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Cloud- and Edge-based ERP systems for Industrial Internet of Things and Smart Factory

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Abstract

Enterprise Resource Planning (ERP) system is a collection of collaborative software programs. It handles transactions through enterprise-wide business processes using shared databases, standard methodologies, and data exchange across and within functional domains. Setting up an enterprise system is a complex activity and a costly and dangerous investment. Further, ERP system potentially affects core business and supporting processes, especially in complex and cyber-physical domains such as Industrial Internet of Things (IIoT) and Smart Factory. Cloud ERP (C-ERP) and Edge ERP (E-ERP) are alternatives to traditional, centralised and monolithic ERP implementation for incorporating the benefits of Cloud and Edge Computing. Their main benefits include ease of use, resource balancing, bandwidth, cost-saving, and higher privacy/security. This paper discusses the benefits and limitations of using C-ERP and E- ERP in IIoT and Smart Factory domains, along with future directions in the ERP era of demand.

Keywords: Enterprise Resource Planning, Cloud ERP, Edge Computing, Edge ERP, Industrial Internet of Things, ERP Adoption, Smart Factory.

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1. Introduction

One of the most widely utilised information technology (IT) solutions in organisations are ERP systems [1]. These are well-organised collections of software that works together to timely integrate business processes and support the management of effective cross-functional operations within an organisation. In particular, in ERP systems, a single database has all of the information. It acts as a central location for storing, distributing, and sending data between departments and business processes to manage transactions and data exchange across and within different functional areas. Setting up such a complex, shared and monolith system as an ERP is more than a computer project. It's a costly and hazardous investment, and the process impacts the organisation's core and support operations [2]. However, business operations' technical and functional integration to synchronise the flow of information with the content flow of products or services is very attractive for the companies, representing one of the significant reasons for ERP adoption [3] [4].

Simultaneously, companies can also benefit from novel enabling technologies such as Cloud and Edge computing. First, they provide the capability to process and store large amounts of data. Second, they allow continuous and real-time information sharing between customers and consumers; and third, they can rapidly and agilely respond to consumer behaviour and organisation needs [5]. The main benefits and features of Cloud and Edge computing perfectly match with ERP systems' needs. Indeed, Cloud-based ERP (C-ERP) and Edge-based ERP (E-ERP) systems consist of a host ERP that operates, respectively, on a cloud and edge provider's infrastructure. These infrastructures include software, hardware, storage, networks and other resources which can overcome the limits of conventional, centralised ERP systems. C-ERP and E-ERP solutions have been recently developed for many application domains, including the Industrial Internet of Things (IIoT) and Smart Factories. ERP systems can simplify the facility and business automation and support the integration of internal/ external resources and management decisions. Indeed, especially in such domains, bringing data and cyber-physical processes together by simultaneously complying with business and organisational needs is key for addressing the increasingly complex challenges of economy 4.0.

To the best of our knowledge, this paper (the first one) aims to determine the elements that impact the choice to move ERP as a resource to the Cloud and Edge in IIoT and Smart Factory application domains. The rest of the paper is organised as follows. Section 2 provides an introduction to C-ERP and E-ERP. Section 3 discusses the advantages, limitations, opportunities, and constraints of adopting C-ERP and E-ERP, specifically concerning Smart Factory and IIoT. Main findings and future recommended research lines in this field conclude the paper.

2. Background and review of literature

This Section presents a brief literature review about IIoT, Smart Factory, ERP, C-CRP, and E-ERP systems.

