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How Big Data Analytics Applications Address Industrial Parks Operations Challenges

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Abstract: Big Data Analytics (BDA) applications have proliferated across diverse industries, from healthcare to manufacturing, showcasing their potential to revolutionize operations and enhance efficiency. However, despite this widespread adoption, there's limited comprehension of how BDA specifically impacts and addresses sustainability challenges within the operational context of industrial parks. This study delves into exploring how Big Data Analytics (BDA) address industrial parks sustainable operations challenges. The investigation particularly identified three main themes big data analytics addressing industrial parks operations challenges these are power management, waste management, and security and safety management The study has employed a qualitative methodology to comprehensively understand how BDA addresses challenges in these settings. The study findings showed various big data analytics approaches and its limitations. Ultimately, this study aspires to contribute a nuanced understanding of how BDA impacts industrial park operations and management, laying the groundwork for future exploratory case studies that will provide more comprehensive insights into the practical implementation of BDA strategies in these settings.

Keywords*: Industrial Parks; Big Data Analytics; Business Development; Sustainability Challenges; Data Management*

1. Introduction

The advent of big data analytics technologies has initiated a paradigm shift across industries, presenting unprecedented prospects for innovation, operational efficiency, and sustainability. The application of big data analytics practices in industrial parks has yielded transformative impacts across power management, waste management, and security and safety protocols. Studies such as Zhang et al. (2016) have highlighted the pivotal role of big data in power management, emphasizing the necessity of valid data utilization for smart consumption and demand management. The complexities of power consumption data, including its massive volume and the intricacy of processing and analysis, have prompted the adoption of advanced data processing techniques to tackle these challenges (S. Zhang et al., 2016). Similarly, in waste management, the works of Wang, Bao, Yuan, Zhou, & Li (2019) underscored the absence of dedicated platforms focusing on managing hazardous waste within industrial parks. Big data analytics solutions offer promise in optimizing waste handling by integrating diverse datasets and employing predictive modeling for more efficient and sustainable waste management practices(Wang, Bao, Yuan, Zhou, & Li, 2019). Moreover, concerning security and safety management, advancements in big data analytics have been pivotal. Studies by Hu & He (2021) emphasized the importance of robust security frameworks in logistics industrial parks amidst extensive digitization. The integration of data-driven insights aids in proactively addressing cybersecurity threats, enhancing surveillance, and bolstering safety measures within industrial precincts. These applications signify the multifaceted utility of big data analytics practices, not only optimizing industrial operations but also fostering sustainability and resilience in industrial park management (Hu & He, 2021).

However, despite substantial scholarship elucidating the applications and advantages of these technologies, a notable gap exists in comprehensive investigations of the challenges confronted by industrial parks in implementing and harnessing such advancements. Notably, the bulk of existing research originates from regions like China, predominantly focusing on the implementation aspects rather than the strategic development of big data analytics initiatives within industrial park environments.

Thus, the primary objective of this research is to scrutinize the development and utilization of a Big Data Analytics strategy within the domain of Industrial Parks (IPs) management. However, upon conducting a literature review concerning Big Data in Information and Communication Technology (ICT) and management, a conspicuous gap in research is observed, particularly regarding the application of BDA in Industrial Parks (IPs) all over the world and particularly in Oman. Most existing studies recommend swift adoption of this technology to align with organizational objectives and national goals. In response to this gap, the current study focuses on the

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adoption of BDA in IP management across various regions within the Sultanate of Oman. The research sets out to address a research question: How does Big data analytics help to address challenges faced by industrial parks? To delve into this inquiry, the study adopts a qualitative case study method, meticulously investigating the development and implementation of Big Data Analytics (BDA) strategies specifically in the context of industrial park (IP) management in Oman.

2. Literature Review

Overview of Industrial Parks

Industrial parks encompass expansive land areas subdivided into plots, designed for multi-industrial use, with a predominant focus on manufacturing. They are equipped with specialized infrastructure, governed by specific laws and regulations aimed at fostering economic and social development contributions (Sosnovskikh, 2017; UNIDO, 2019). The widespread establishment of industrial parks is notably increasing, particularly in developing countries, aiming to achieve economic diversification, foster growth, and generate employment opportunities for citizens (Pai, 2015; Workenh Eshatuu, Eshetu, & Shemilis, 2021). However, these parks encounter significant operational sustainability challenges, particularly in managing power, waste, and ensuring security and safety. The utilization of big data analytics to enhance business operations has seen a rise across various sectors, including healthcare, manufacturing, and within industrial parks.

