologies) of this model with different research methods (such as Delphi Technique) should be considered as a future study. A sectoral separation has also been identified as an important future study.

In addition, the implementation of the developed model in manufacturing companies and evaluation of its effectiveness should be considered as an important future study.

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