2.1 ERP within Industrial IoT and Smart Factory

The acronym IIoT refers to applying the paradigms and technologies of the IoT to the industrial world. With the IIoT, a full convergence is achieved between operational technologies (made up of systems for the automation of machinery or industrial plants and production monitoring) which have always been applied in the factory. The digital ones (made up of acquisition technologies and digital data management that enable new data-driven and "intelligent" business models) which only in recent years have found space in the manufacturing sector. Two traditionally separate worlds that come together in the concept of Smart Factory. Firstly, with typical applications such as quality control ("zero defect" approaches), the containment of downtime and machinery malfunctions through predictive maintenance. Secondly, the progress control solutions of production implemented through Machine-to-Machine (M2M) communications and intelligent material handling [6]. Indeed, the Smart Factories leverage modern technologies to provide operators and administrators with an overview of the events and the processes happening in the various sectors of the factory [7]. In detail, they provide for the growing integration of "Cyber-Physical Systems" (CPS), intelligent machines connected to the Internet through the digitisation and computerisation of the production chain that leads to the final product. ERPs, already crucial in traditionally structured business, can give even greater advantages in such a technology-aided scenario by aggregating data and making them immediately available, but above all, by allowing advanced levels of analysis that are impossible in a non-integrated system [8]. For example, integrating an ERP into a Smart Factory can harmonise communications and allow a more precise and efficient data analysis, enabling monitoring the times for each production cycle and the coordination of the necessary tasks to identify inefficiencies and potential criticalities. ERP systems can effectively monitor the entire production chain, identify any critical issues within the workshop, and contribute to downtime prevention or workload balancing if equipped with a predictive maintenance system. In general, an ERP within a Smart Factory can create a context-sensitive factory environment, track and monitor critical production activities in real-time using a decentralised communication system for optimal management of production processes [9]. Provided with benefits of Cloud and Edge computing, ERP can further impact Smart Factory, as detailed.

2.2 Cloud ERP

High computer processing capabilities, scalability, and storage are required for the vast majority of applications supporting IT tasks [10], [11]. Based on these criteria, Cloud computing allows businesses to get services in various formats, including software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Cloud computing features include the availability of resources regardless of their actual location, their simple acquisition and maintenance, and a flexible pay-as-you-need cost model. Suppliers might outsource hardware and software by providing IT infrastructure requirements and technology as well as undertake all of the work involved in operating and maintaining these services [12]. Companies can utilise a dedicated line from a telecommunications company or a VPN connection via the Internet to access these services. Some ERP service providers are sometimes also referred to as “cloud service providers”.

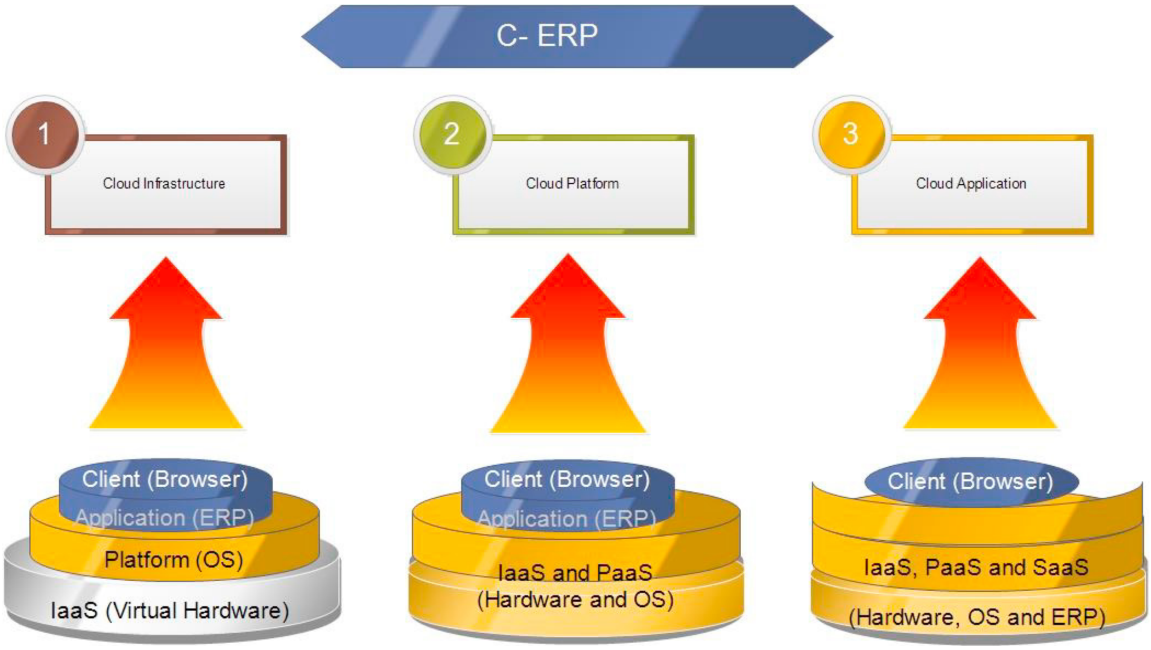

Figure 1. Cloud ERP Service models [13]