Overview of Big Data in Industrial Park

The development and utilization of big data analytics in industrial parks have emerged as a significant area of interest (Fang, Fan, & Liu, 2023; Z. Yang, Hao, & Cheng, 2018). These parks harbor a wealth of data generated through an array of sensors, social media integrations, and internal Enterprise Resource Planning (ERP) systems (Lele & Lihua, 2016; Xu, Wang, Wang, Jia, & Ma, 2016; Zong, Chen, Li, & Liu, 2018). Notably, the Internet of Things (IoT) sensors contribute diverse data streams, including vibration, temperature, humidity, infrared signals, smart meter readings, intelligent terminal inputs, and communication infrastructure data (Song, Yeo, Kohls, & Herrmann, 2017). Similarly, the implementation of smart grids generates extensive and varied data, encompassing heterogeneous and multi-state information vital during operational, maintenance, and administrative phases (Li, Anduv, Zhu, Jin, & Du, 2023; Q. Wu et al., 2023; Y. Zhang, Liang, & Liu, 2019). Moreover, within the domain of utilities like water supply, data records cumulative flow, instantaneous flow rate, and pressure, while gas consumption data includes temperature, pressure, instantaneous flow rate, and cumulative standardized flow. Additionally, in managing cooling/heating systems, datasets capture parameters such as temperature, pressure, cumulative flow, and instantaneous flow rate (D. Wu et al., 2019). Moreover, the expansive data landscape within industrial parks extends to surveillance systems, encompassing diverse datasets vital for security and safety. Surveillance systems contribute substantial data streams, including video feeds, motion sensor logs, access control records, and environmental monitoring data, forming a critical component in ensuring the security and safety of industrial park premises (Fan, Liu, Cai, & Yue, 2019). These datasets add to the complexity and richness of information available for analysis within these settings. Furthermore, the monitoring of air quality involves hundreds of pollutants tracked synchronously through multiple devices stationed at various points (Y. Chen et al., 2022).

As industrial parks evolve, intelligent infrastructures equipped with data centers are witnessing rapid growth, leveraging cloud computing, Artificial Intelligence (AI), and Big Data Analytics (BDA) applications. Advancements in these technologies have streamlined the analytics of industrial park big data, revolutionizing traditional approaches. For instance, parallel data mining using the MapReduce framework has enabled the implementation of diverse data mining algorithms, including clustering, classification, prediction, and outlier analysis, facilitating valuable knowledge extraction from the vast datasets inherent in industrial park operations (T. Yang, Zhao, Pen, & Wang, 2018; Y. Zhang et al., 2019) .

Application of Big Data Analytics in Industrial Parks

The application of Big Data Analytics in Industrial Parks refers to the utilization of advanced data processing, analysis, and interpretation techniques within industrial park settings. It involves harnessing vast amounts of data generated from various sources within these parks, including sensors, equipment, operations, and external factors (Caraka et al., 2023; Fang et al., 2023). Big Data Analytics enables the extraction of meaningful insights, patterns, and correlations from this diverse dataset to enhance decision-making, optimize operations, improve efficiency, address sustainability challenges, and drive business development within industrial parks. There are three primary themes scholars have emphasized in exploring the applications of big data analytics in industrial parks, namely, power efficiency, waste optimization, and security and safety, which will be discussed in the following section.

Big Data Applications in Power Efficiency Management

studies collectively exemplify the applications of big data analytics in power management, illustrating how diagnosis, real-time monitoring, and forecasting facilitate efficient power usage, sustainability, and informed decision-making within industrial contexts.

