Sustainability in and through IoT-enhanced Business Processes

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Abstract

In today's interconnected world, businesses integrate Internet of Things (IoT) devices to enhance efficiency, gather real-time data, and make informed decisions. These devices autonomously execute tasks and collect data, revolutionizing business processes (IoT-enhanced BPs). They optimize operations, improve productivity, and streamline resource utilization across various industries, such as manufacturing, retail, and logistics. However, businesses must also focus on sustainability beyond environmental concerns, encompassing economic, social, human, and technical aspects. Measuring the sustainability of IoT-enhanced BPs across these dimensions is crucial for long-term viability. While sustainability in business processes has been integrated over the past two decades, existing research has not sufficiently considered the role that IoT devices play in this context. To this end, this work aims to analyze the impact of IoT devices on sustainability issues, emphasizing the need for ongoing research in the BPM field to achieve sustainable IoT-enhanced BPs.

Keywords

IoT-enhanced business processes, Sustainability dimensions, IoT devices impact

1. Introduction

In today's interconnected world, businesses are increasingly integrating Internet of Things (IoT) devices into their operations to enhance efficiency, gather real-time data from their environments, and make more informed decisions [1]. These IoT devices play a pivotal role in executing tasks autonomously or collecting data from various sensors embedded in the environment. This symbiotic relationship between IoT devices and business processes (BPs), hereinafter *IoT-enhanced BPs* [2], has revolutionized the way organizations operate, offering unprecedented insights and capabilities.

By leveraging IoT devices, businesses can streamline operations, optimize resource utilization, and improve overall productivity. However, beyond enhancing operational efficiency, it is imperative to enhance sustainability[3] across various dimensions as identified in [4]. More specifically across economic, social, human, environmental, and technical aspects, all of which are interconnected and essential for long-term viability. Measuring sustainability of IoT-enhanced BPs from these five dimensions becomes paramount for organizations striving to align with sustainability goals and mitigate potential risks.

While concern for sustainability in BPs began to take shape in the 1970s and 1980s, it has been over the past two decades that it has been more deeply and strategically integrated into the BPM field. To this end, we find many works in the literature addressing how to integrate sustainability aspects into BPs. This integration is achieved in different ways but also at different levels. For example, while some works focus on how to measure specific sustainability aspects such as carbon emissions ([5]) or power consumption ([6]) of BPs, others take a broader perspective providing: guidelines aimed at improving BPs in terms of several environmental aspects [7], [8], sustainability patterns for the improvement of existing BPs or for the design of new processes based on ecological goals [9], or considering several phases of the BPM lifecycle ([10], [11],[8]).

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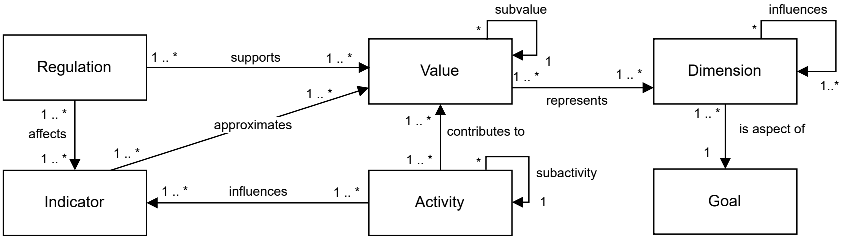

Figure 1: Generic sustainability meta-model from [4]

In the context of our work, we investigate sustainability aspects related to these *IoT-enhanced BPs*. Using the IoT to support the automated execution of process activities or to acquire real-data from the environment might positively contribute to sustainability in all dimensions. On the downside, might also have a negative impact as the IoT devices generate costs along the sustainability dimensions mentioned above. Among others, these refer to the provisioning, operation, and maintenance of the IoT devices as well as to the necessary software and data processing infrastructure [12]. In addition, the IoT provides novel opportunities to directly measure process-related sustainability indicators via sensors to analyze the sustainability of business processes and activities. Thus, considering sustainability in and through IoT-enhanced business processes necessitates an extensive analysis and trade-off discussion to find feasible solutions. For this reason, in this work we aim at providing a comprehensive analysis over the impact that IoT devices have over BPs when these need to be measured and improved according to different sustainability dimensions.

The remainder of the paper is organized as follows. Section 2 introduces sustainability and presents a generic meta-model for sustainability that will be used in section 3 to analize the impact that IoT devices have over sustainability when dealing with IoT-enhanced BPs. Finally, section 4 concludes and points out future work.

2. Sustainability

We can find in the literature several definitions of sustainability ([13],[14], [15]). Although the essence of sustainability remains constant in all, its definition and application can vary depending on the specific context where it is applied. However, all disciplines share the idea that sustainability consists of various dimensions, some of which are considered relevant by all (i.e., the social, economic, and environmental dimensions) and others more specific to the applied context (e.g., the governance, technological, cultural, or knowledge dimensions)[16].