ERP has developed into a C- ERP just due to the newest technological advances in Cloud computing. Indeed, on-premise ERP solutions force organisations to maintain their own IT infrastructure, thus demanding considerable investment in IT infrastructure – hardware and software – and maintenance costs. Conversely, C-ERP solutions offer the same functionality as an on-premise ERP but at considerably lower costs due to off-site setup, maintenance and support. Cloud service providers partnering with ERP suppliers may provide simple, rapid, and convenient modular payments. They can also think about standard features like responding to a variety of prospective difficulties and business practices, as well as the financial consequences of installing and deploying on-premises ERP. Regardless of its undoubted benefits, C-ERP is still in its infancy [14], and, according to Salleh et al. [15], there is no agreement on the exact meaning of C-ERP, also known as Cloud Enterprise System (CES). Therefore C-ERP/CES definitions have been somewhat contentious and, because of the limited research, the theoretical concepts are likewise constrained. Virtualisation, agility, on-demand, and pay-as-you-go are four characteristics that have become common ground in terms of characterisation. Still, vendors and academia cannot agree on a single universal definition [4]. Therefore, the reference model for C-ERP used in this study will follow the National Institute of Standards and Technology (NIST) standard, as shown in Figure 1.

Al-Mashari [3] underlined, the mainly adopted C-ERP models are based on IaaS and SaaS. The driving factors lie in the size of the business and the privacy and security requirements. In particular, ERP on IaaS is better suited for mid-sized businesses with a limited budget for ERP and are willing to tolerate a lesser degree of protection; conversely, ERP on SaaS is helpful to small enterprises [16] since it delivers C-ERP as a "ready to use" solution. Indeed, ERP SaaS is better adapted for small industries that lack the initial financing to implement ERP; as a result, it is a more cost-effective alternative that accepts a lower level of security. Also, according to Fauscette [17], C-ERP on SaaS disrupts and creates new business value while gaining a competitive advantage.

2.3 Edge ERP

Edge Computing is a recent paradigm focused on data process and storage close to the event source rather than on remote servers, thus introducing many positive implications. According to Gezer et al. [18], edge computing allows security elements to be relocated closer to the source of an attack, enables higher-performance security applications, and extends the number of layers that help defend the core against breaches and risk based on the size and type of an organization. Beyond the security aspect, by moving computing resources closer to the edge, edge computing allows organisations to function autonomously while still using the benefits of public and private clouds and more efficiently perform complex computing procedures by offloading workload from centralised data centres acting as a way of endpoint terminal authentication. As a result, Edge computing has bridged the gap between big data analytics and intensive computer processing by building apps that run on the edge and the Cloud. In particular, Industrial edge computing enables intelligent applications, ensures tight security, and protects privacy while facilitating flexible connection, real-time control, and data optimisation [19].