Challenges Faced by Industrial Parks	Methodology used	Key findings	Studies References
Energy storage, economic viability	Energy storage scenarios, commercialization measures	Proposed energy storage configurations for zero-carbon industrial parks, suggestions to enhance economic viability and promote development through third-party investment.	(Fang et al., 2023)
Energy consumption analysis, load forecasting	CH-K-means clustering, LSTM neural network	Identification of energy consumption behaviors, significant reduction in steam load during holidays, coupling ambient temperature for higher accuracy in load forecasting.	(Q. Wu et al., 2023)
Fault diagnosis	Deep Belief Network (DBN) and Enhanced Extreme Learning Machine (ELM)	The study utilizes IoT technology to collect operational data from the chiller system, situated in IP in Taicang City, Jiangsu Province. The experiments encompass fault-free tests and those inducing refrigerant undercharge faults, with varied conditions manipulated to assess chiller performance. The study emphasizes the feasibility and practicality of the DBN-ELM method for chiller fault diagnosis	(Li et al., 2023)
Big data integration, energy savings	Power big data applications, cloud computing, BI integration	Successful applications integrating cloud computing and business intelligence in power big data systems, achieving over 8.6% energy savings and preliminary intelligent living systems.	(Y. Zhang et al., 2019)
Smart consumption, clean energy	Big data and cloud computing for smart power consumption	Implementation of smart power consumption management platforms, effective power consumption strategies for different users, promoting clean and green energy development.	(S. Zhang et al., 2016)
Demand response, renewable integration	Holistic demand response algorithm, renewable energy integration	Proposed algorithms to manage power fluctuations in data centers using renewable energy, ensuring reliability and stability, and contributing to sustainable development.	(T. Yang et al., 2018)
Energy system optimization, multi-objective scheduling	Digital twin technology, multi-energy flow simulation	Use of digital twin technology for energy system optimization, prediction and correction of unit outputs, multi-objective scheduling leading to improved economic and energy consumption levels.	(Xing et al., 2022)

Diagnosis

Big data analytics enables precise diagnosis of power-related issues within industrial settings. By processing large volumes of data from various sources like IoT sensors, smart meters, and grid systems, analytics tools can swiftly identify anomalies, faults, or inefficiencies in power distribution. For instance, using advanced algorithms, anomalies in voltage, load fluctuations, or irregularities in power consumption can be swiftly pinpointed. This diagnosis helps in proactive maintenance, preventing potential power failures or system breakdowns.

(Fang et al., 2023): The study by Fang et al. emphasizes load-storage collaboration for zero-carbon industrial parks. By diagnosing energy storage application scenarios and conducting economic analyses, it diagnoses optimal energy storage strategies, crucial for ensuring efficient power usage and carbon neutrality.

Li, Anduv, Zhu, Jin, & Du (2023) addresses the fault diagnosis of refrigerant undercharge in air-cooled screw chillers within an industrial park. The study utilizes IoT technology to collect operational data from the chiller system, situated in Taicang City, Jiangsu Province. The experiments encompass fault-free tests and those inducing refrigerant undercharge faults, with varied conditions manipulated to assess chiller performance. combining a Deep Belief Network (DBN) with an Extreme Learning Machine (ELM), optimized through Particle Swarm Optimization (PSO). Key findings include the analysis of fault characteristics, the selection of 23 relevant parameters, and the superior performance of the DBN-ELM model in comparison to traditional algorithms, achieving a remarkable accuracy rate of 99.86%. The study emphasizes the feasibility and practicality of the DBN-ELM method for chiller fault diagnosis, offering a comprehensive and efficient strategy (Li et al., 2023).

Real-time Monitoring

Real-time monitoring involves continuous observation and analysis of power-related parameters and activities. With big data analytics, industrial parks can monitor power consumption patterns, grid performance, and equipment efficiency in real time. This monitoring often involves dashboards or visualizations that provide live updates on power usage, load distribution, or grid stability. Anomalies or deviations from normal patterns trigger immediate alerts, allowing prompt actions to mitigate risks and optimize power usage.

(Q. Wu et al., 2023): Wu et al.'s research uses clustering and forecasting techniques based on steam load data. Their methodology enables real-time monitoring through the CH-K-means algorithm for clustering and LSTM neural networks for forecasting, facilitating ongoing assessment and adjustment of energy consumption patterns.

User Behavior Analysis (T. Chen, Chen, Zhang, Shu, & Chen, 2020) (T. Chen et al., 2020): Chen et al.'s research concentrates on user behavior analysis based on power big data. Their approach diagnoses user behavior comprehensively, enabling real-time monitoring of power usage patterns, allowing the power industry to forecast and optimize energy distribution efficiently.