To provide a comprehensive framework that enhances holistic understanding, informed decision-making, and consistent measurement of sustainability, *conceptual models* are commonly used. In the context of software engineering, it is worth noting the sustainability model proposed by [4]. This model introduces a generic sustainability model based on the six key concepts shown in Fig. 1. Here, the sustainability *Dimension* plays a central role and refers to an aspect of or perspective on a *Goal* related to sustainability. More specifically, to have a better understanding over sustainability issues, [17] identified the importance of addressing the following five interrelated dimensions: 1) *Individual (Human) dimension* that encompasses personal freedom and the capacity to act within an environment, human dignity, and fulfillment, 2) *Social dimension* that involves the relationships between individuals and groups, 3) *Economic dimension* that includes capital growth and liquidity, investment considerations, and financial operations, 4) *Technical dimension* that relates to the maintenance and evolution of software systems over time, and finally 5) *Environmental dimension* that concerns the use and stewardship of natural resources. Each of these five dimensions is characterized by a set of *values*, i.e., by a moral or natural good perceived as an expression of a particular dimension. Values may not be exclusive to one dimension but can apply to multiple dimensions (e.g., a healthy environment is relevant to both the environmental and individual dimensions). To measure a specific degree or score related to a value, an *indicator* is used, which can be either a qualitative (e.g., satisfaction indexes) or quantitative metric (e.g., carbon emissions). A group of indicators collectively reflects a value that is supported by *regulations*, optional elements that impact a value by either supporting or enforcing it (e.g., emission regulations set legal limits for specific indicators). Many values across dimensions are regulated to protect them, such as individual freedom supported by human rights and healthy air supported by carbon emission directives from entities like the European Union. Finally, *activities* contribute to a specific value, like using a train instead of an aircraft for mid-distance travel. The impact of these activities is measured by the indicators they influence (e.g., choosing a train reduces emissions). Each value has corresponding activities, and their impact is assessed by the indicators affected.

This model is used as a reference to perform the analysis developed next. More specifically, the dimension, value, and indicator concepts are considered in this analysis. The remainder concepts are out of the scope of this analysis.

3. Analyzing the Sustainability Impact of IoT Devices

Integrating IoT devices into BPs has significant implications for sustainability, encompassing the five dimensions previously discussed: economic, social, human, environmental, and technical. While these devices have the potential to significantly enhance sustainability, they also have negative impacts that must be addressed. Balancing the positive impacts with the negative implications will be key to maximizing the benefits of IoT regarding sustainably in BPs.

In this section, we explore the positive and negative impacts that IoT devices have across the dimensions. To this end, each dimension is briefly defined and characterized by a set of values to illustrate this duality of impact and to serve as a guide for conducting a sustainability analysis in IoT-enhanced BPs. However, it is important to note that, in practice, the values identified for each domain should be defined by the organizations themselves based on their sustainability objectives.

3.1. Individual (Human) Dimension

This dimension encompasses BPs participants' freedom and the capacity to act within an environment, human dignity, and fulfillment. Some related *values* include:

- **Human Health**. Refers to individuals' overall well-being and physical condition, considering factors such as nutrition, fitness, mental health, etc. A positive impact on human health is expected when BPs use IoT devices since these can enable remote health monitoring, facilitate timely intervention in medical emergencies, and promote preventive care through continuous data collection and analysis (e.g., wearable devices designed to support physical tasks can enhance worker ergonomics).
- **Security**. Security refers to the protection of individuals' physical and digital well-being. The overall impact of IoT devices on this value is expected to be positive since IoT technologies enhance monitoring capabilities and enable proactive measures to mitigate risks (e.g., IoT sensors can detect unauthorized access attempts or anomalies in physical environments, triggering immediate alerts). However, IoT devices also introduce new security challenges and vulnerabilities (e.g., poorly secured IoT cameras have been exploited by hackers to invade privacy or conduct surveillance without authorization).

Indicators that may assess these values include quantitative metrics like the number of health-related incidents detected early through IoT monitoring, employee satisfaction scores related to IoT-enabled work environments, or qualitative assessments such as surveys gauging perceptions of privacy and comfort with IoT technologies among stakeholders.

3.2. Social Dimension

This dimension involves the relationships between BPs participants and groups, aiming at ensuring that BPs positively influence societies or communities. Some related *values* include:

- **Inclusion**. Ensuring that all individuals, regardless of their background or abilities, have equal access to resources, opportunities, and participation in the BPs. IoT devices may have both, positive and negative impacts on inclusion. For example, some assistive IoT devices can aid individuals with disabilities, promoting greater inclusion. However, unequal access to IoT technology may widen disparities, leading to a digital gap between those who have and lack access to digital technologies (because of limited capacity or ability to use them).
- **Transparency**. Refers to ensuring openness, clarity, and accountability about data practices, enabling real-time monitoring and reporting, ensuring regulatory compliance, and empowering individuals to make informed decisions about their interactions with IoT-enabled services and products. The impact of IoT devices is generally expected to be positive (e.g., IoT devices can enhance transparency by providing clear information to individuals about what data is being collected, how it is being used, and who has access to it).