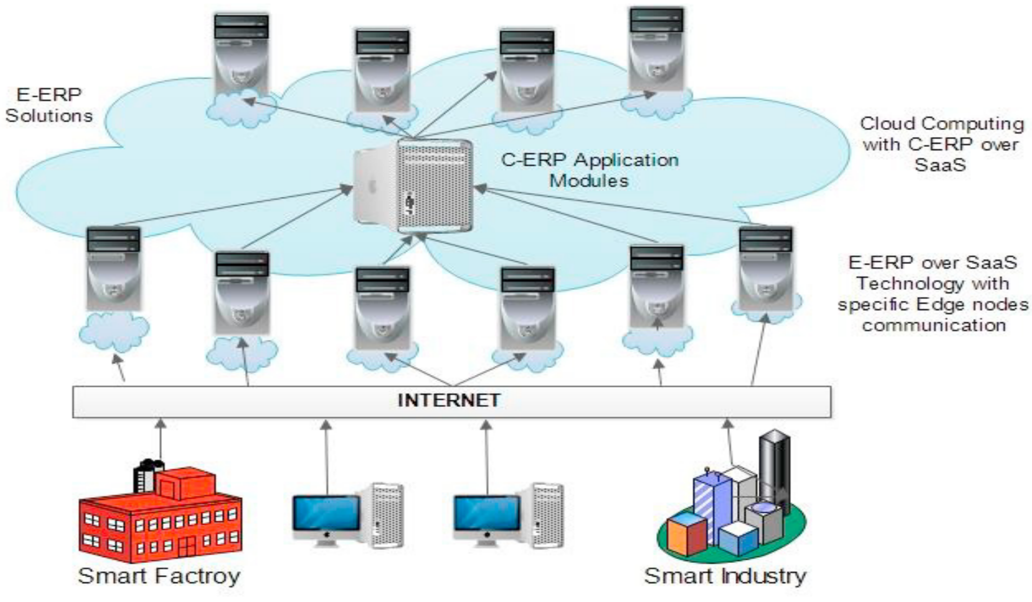

Figure 2. Edge ERP service model [20]

When combined with ERP, Edge computing has the potential to provide organisations with a substantial competitive advantage. The Edge computing platform that a firm uses to enable application suites is usually customised: Edge computing paired with distributed infrastructure is a widespread usage for the firm to reduce latency, enhance throughput, increase flexibility, and permits computational tasks to be performed instantly. According to Chand et al. [20] and as depicted in Figure 2, an E-ERP model extends ERP modules and is built on a comparable SaaS cloud service layer. Each of these modules is connected as a SaaS ERP application server in the Cloud. Requests from ERP customers, such as companies, are routed through network edge nodes to the SaaS ERP application server. With standard modules (e.g., finance, buy to pay, human resources, customer relationship management), C-ERP may be readily customised in a firm. The network edge server nodes then send partial requests to the core ERP application server, which completes and commits the request as needed, responds along the same channel – from the core application server to the edge network nodes, and finally back to the original client requestors. The bulk of ERP service providers offer a common cloud platform. As a result, E-ERP is better suited to small-sized businesses with sensitive data to protect, the need for business continuity, and not enough financial resources (mission-critical systems and high-security requirements) [16]. Indeed, small and medium-sized businesses (SMEs) struggle to be highly efficient in IIoT applications and technology. This is because those businesses typically lack the human resources to explore outside their product and product range to penetrate new markets. They seldom have the resources to invest in technologies that emerge as early adopters. Make sure you're not wasting money by concentrating on the wrong strategies. On the other hand, those businesses must be taught to want technology that can be created effectively enough to exist in a globalised world [8].

3. Discussion

As for every technology, the adoption of C-ERP and E-ERP systems implies both pros and cons that need to be carefully and full-fledged analysed. We identified the following incentives and obstacles relevant to C-ERP and E-ERP adoption within IIoT and Smart Factory domains by reviewing the literature. In particular, organisational characteristics and industry size are key factors for the C-ERP and E-ERP adoption [19]. The main findings of this Section are reported in Table 1.

3.1 Advantages of C-ERP and E-ERP for IIoT and Smart Factory

The financial, technological, and organisational viewpoints mentioned in the following subsections, ERP, Cloud and Edge Computing, open attractive opportunities connected with service and deployment strategy.

- ***Cost Savings and Novel Business Model:*** From a financial standpoint, implementing C-ERP and E-ERP is mainly motivated by cost reductions. Both C-ERP and E-ERP, indeed, allow for three forms of cost savings: reduced upfront expenses, lower operational costs, and transparency of the total cost of ownership, all of which contribute to a better financial image for the organisation [21]. According to Loukis et al. [22], high pricing competitiveness leads to lower operating and maintenance expenses, which is simple to leverage on Cloud Computing. A separate discussion for hybrid (Cloud/Edge) ERP models is needed: large corporations are eager to adopt the hybrid ERP since it is a good approach for cutting costs while keeping important data protected. Conversely, Grubisic [23] has found that the C-ERP hybrid model is unappealing for SMEs since it would result in higher expenses. Apart from cost saving, the last quality that most senior managers are looking for C-ERP and E-ERP is achieving a business value from such IT transformation [21] [22]. Indeed, the authors have discovered that novel information provided by C-ERP and E-ERP may be used to drive current company plans toward a more customer-centric approach as well as new business leads [19], [24]. Indeed, since data are processed close to the head, and just a little information is transferred to a centralised cloud server, there is also a faster response time, the capability of handling large volumes of data regularly and greater reliability by reducing the downtimes (for larger organisations, if the system is down for numerous hours, then it can result in a financial loss). These three advantages thus allow the companies to consider novel business models. In particular, E-ERP design can help with this by offloading part of the effort from the core cloud ERP and only forwarding the most computationally expensive tasks. Even though the Cloud has a lot of storage, processing power, and speed, if the network connecting the Cloud's internal workings slows down due to heavy workloads, it might disrupt customers' regular business activities. Any network failure might put the firm in danger and result in unpleasant debts.