Forecasting

Big data analytics facilitates accurate forecasting of power demand and consumption behaviors. Utilizing historical data, weather patterns, user behaviors, and other relevant factors, predictive models are developed to anticipate future power needs. For instance, machine learning algorithms like neural networks or regression models can forecast peak demand periods, enabling efficient grid management and resource allocation. This forecasting capability aids in load balancing, grid optimization, and strategic planning for energy storage and distribution. These applications demonstrate how big data analytics empowers industrial parks in power management by offering precise diagnosis of issues, enabling real-time monitoring for immediate interventions, and forecasting future demand for proactive planning and resource allocation.

(S. Zhang et al., 2016): Zhang et al.'s study emphasizes the importance of forecasting and future-oriented strategies. By integrating big data and cloud computing technologies, it forecasts energy demand, enabling predictive insights to optimize power consumption in real-time, thus preparing for future energy needs proactively.

Big Data Applications in Waste Optimization Management

Industrial parks encounter multifaceted challenges in waste management. The challenges faced by industrial parks primarily stemmed from the complexity, diversity, and dynamic nature of waste generation sources. It necessitating innovative approaches to optimize resource utilization and minimize environmental impact. Studies underscored the significance of big data analytics in addressing waste management challenges in industrial parks. Leveraging diverse data sources and analytical approaches, they proposed structured frameworks for waste stream characterization, identification of symbiotic partnerships, and integrated hazardous waste management, laying the foundation for more sustainable and efficient industrial waste practices.

(Bin et al., 2015)underscored the complexities in waste management arising from increasing urban waste generation. They proposed leveraging big data analytics to realize industrial symbioses among companies within close proximity, addressing challenges related to limited types and scales of companies in eco-industrial parks. Employing a three-step big data approach - data discovery, eco-network detection, and evaluation - the study aimed to match waste streams with resource requirements, offering a structured framework for identifying potential industrial symbioses. (Song et al., 2017) delved into the intricacies of industrial symbiosis and the hurdles in gathering comprehensive waste data. They advocated employing big data analytics to obtain crucial waste generation data by amalgamating diverse internet sources and engineering manuals. Their proposed methodology involved web portal searches, modeling of business processes, and revenue-based estimations to identify potential symbiotic partnerships. They emphasized the need for further research to address critical challenges, including comprehensive data discovery algorithms and technical properties of waste streams. Conversely, (Wang et al., 2019) directed attention to hazardous waste management within chemical parks, emphasizing the necessity for integrated management systems. Proposing principles such as closed management and clustering, they suggested big data analytics as a key enabler for optimized hazardous waste management. The study highlighted the potential of big data to facilitate integrated hazardous waste management through unified environmental services, intelligent standard box systems, and system optimization scenarios. Methodologically, these studies utilized a combination of data discovery techniques, modeling approaches, and scenario analyses to address challenges. Their findings collectively emphasized the importance of big data analytics in waste management by integrating and analyzing diverse datasets. They proposed structured methodologies for waste stream categorization, identification of potential symbiotic relationships, and comprehensive waste management at industrial and chemical park levels.

Challenges Faced by Industrial Parks	Methodology used	Key findings	Studies References
Diverse and dynamic waste sources, hindering symbioses	Data discovery, eco-network detection, evaluation	Proposed big data approach for symbiotic partnerships among companies, addressing waste complexities	(Bin et al., 2015)
Complexity in waste data gathering	Web portal searches, modeling, revenue-based estimations	Advocated big data analytics for waste data acquisition, stressed the need for advanced algorithms	(Song et al., 2017)
Hazardous waste management challenges	Integrated management principles, big data application	Highlighted big data's role in optimizing hazardous waste management with structured methodologies	(Wang et al., 2019)

In summary, these studies underscored the significance of big data analytics in addressing waste management challenges in industrial parks. Leveraging diverse data sources and analytical approaches, they proposed structured frameworks for waste stream characterization, identification of symbiotic partnerships, and integrated hazardous waste management, laying the foundation for more sustainable and efficient industrial waste practices.

