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Implications of digital twin applications on management accounting practices to support competitive advantage: A foresight view from the Saudi business environment

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Abstract

The study addresses the transformative implications of digitalization, notably the integration of digital twins, in various manufacturing and management application areas, including accounting information systems, operational costs, and organizational changes. It emphasizes the need for comprehensive policies and training programs to enhance preparedness and adaptability within Saudi organizations while highlighting the importance of robust cybersecurity measures and strategic partnerships with technology providers. This study applied exploratory research and a qualitative case study to collect data using multiple tools such as interviews, observations, and content analysis. The findings emphasize the proactive and forward-thinking approach required for organizations to effectively navigate the digital landscape, embrace emerging technologies, and maintain flexibility to drive growth and success. The study's primary objective is to enhance the comprehension of how digital twins can generate additional value and provide a competitive edge within the Saudi business landscape. This emphasizes the significance of utilizing digital technologies to maintain a leading position in the global market. The research enhances our understanding of how Digital Twins can bolster management analytics (MA) practices to gain a competitive advantage, yet it underscores a significant gap for future studies. Current investigations have largely centered on individual technologies, such as big data, AI, or IoT, concerning MA, rather than exploring the intricate interactions among multiple technologies within Digital Twins. A more in-depth examination of these integrations across different applications is essential to identify the challenges and impacts on MA practices, especially considering the reliance on extensive unstructured data. However, the findings are somewhat limited as they are derived from a case study of a leading energy company, which may not accurately represent broader circumstances due to diminished uncertainty and competitive pressures. Future research should investigate these associations across varied contexts to deepen our understanding.

Keywords: Digital twin applications, relevant management accounting practices, competitive advantage, data-driven value creation.

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1. Introduction

Management accounting (MA) has emerged as a vital information system amidst the incessant changes in contextual variables and business conditions [1]. Consequently, it is crucial to continuously assess the relevance of MA to effectively communicate with decision-making processes and furnish pertinent, accurate, and insightful data for the analysis of future organizational activities by scrutinizing both financial and non-financial information. Recent trends in MA underscore the need for adaptability to digitalization and its multifaceted applications in business practices. Digitalization has fundamentally altered the accounting function by superseding traditional accounting methodologies with artificial intelligence frameworks capable of managing extensive datasets, akin to a real digital twin, thereby facilitating the preparation of financial and non-financial reports that bolster data-driven decision-making [2, 3].

One central aim of this paper is to evaluate the preparedness of MA practices for the integration of digital twin applications within the Saudi context. The findings suggest that the implementation of the digital twin concept positively impacts various dimensions of the accounting function, including accounting information systems, internal operational cost management, organizational changes, data analytics, and decision-making processes, albeit necessitating appropriate preventive measures [4, 5].

The study advocates for the establishment of comprehensive policies and procedures aimed at addressing the challenges that arise during pivotal transformations, automation, and the adoption of innovative techniques in the accounting domain. Enhanced preparedness and adaptability of MA practices within Saudi organizations can be achieved through regular training initiatives designed to upskill practitioners concerning contemporary digital implications, fostering an organizational culture that prioritizes innovation. Furthermore, organizations need to invest in robust cybersecurity measures to safeguard sensitive financial data in an increasingly digitized environment. Additionally, forging strong partnerships with technology providers can facilitate the seamless integration of digital solutions into MA processes [6, 7].

As organizations continue to navigate the continuously evolving digital landscape, a proactive stance towards emerging technologies is essential to maintain a competitive advantage. This entails remaining attuned to industry trends, identifying automation opportunities, and streamlining processes where feasible. Moreover, organizations must uphold a high degree of flexibility and adaptability in response to the new possibilities and challenges ushered in by digitalization. By harnessing the capabilities of digital technologies and adopting a forward-thinking ethos, management accounting can significantly contribute to driving growth and success for Saudi enterprises in both the present and the future. Hence, organizations must prioritize the effectiveness and readiness of their management accounting practices in the digital era. [8, 9].

This study endeavors to contribute to the existing literature on the influence of digital twin applications on management accounting practices as a means of supporting competitive advantage within the rapidly evolving context of the Saudi economy, which is recognized as one of the most dynamic markets in the Middle East. Leading organizations in Saudi Arabia are consistently striving to invest in cutting-edge technologies to harness their potential for competitive differentiation.