- ***Flexibility, Agility and Scalability***: One of the main advantages of Cloud and Edge computing is improved agility and flexibility since businesses can adapt quickly to changing markets [19], [24], [25]. Thus it is not surprising that C-ERP and E-ERP provide organisations with a relevant competitive advantage [12]. Lenart [13] discussed the majority of the benefits stem from the qualities of management and scalability. Similarly, Saa et al. [16] recognise that scalability allows organisations to better utilise their resources with simplified maintenance. C-ERP enables an organisation to pay for the services they need and removes the need to maintain information technology infrastructures.

- ***Improved Business Productivity and Efficiency:*** The capability of automating services, processes and procedures (e.g., production, purchasing, distribution, and inventories) leads to higher productivity, and hence it is extremely appealing within the IIoT domain. C-ERP and E-ERP allow for automation and increased production, resulting in increased overall efficiency [12] [19]. According to authors [19] [26], C-ERP and E-ERP resulted in increased company efficiency, operations, and user perception [24]. In this regard, standardisation is key to enhance cooperation across several sites in streamline business operations: indeed, as underlined in [12], data standardisation in C-ERP and E-ERP is also possible, resulting in improved operations management. Integration of C-ERP and E-ERP with other systems, such as business intelligence, enables better planning and decision-making [19] [26]. Particularly, the E-ERP model offers an efficient setting for faster decision making and reporting by providing real-time information: it achieves a low latency rate by sharing workloads with the core ERP application server and a high-performance rate by handling partial execution at the edge nodes.

3.2 Disadvantages of C-ERP and E-ERP for IIoT and Smart Factory

The major barriers for C-ERP and E-ERP installation solutions may change depending on whether the deployment is from the ground up or a migration from a traditional ERP to a Cloud- and Edge-based systems. Nonetheless, the problems in both paradigms are the same. These difficulties are presented in the following.

- ***Organisation issue and conservative mindset:*** Cloud and Edge computing already impact organisational features on infrastructure, staff skill sets, strategy, and scale [22]. Moving conventional ERP to C-ERP or E-ERP demand additional investments and re-organisation of assets and procedures. Thus, managers are often discouraged and scared by the required significant changes in the way organisations execute their routine operations and processes. Hence, the organisation should be flexible enough for business process re-engineering that forms the basis of successful cloud/edge-based ERP implementation. On this basis, despite Cloud computing facilitating new business, from [27] [28]. It results that SMEs quickly adopt C-ERP to focus more on core business operations and business continuity. At the same time, significant corporations take their time, encountering obstacles such as a conservative mindset and issues with sensitive data in Cloud servers or Edge nodes. In particular, the authors of [21] studied the relationship between C-ERP and the size of an organisation, finding that the organisation's intrinsic features, such as geographical activity and dispersion, might influence how C-ERP and E-ERP adoption is perceived.

- Moreover, they found that companies with more advanced infrastructures are more likely to move to C-ERP and E-ERP, regardless of their size. In a deeper analysis, it can be found that successful C-ERP and E-ERP adoption depend on people both within an organisation (employees and top management) and outside (ERP vendor). Involving employees as a part of the implementation process facilitates the transition as employees become familiar with the technology. The same importance has the selection of a cloud vendor and selecting the right edge technology (gateway, edge servers, etc.).