Big Data Applications in Security and Safety Management

Big data analytics stands as a pivotal tool shaping the future of industrial park security and safety management, offering unprecedented insights from diverse data sources to mitigate risks and ensure a proactive approach to safety. The amalgamation of studies by Fan et al. (2019), Lele & Lihua (2016), Yan et al. (2023), H. Xu et al. (2023), and Taylan et al. (2021) portrays the comprehensive landscape of security and safety challenges within industrial parks, offering insights into how big data and advanced technologies address these concerns. Industrial parks, as depicted by Lele & Lihua (2016), encapsulate heightened risks due to the nature of activities conducted within, especially in chemical industries, which pose threats of inflammability, toxicity, and accidents, necessitating robust safety measures. Meanwhile, Fan et al. (2019) focus on the critical issue of traffic safety, identifying accident black spots within urban settings. These studies emphasize the imperative need for predictive safety measures and effective accident management. The integration of big data and innovative technologies emerges as a crucial solution to these challenges. Lele & Lihua (2016) introduce a safety production information management platform, leveraging the Internet of Things and Big Data, orchestrating compliance management, risk grading, and preemptive rescue plans within chemical industrial parks. Similarly, Fan et al. (2019) deploy Support Vector Machine and Deep Neural Networks to predict traffic accident black spots, showcasing the role of machine learning in addressing traffic safety concerns.

Additionally, Yan et al. (2023) propose an edge fusion solution for intelligent industrial parks, optimizing data transmission, computing, and storage, thereby enhancing real-time multimedia data processing at the edge. H. Xu et al. (2023) delve into the evaluation of carbon neutrality, employing big data and artificial intelligence techniques to integrate heterogeneous data sources, fostering a comprehensive understanding of the carbon neutrality status in Chongming District.

Methodologically, these studies underscore the significance of machine learning algorithms, IoT integration, edge computing solutions, and comprehensive data acquisition frameworks. Their findings collectively underscore the pivotal role of big data analytics, AI, and technological innovations in mitigating security and safety challenges faced by industrial parks, encompassing traffic safety, chemical hazards, and environmental sustainability. This synthesis highlights the cohesive nature of these studies in advocating for technologically-driven solutions to fortify safety and security in industrial settings.

Challenges Faced by Industrial Parks	Methodology used	Key findings	Studies References
Traffic safety	Support Vector Machine, Deep Neural Network	Proposed algorithms for predicting accident black spots	(Fan et al., 2019)
Safety in chemical industry	Internet of Things, Big Data, Cloud Computing	Developed safety management platform for chemical industrial parks	(Lele & Lihua, 2016)
Data transmission & storage	MatrixOne, Pravega	Proposed edge fusion solution for multimedia data in industrial parks	(Yan et al., 2023)
Carbon neutrality assessment	Big Data, Artificial Intelligence	Proposed methods using AI and big data for low-carbon transformation	(Zhu, Gui, & Guo, 2023)
Air quality monitoring	Artificial Neural Networks, ANFIS, NARX	Established models for predicting air quality in urban zones	(Taylan et al., 2021)

3. Methodology

In the pursuit of addressing the research question on developing a big data strategy for industrial zone management and achieving the associated objectives of uncovering challenges in business development, exploring the role of big data in addressing industrial challenges, and understanding factors influencing the adoption of big data analysis in industrial areas, our research took several strategic steps. A comprehensive review of existing literature on big data was conducted, emphasizing the benefits and challenges, as well as organizational strategies for implementing big data analysis. This review guided the formulation of research questions and propositions. Adopting a qualitative methodology, a single case study focused on the Sultanate of Oman (Madayn) was executed. A case study protocol was developed to ensure systematic data collection, observation recording, and result quality control. Following a pilot study in January 2021, purposive sampling was employed, involving five employees from Madayn's industrial zones, to inquire about big data, challenges faced, and the impact of big data analysis. Manual and electronic analysis, facilitated by Atlas ti software, revealed patterns and themes from the interviews. Subsequently, 23 employees at various levels were interviewed from late January to July. Interviews were transcribed, and reviewed by participants for accuracy, and a secure database was established. Participant anonymity was ensured through encryption and symbolic identifiers. Thematic Analysis methodology was applied, creating codes for interview transcripts, which were then organized into a corpus. The research findings were synthesized, and the comprehensive report was compiled, marking the culmination of the study.