2. Literature Review

In the recent digital transformation era, digital twins have become a focal point in the realm of MA and are being utilized across a wide array of organizations. By combining physical and digital elements, companies can leverage digital twins to meet specific needs related to information processing functions, including managerial accounting systems, driven by globalization, regionalization, and the rise of accounting data and technology-led information. In Saudi Arabia, there has been a notable increase in the use of information technology, partly driven by initiatives that aim to enhance skills in high-tech applications [10].

The MA system is considered one of the most important parts of the economy, joining strategy and technology to accomplish objectives. The MA system relies on authentic information technology, as the management system can be built to equip the information types and levels of information control needed to accomplish the objectives of decisions in the new innovative economy. MA handles complex costs and prioritizes customer needs and preferences to maximize profit. This is achieved by using advanced techniques to accurately cost and preserve resources. The integrated system in MA can be established using digital twin technology to identify essential information required for effective management. This technology utilizes advanced IT applications to account for a wide range of information [11, 12].

2.1. Digital Twins in Management Accounting

The research surrounding digital twins and management accounting (MA) is still in its early stages. There is a limited number of published papers that explore the implications of digital twins for MA. Digital twins create virtual models of physical products, assets, and processes using real-world data, providing a real-time representation of their performance. Given the increasing array of digital innovations and the vast availability of big data within organizations, what is digital-twin technology [13], it is crucial to broaden the examination of digital twins' effects to encompass a more comprehensive understanding of MA data [14].

My paper aims to deepen the understanding of the programmable, real-time, interdisciplinary, service-oriented, and decision-making characteristics of digital twins, particularly in their support for the MA community as they navigate challenges and opportunities in the digital era. This work will highlight the impact that digital twins can have on management accounting, enabling researchers to identify various applications, which could lead to new development opportunities.

The methodological approach of this paper is both conceptual and qualitative. The implications of this conceptual framework are particularly significant for the MA academic community, as it will assist in specifying the applications of digital twins concerning multidisciplinary models, virtual representations, big data, and real-time outcomes across various functional areas relevant to MA, including cost analysis, investment decisions, and performance evaluation.

2.2. Potential Applications of Digital Twins and Implications for MA Practices

For a company to maintain its competitiveness within an increasingly crowded consumer marketplace, it is essential to monitor both its internal and external environments, enhance operations, seek optimal solutions, and streamline processes [15]. This approach will allow the organization to become more focused and agile, enabling it to adapt to the ever-evolving business landscape [5]. This study seeks to underscore the critical role of digital twins in embracing technological advancements to boost competitiveness. By doing so, it aims to provide a clearer vision of the future of management accounting in the era of digital twins [16].

The digital twin concept involves creating a virtual model that mirrors the physical state of assets or processes in real time, utilizing data collected from attached sensors. This methodology facilitates the analysis of consumption patterns and employs machine learning to establish predictive links that offer valuable insights into optimal asset utilization, expenditure trends, and effective business planning [17]. Additionally, the digital twin can simulate potential future changes, assess the organization's sensitivity to such changes, and identify points of diminishing returns. Furthermore, it provides optimization mechanisms to evaluate trade-offs between costs, effectiveness, service, and other factors. This concept beautifully illustrates the direct connection between technological advancement and practical application, with the support of artificial intelligence and machine learning capable of predicting damage or failure and monitoring performance [18].

2.2.1. Digital Twin and Asset Management Mechanisms (Cost Identification and Reduction Techniques)

To sustain competitiveness in an increasingly saturated consumer marketplace, organizations must diligently monitor both their internal and external environments, enhance operational efficiency, pursue optimal solutions, and streamline processes. This strategy is vital for fostering a more focused and agile organization capable of adapting to the dynamic nature of the business environment [5]. The present study aims to emphasize the pivotal role of digital twins in facilitating the adoption of technological advancements to enhance organizational competitiveness. In doing so, it strives to articulate a more coherent vision of the future of management accounting in the context of digital twins [16].

The concept of a digital twin is defined as the process of generating a real-time virtual model that reflects the physical state of assets or processes through data acquired from sensors affixed to them [19]. This approach enables the analysis of consumption patterns and leverages machine learning to establish predictive relationships that yield critical insights into optimal asset utilization, expenditure trends, and strategic business planning. Moreover, digital twins can simulate potential future alterations, evaluate organizational responsiveness to such changes, and identify points of diminishing returns. They also provide optimization mechanisms to assess trade-offs among costs, efficiency, service quality, and other relevant variables. This paradigm effectively illustrates the intrinsic link between technological advancements and their practical applications, bolstered by artificial intelligence and machine learning capabilities that facilitate the prediction of potential failures or damages and the monitoring of performance metrics [18].