Indicators for the social dimension include quantitative metrics such as the percentage of individuals with disabilities benefiting from IoT assistive technologies, and qualitative assessments like surveys gauging perceptions of transparency in IoT data practices among stakeholders.

3.3. Economic Dimension

This dimension refers to the capital growth and liquidity, investment considerations, and financial BP operations. Therefore, it aims to responsibly manage the BP's finite resources in a manner that is economically beneficial to organizations. In this case, IoT devices play a crucial role in enhancing the economic sustainability of BPs by improving operational efficiency, optimizing supply chains, and boosting productivity. Some related *values* include:

- **Efficacy.** Refers to the amount of errors that occur within the execution of a BP. IoT devices are expected to positively impact this value since thse are capable of automating tasks and avoiding or minimizing the introduction of human errors (e.g., an automated irrigation system ensures precise watering schedules, reducing the likelihood of over- or under-watering crops). However, it is also important to consider that IoT devices are not entirely error-free and have a margin of error. Nevertheless, this margin is typically much smaller than the errors introduced by manual processes, making IoT devices valuable in improving overall process efficacy.
- **Cost.** Refers to the expenses associated with the execution of BPs. These can reduce operational costs by substituting human labor with IoT-enabled machines like transportation robots, minimizing waste, and improving operational efficiency. Nevertheless, at the same time, these involve infrastructure and maintenance costs.

Indicators that may assess these values encompass both quantitative and qualitative measures. For example, quantitative indicators may include total revenue generated, cost savings achieved through IoT adoption, or return on investment from IoT implementations. On the other hand, qualitative measures could gauge stakeholder perception of cost-saving initiatives and employee satisfaction with new technology deployments.

3.4. Technical Dimension

This dimension relates to the maintenance and evolution of BPs over time. It seeks to optimize maintenance factors, ensuring that the maintenance system will cost-effectively perform its functions in the future, considering environmental and social impacts. Some related *values* include:

- **Scalability.** Refers to the capability of a BP to handle growth or reduction in size and demand. When the tasks of a BP are supported by IoT devices, an appropriate architectural design can facilitate the deployment of additional IoT devices when there is an increasing workload in terms of data processing or number of users.

- **Adaptability.** Refers to the ability of a BP to meet specific needs based on the current context and without significant disruptions. IoT-enhanced BPs can support adaptability by enabling real-time adjustments based on detected changes and anomalies in the execution environment. For instance, the raw data that is continuously captured by sensors can be used to identify unexpected user behaviour or new environmental conditions to adapt the tasks of the process.

Examples of indicators for these values can include quantitative measurements such as the number of supported users, amount of data processed per second, cost to evolve the system in person/hour; and qualitative measurements such as the level of user satisfaction with system reliability or the perception of the speed and effectiveness of adaptive responses to changing conditions.

3.5. Environmental Dimension

This dimension refers to the use and stewardship of natural resources in BPs. It focuses on the impact of IoT devices supporting organization's business activities related to living and non-living natural systems in the environment, including ecosystems, land, air, and water [18]. IoT devices make a resource consumption that have a negative impact on the environment (e.g., during their manufacturing, distribution, installation, use, and end-of-life phases as illustrated in the Product Environmental Profile (PEP) ecopassport database [1]).

- **Water.** Pertains to the use and management of water resources. Water management is critical in sustainable practices. IoT devices, such as smart water tap sensors preventing wastage, play a pivotal role in optimizing water use efficiency.
- **Air.** Involves the quality of the atmosphere and the presence of pollutants. Air quality is crucial for environmental health and, therefore, for humans. IoT devices, such as pollution filters, reduce environmental pollutants and help to maintain air quality.

Examples of indicators measuring these values include quantitative measurements such as the number of liters of water consumed, or the kilograms of paper recycled, and qualitative such as the maturity of the e-waste management policy implemented in the company's BPs, or the quality of the air perceived by the humans involved in the BP.

4. Conclusions and further work

In this paper we have analyzed the impact that IoT devices have on BPs from a sustainability perspective, considering economic, social, human, environmental, and technical dimensions. The analysis shows that while IoT devices significantly enhance the sustainability of BPs, they also introduce costs and challenges that need to be considered. In addition, in this analysis, we have provided some examples of different types of indicators that can be used to assess the sustainability of each dimension.

At this point, it is important to highlight that IoT devices can serve both, directly and indirectly to sustainability measurements. On the one hand, directly as a source of data to obtain these measurements. On the other hand, indirectly by supporting the BP activity tasks that are being measured. This dual role highlights their potential to enhance efficiency while simultaneously facilitating the measurement of sustainability metrics.

This work constitutes a first step towards addressing sustainability in IoT-enhanced BPs. Thus, it can be used as a guide to understanding how IoT devices can contribute in improving sustainability. However, more advances in this context regarding sustainability are needed. Future research should focus on sustainable models as the one presented by [4] where the IoT device concept should be taken into account, as well as the relationships that this has with the remaining concepts in the model. Besides revising this conceptual model, tools to specify and visualize the different aspects considered in it are also needed.

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[1] https://register.pep-ecopassport.org/

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