Results and Discussion

Big Data Analytics applications limitation

Big data analytics in Power Management

Industrial parks management have challenges in utilizing big data analytics to address power management challenges. In one hand, the Industrial activities consume large quantity of energy and there is shortage supply in some industrial parks. On other hand, the big data analytics practices are still in initial stages the consumption data is collected manually and implementation of smart maters readers still in progress. Thus, makes difficult real-time monitoring. Even though the government have policies and intention for reducing carbon protection but make balance between industrial activates growth and implementing and mentoring is difficult. In addition, the renewable power resources are hardly utilized. Overall, there is a lack of proactive strategies support operations sustainability challenges

“Monthly consumption bills (sent by email). Causes of outages and the duration of interruptions are not electronic.”ML-R3

‘’Let us say Madayn decides to go carbon neutral by 2040. To start working towards something like that, we should know where and what is the intensity of energy use now? What kind of industry as per the international Industry Classification (ISIC) All those things so you can correlate these data and say the average utilization of energy use per unit value addition in a given sector is so much. Beyond this, it is also possible to estimate the energy productivity

– meaning, which sector or industry gives you better value addition for a given energy consumption. These are valuable inferences to lessen the negative impact of industrialisation. Energy intensity is very high in certain sectors and certain sectors very low. When we have this indication then we know we don't say only considered in energy but it's one factor to be manipulated to be controlled for carbon emission targets in setin time or year and influence air pollution’’ELM-R4

“Analyzing utilities data (electricity, water and gas consumption) and Pollution data (types and reasoning of pollutions) Thus, provides Innovative and Proactive Strategies to Support Operation Sustainability.’’ ELM-R2 and ML-R10

‘’By utilizing network sensors in the buildings, which are working based on employees' motion, could help to manage and consume energy and disaster Management’’ EDL-R2

“BDA can provide answer whether it needs a new electricity station, and to know the size of the current station and the usage. Providing Infrastructure facilities depends on the factory’s type”ML-R3 and ML-R4

“Power utilization data, Environmental related data for instance, Air quality, safety incidences, fire, effluents from various factories, what is quality treated water sewage, what is application time and long takes to approve and setup industry Also in economics data for example, Investment value, employment per units, dispersion. Moreover, in social data like Men and Women, employment, level of employment in which salary they will come then we can get very beautiful data, analysis by county, nationality qualification you can have a matrix, correlate unfortunately useful data but are hardly used” ELM-R4

“Data used to standardize organizations’ resources. Investors need Necessary and appropriate Feedback. For example: if the investor required 50 Megawatt of electricity, can the internal network provide this capacity? And what about the external network? Is this data available? The capacity of water, type of electricity and connections this happened when data linked to other entities databases like service providers, internal Security” ELM-7

The challenges confronted by industrial parks in the realm of energy management and utilization have been multifaceted. Fang et al. (2023) underscored the economic complexities within energy storage configurations, delineating challenges in grid-centric, user-centric, and market-centric scenarios, stressing the need for comprehensive economic viability assessments. Similarly, studies by Wu et al. (2023), Y. Zhang et al. (2019), and Zhang et al. (2016) accentuated the challenges in predictive analysis and user behavior modeling, citing data errors, and the necessity of coupling with external factors for enhanced accuracy. These studies reveal research gaps concerning the limited consideration of external factors influencing predictive models' accuracy. In parallel, technological integration complexities, as identified by T. Chen et al. (2020) and others, have raised concerns, calling for comprehensive frameworks to integrate community-driven power management leveraging advanced technologies. Adoption factors predominantly highlighted real-time monitoring, proactive management, and advanced algorithms. Yet, these studies collectively unveil gaps in the absence of comprehensive adoption models, urging future research to address multifaceted factors across diverse scenarios. Strategies developed in these studies spanned energy storage configurations, predictive algorithms, user-centric strategies, and community-driven implementations. However, gaps persisted in the economic assessment of energy storage, predictive accuracy influenced by external factors, and the absence of holistic frameworks for community-driven power management. Future research endeavors should emphasize comprehensive economic viability assessments, improved predictive accuracy by integrating external factors, and the development of holistic frameworks for community-driven power management leveraging technology.

Big data analytics in Waste Management

Industrial parks management have challenges in utilizing big data analytics to address waste management challenges. In one hand, the big data analytics practices are still in initial stages the majority of waste data is missed and implementation of smart waste maters and sensors readers still in progress. Thus, makes difficult real-time waste monitoring. In addition, despite of volume of waste generating from industrial productions the recycle practices are hardly implemented. Even though the government have policies and intention for reducing waste but make balance between industrial activates growth and implementing and mentoring is difficult.