2.2.2. Digital Twins and Organizational Control Tools (KPIs and Budgets)

Digital twins will impact internal control mechanisms in the future, whether organizations want them to or not. While organizations need to understand that digital twins will impact internal controls, it is essential to understand how they will impact them. As such, Ukko et al. [20] outline what characteristics managers should consider when using digital twins for internal control, specifically social and formal control. Managers involved in management control systems should consider the important role of digital twins in regulatory control and leverage this type of information system (based on digital twins) to develop performance indicators and plan budgets based on actual data so that they become more flexible and can be updated immediately and continuously [21].

2.2.3. Digital Twin and Product Lifecycle Management (Activity Costs and Specification Costs)

Digital twin technology provides a multidimensional view of physical asset performance by simulating and predicting outcomes based on real-world conditions, Autodesk [22]. Gary et al. [23] emphasize its capabilities in advanced simulation and modeling, which are vital for improving industrial performance.

The primary aim of digital twin technology in the industrial sector is to simulate complex systems while accounting for human interactions, external influences, and design constraints. Its applications include:

- Enhancing product life cycles.
- Developing automated production planning systems.
- Redesigning industrial processes.
- Optimizing production monitoring and decision-making.
- Predicting and managing maintenance operations [24].

Product life cycle cost (LCC) refers to all expenses incurred over a product's life, examining the relationship between customer payments and total acquisition costs [25]. Implementing product life cycle management (PLM) based on digital twin technology provides essential insights for decision-makers on environmental impacts and cost reduction opportunities across the product's life cycle. This approach aims to increase the competitiveness of industrial companies [22].

2.2.4. Digital Twin and Supply Chain Management (Risk Management – Zero Inventory Management – Just-in-Time Production)

This technology is primarily utilized to assess various risks, particularly potential disruptions within the supply chain. Its focus is on enhancing supply chain resilience, and it aids in generating alerts and forecasting key performance indicators (KPIs) such as service levels, profitability, and product turnover.

By leveraging AI and advanced analytics, the digital twin can simulate supply chain performance, capturing the complexities that lead to issues like stockouts and overstocking. It identifies potential risks early on and facilitates better planning of transportation resources. Overall, the digital twin effectively addresses inventory-related challenges faced by companies, as noted by AlNasrallah and Saleem [26].

Moreover, the digital twin supports short-term planning and execution, allowing companies to minimize losses associated with misaligned plans, system constraints, and hidden bottlenecks. The early insights generated by digital twins enable companies to align their maintenance schedules and inventory with market demand, according to Alrashed et al. [27].

The digital twin integrates a wide range of information, including inventory levels, supplier details, sales data, and various other parameters [28]. AI is employed to analyze this information, while machine learning is used to generate accurate predictions. As stated by Prepare For The Impact Of Digital Twins [29], "Companies will run real-time simulations on all available information, enabling them to anticipate risks that are crucial for decision-making."

2.2.5. Digital Twins and Strategic Decision-Making (Data Analytics Tools Using Smart Algorithms)

The initial phase of decision support provided by digital twins involves delivering comprehensive data visualizations through dashboards and advanced business intelligence tools. Business users leverage this detailed and up-to-date information in conjunction with their professional expertise to make informed operational decisions. However, the role of digital twins is continually evolving. They are no longer limited to providing information; with the integration of artificial intelligence and advanced analytics, they can uncover hidden insights from vast datasets that may be challenging, if not impossible, for users to process manually in real time. This capability leads to decision augmentation, resulting in prescriptive recommendations that users can choose from when determining a course of action [4, 30].

As we look to the future, the scope of digital twins will expand beyond just decision augmentation to encompass decision automation. They will function within a secure framework, making strategic decisions based on AI, analytics, and well-established business rules. This advancement will pave the way for "lights-out" operations, driving the algorithmic business model.

2.2.6. Digital Twin and Operations Planning (Cost Management & Planning and Operational Budgeting)

Digital twin simulations help optimize factory layouts, improve resource allocation, and reduce waste. When applied across the entire supply chain, the technology provides a comprehensive view of operations that can lead to better inventory management, demand forecasting, and overall customer experience [31].