- ***Network balancing and Latency:*** Traditional on-premise ERP systems consist of hardware and software that are connected via a local area network. Maintaining a high-speed network for both the client and the service provider is essential and the company must comprehend the cost of delay and how it affects the company. Therefore, the deployment of C-ERP solutions might be hampered by network latency and traffic unbalancing. Indeed, some SaaS consumers may be geographically separated from the data centre's centralised location and peaks of traffic might lead to poor networking: latency and performance concerns must be addressed in this scenario since the Cloud user may wish to execute business activities in real-time with a predictable response time [20] [29]. For example, implementing solutions integrating supply chain management systems with C-ERP should be carefully assessed because of the need for timely access to crucial manufacturing, inventory, and logistics-related information. However, apart from supply chains and few other cases, rarely real-timeliness is critical for ERPs. In this regard, E-ERP solutions can be a good compromise by providing higher responsiveness concerning C-ERP.

- ***Security and Privacy:*** Data security is critical since ERP might expose sensitive data such as financial or industrial data in Cloud and edge settings. When a company opts for C-ERP, it also agrees to share business-critical and sensitive data with third-party service providers. It may be mixed with data from other companies. Therefore, security and privacy may become an issue due to the Cloud's openness and multi-tenant functionality [4] [30]. The security settings can be complicated due to ERP system complexity, which can lead to security issues.

- Moreover, since ERP data is stored in a single database, controlling access levels to data and resources is challenging. Implementing an effective authentication and authorisation mechanism for C-ERP is challenging since the cloud service provider's services are shared with other tenants [31]. Adopting E-ERP can reduce security and privacy risk since the data can be processed and stored locally. Still, protection mechanisms and policies are to handle and managed directly, thus leading to higher management costs concerning C-ERP.

- ***Vendor Lock-in and Interoperability***: Most industrial sectors are concerned about vendor lock-in since the risk of becoming dissatisfied with a supplier is high [21]. Interoperability, security, and vendor lock-in are all issues when moving old systems to the Cloud. On the other hand, legacy systems were not built with the Cloud and Edge computing features of elasticity, interoperability, cloud service model choices, and multi-tenancy in mind [10]. This also holds for both C-ERP and E-ERP, whose adoption can be discouraged due to vendor lock-in and interoperability issues.

Table 1 Main findings (maximum ●●●, medium ●●○, minimum ●○○)

	C-ERP	**E-ERP**	**References**
Cost Saving	●●○	●●●	[23] [21] [22] [19], [24]
Increased Productivity	●●●	●●●	[27] [19], [24] [26]
Resource availability	●●●	●●○	[12] [16] [13] [19], [24] [25]
Responsiveness	●○○	●●●	[20] [29]
Business innovation	●●○	●●●	[23] [21] [22] [19], [24]
Interoperability	●●●	●●○	[10]
Security and Privacy	●●○	●●●	[4] [30] [31]
Ease of use	●●●	●●○	[27] [16] [13] [21] [22] [28]
Ease of adoption	●●○	●○○	[27] [21] [22] [28]

4. Conclusion and Future Scope

The adoption of C-ERP and E-ERP is a strategic choice made by any industry. ERP's competitive advantage stems from its integration with newer technologies (IIoT), which hides the constant need for change in an organisation's operation. The study of the industrial decision-making process began with examining the factors that impact C-ERP and E-ERP adoption. E-ERP solutions can beat C-ERP solutions in terms of faster provisional delivery, better query execution, and closeness to the client. Edge computing may also be utilised in a variety of ERP systems and modules. Edge nodes may handle specific task allocations right at the edge network, simplifying and dividing activities to be done partially at the edge and transmitting only the most intensive computing jobs to C-ERP. Finally, the E-ERP model delivers real-time data, making it a more effective and efficient decision-making and reporting tool. Sharing workloads with the central ERP application server and controlling partial execution at the edge nodes achieve low latency and high performance.

Future work should focus on developing a new Edge computing reference architecture-based ERP system on the essential features that overcome the limitations in the currently used C-ERP and E-ERP. The main goal of this unique reference architecture will be to achieve real-time data analysis on local devices and edge nodes rather than in the Cloud. Further, to reduce the operating and management costs by reducing traffic and data transfer between the edge and the Cloud and to improve application performance by allowing latency-tolerant applications to reach lower latency levels to be used in E-ERP.

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