“We have challenges in industrial waste data.”ML-R1

“Madayn have swage stations but still data not in one system and we collected manually from the contractors (maintenance company)”ML-R4

‘’Power utilization data, Environmental related data for instance, Air quality, safety incidences, fire, effluents from various factories, what is quality treated water sewage, what is application time and long takes to approve and setup industry Also in economics data for example, Investment value, employment per units, dispersion. Moreover, in social data like Men and Women, employment, level of employment in which salary they will come then we can get very beautiful data, analysis by county, nationality qualification you can have a matrix, correlate unfortunately useful data but are hardly use''ELM-R4

'There are big data not captured namely; raw materials, productions, waste and value chains, workforces in more detailed manner like requested jobs, Omani positions, and cancelled contracts.'' ELM-R19

"Waste data and how its recycles" ELM-R6

''There are big data not captured namly; raw materials, productions, waste and value chains, workforces in more detailed manner like requested jobs, Omani positions, and cancelled contracts.'' EDL-R4

The synthesis of studies addressing waste management challenges in industrial parks through big data analytics reveals multifaceted obstacles in harnessing data-driven approaches for efficient waste handling. Bin et al. (2015) highlighted the complexities arising from diverse and dynamic waste sources, impeding the comprehensive characterization required for industrial symbioses. B. Song et al. (2017) underscored challenges in integrating varied data sources, indicating limitations in algorithms and technical capabilities for precise waste stream identification. Additionally, W. Wang et al. (2019) brought attention to financial constraints linked to implementing big data solutions, hindering practical execution due to IoT and intelligent application expenses. These studies identified several limitations and proposed essential recommendations. Bin et al. (2015) emphasized the necessity for further research to enhance data discovery algorithms and refine waste stream characterization. B. Song et al. (2017) pointed to technical barriers that require specialized expertise and resource allocation for effective implementation. W. Wang et al. (2019) stressed the importance of cooperation among entities and environmental departments, coupled with continued research efforts to overcome financial barriers and advance waste management practices. Collectively, these prior studies confirm what we found in our study and illuminate the need for ongoing research, financial investment, technical expertise, and collaborative partnerships to overcome complexities and harness the potential of big data analytics in waste management within industrial parks.

Big data analytics in Security and safety

Industrial parks management have challenges in utilizing big data analytics to address Security and Safety management challenges. In one hand, the big data analytics practices are still in initial stages. Despite of implementing various surveillance systems in various industrial parks but there is lack of security and safety protocols. Also, data is stored in various data warehouses which hardily utilized for enhance security and safety challenges.

''analyzing network sensors and CCTV big data could be used for monitoring parks Health Safety and Environment (HSE) which predict parks threats and improve risk management.'' ML-R3

''Let us say Madayn decides to go carbon neutral by 2040. To start working towards something like that, we should know where and what is the intensity of energy use now? What kind of industry as per the international Industry Classification (ISIC) All those things so you can correlate these data and say the average utilization of energy use per unit value addition in a given sector is so much. Beyond this, it is also possible to estimate the energy productivity – meaning, which sector or industry gives you better value addition for a given energy consumption. These are valuable inferences to lessen the negative impact of industrialisation. Energy intensity is very high in certain sectors and certain sectors very low. When we have this indication then we know we don't say only considered in energy but it's one factor to be manipulated to be controlled for carbon emission targets in setin time or year and influence air pollution''ELM-R4

"The feasibility studies, The available information is in files which is difficult to refer to it difficulty accessing to useful information in Madayn for instance, Maps, contracts, price gradation, surveillance cameras, truck movement, truck size, investor movement, number and type of transactions and requests, the impact of industrial areas on the surrounding environment (noise, smoke, waste, traffic, future plans, city design, etc.)" ELM-R8

''shortage of data related to employment segmentation, nationalities, salaries, types of food, data related to safety, frequent fire and risk and reasons behind these fires. Also, data related history amendment regulations.'' ELM-R8

In the realm of security and safety, the implementation of big data analytics confronts multifaceted challenges, as highlighted across several studies. One fundamental challenge lies in the complexity and sheer volume of data generated within industrial parks and urban settings. Fan et al. (2019) and Yan et al. (2023) emphasize the need to manage vast amounts of heterogeneous data, comprising traffic patterns, accident histories, environmental parameters, and multimedia streams. Integrating and analyzing these diverse data types while ensuring accuracy and real-time processing presents a significant challenge. Another hurdle pertains to the dynamic nature of security threats. Lele & Lihua (2016) illustrate this in the context of chemical industrial parks, where the risks associated with inflammable, toxic materials, and potential accidents continuously evolve. The challenge lies not only in predicting these risks but also in adapting safety measures swiftly to mitigate emerging threats effectively. Furthermore, ensuring the reliability and accuracy of predictive models remains a critical concern. Fan et al. (2019) note the importance of precision and recall rates in identifying traffic accident black spots, highlighting the necessity for continually improving and refining predictive models in response to changing data patterns. Despite the potential of big data analytics, limitations persist. These encompass the need for robust infrastructure capable of handling massive data volumes in real-time, as emphasized by Yan et al. (2023). Additionally, ensuring data security and privacy while collecting and processing sensitive information remains a prominent concern, especially in safety-critical domains. Recommendations stem from these challenges and limitations, emphasizing the need for advanced technologies that facilitate real-time data processing, machine learning algorithms, and edge computing solutions to handle the complexities of security data. Fan et al. (2019) advocate for continual model refinement to enhance prediction accuracy, while Yan et al. (2023) highlight the importance of scalability and reliability in data transmission and storage at the edge.

Thus, addressing these challenges demands a concerted effort towards technological innovation, infrastructure development, and stringent data governance to harness the full potential of big data analytics in ensuring security and safety within industrial parks and urban environments.

Recommendations for Future Studies:

Exploration of Industry-Specific BDA Applications:

Future studies could delve into industry-specific applications of BDA within industrial parks, focusing on sectors like manufacturing, energy, or logistics. This exploration could highlight sector-specific challenges and nuanced BDA solutions for optimized outcomes.

Longitudinal Studies on BDA Implementation: Conducting longitudinal studies that track the implementation of BDA strategies within industrial parks over time can provide insights into the long-term effectiveness, challenges faced during execution, and adaptive measures employed for continual improvement.

Cross-Country Comparative Studies: Comparative studies across various developing countries can offer comprehensive insights into the contextual nuances influencing BDA adoption in diverse industrial park settings. Understanding regional disparities and similarities would be invaluable for tailored BDA strategies.

BDA Ethics and Governance Frameworks: Given the sensitive nature of data, future research could focus on formulating ethical and governance frameworks specific to BDA applications in industrial parks. This would ensure responsible data usage and compliance with regulations.

Integration of Emerging Technologies: Exploring the integration of BDA with emerging technologies like Artificial Intelligence (AI), Internet of Things (IoT), or Blockchain within industrial park environments could unlock novel avenues for efficiency and sustainability.

4. Conclusion

This study aimed to investigate the extent to which big data technology is employed in an emerging environment and a developing country like Oman. The focus was on understanding the level of adoption of big data analytics in industrial sectors, with the Madayan Agency in industrial areas in the Sultanate of Oman selected as a case study. Interviews were conducted with approximately 23 managers across various departments.

The primary areas of focus in this study were the applications of big data in Power management, Waste management, and Security & Safety. The findings revealed that Madayn encounters several challenges in the adoption of big data technology, including issues related to innovation, infrastructure, and a shortage of skilled personnel in this domain. the study shed light on the challenges faced by Madayn in embracing big data technology in the specified industrial domains and linking with the findings of prior studies. These challenges encompassed innovation barriers, infrastructure limitations, and a scarcity of skilled professionals. Addressing these challenges is crucial for Madayn to effectively adopt and leverage big data analytics for enhanced operations and decision-making.

Generally, the exploration of Big Data Analytics' (BDA) applications in industrial parks reveals a critical gap in understanding its impact on operational sustainability. Despite widespread BDA implementation in various sectors, its tailored implications for industrial park challenges remain unexplored. The lack of empirical evidence linking BDA to resource optimization, risk mitigation, and operational efficacy underscores the need for comprehensive research. This study aims to contribute significantly to scholarly discourse by providing a nuanced understanding of how BDA can address sustainability challenges in industrial park operations. Emphasizing empirical evidence from case studies, the research offers practical insights and strategies for stakeholders. The objective is to deepen comprehension and propose implementable recommendations for effective BDA adoption in industrial parks. With diverse BDA applications, a tailored strategy for industrial parks becomes evident, and the proposed BDA strategy aims to enhance operational sustainability. This contribution serves as a guiding framework for future research and practical implementation in the complex landscape of industrial park management.

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