For example, the automotive industry has made significant gains thanks to digital twin technology. Manufacturers are working to reduce costs without sacrificing vehicle safety by using digital twins to simulate crash tests and analyze vehicle components. Also, in the aviation sector, digital twins are improving aircraft performance and safety by monitoring aircraft engines virtually in real time [32].

2.2.7. Digital Twin of Customer Relationships (DToC)

To grasp how DToC operates within a retail organization, consider the use of digital twins to replicate entire stores virtually. By analyzing virtual customers as they navigate through the store, retailers can glean insights into behavior and interactions on the sales floor. This enables them to better understand their customers, create detailed shopper journey maps, and design an optimized and interactive store layout [33]. An agile approach to anticipating customer mindsets becomes particularly crucial during times of upheaval, such as transitioning out of pandemic restrictions or navigating periods of high inflation. In situations of uncertainty, customer habits can shift dramatically, rendering historical data less reliable. DToC can simulate responses from specific customer groups prior to defining the customer journey, ultimately saving time and resources that might be wasted on testing ineffective journey interventions [33, 34].

3. Methodology and Research Design

This research aimed to investigate the influence of the digital twin technique on Management Accounting (MA) practices, with a specific focus on its capacity to enhance value creation. Given that the application of digital twin systems is still nascent in the Saudi context, a qualitative research approach was employed, which included the following methodologies:

An exploratory research design was employed, incorporating a comprehensive literature review as well as focus groups and interviews. This multifaceted approach aimed to gain preliminary insights into awareness of the digital twin system, its various applications, the associated benefits and challenges of its utilization, and the readiness of Saudi companies to invest in this technology.

A qualitative case study was employed to gather data through a range of instruments, including interviews, observations, and content analysis. Remote interviews were conducted to capture non-financial data and to assess the application level of the digital twin system, its influence on organizational practices, and its contribution to achieving a competitive advantage. The selection of interview respondents was carefully curated, focusing on individuals in key positions, particularly those from top management responsible for investing in new technologies, senior financial managers involved in accounting practices and decision-making processes, and senior operations managers overseeing the enhancement of operational processes. Each interview lasted approximately 60 minutes and was guided by a semi-structured questionnaire that was developed in alignment with the initial literature review and the study's objectives. The questionnaire was meticulously designed, incorporating open-ended questions and an array of follow-up inquiries. Particular emphasis was placed on interrogating digital twins' applications within the research framework's confines. Certain questions were deliberately formulated to be broad and somewhat ambiguous, allowing respondents to provide expansive answers that encapsulated a

wider spectrum of perceptions regarding the topics in question. The initial questions were designed to be straightforward, beginning with respondents' early experiences with digital twins before progressing to more intricate and reflective aspects of the technology.

Subsequently, a thematic analysis of the interview data was conducted to elucidate the underlying meanings of participants' responses and to explore how digital twins can augment management accounting practices as a means of achieving competitive advantage.

4. Discussion of the Research Findings

4.1. Findings of the Exploratory Study

Digital twin technology still varies greatly by industry maturity and is at different stages in its diffusion across competing firms within industries. The literature suggests four states (or stages) of awareness, adoption, and usage of digital twin technology among firms within industries, namely: 1) digital twin unaware; 2) digital twin aware; 3) digital twin exploratory (early adopting); and 4) digital twin advanced (beyond early adopting). Firms are further classified into fast, medium, and slow followers of digital twin technology based on their digital twin awareness, adoption, and usage curve.

In Saudi Arabia, many companies are still in the early stages of implementing digital twin technology. However, the number of organizations adopting this technology is on the rise, and it is being utilized across various sectors. To gain a comprehensive understanding of the applications of digital twins among companies in Saudi Arabia, a review is essential. Our preliminary study has identified five companies that stand out for their pioneering roles in adopting this technology, marking a significant step toward advancement. These companies are Saudi Aramco, Saudi Electricity Company, Saudi Telecom Company, Saudi Red Sea Development Company, and the Public Investment Fund.

Digital twins were developed in Saudi Arabia with efforts from national universities, such as the establishment of a Smart City Laboratory at King Saud University in Riyadh to support the Kingdom's 2030 vision, which includes the goal to establish the Riyadh smart city. KSU is collaborating with the Riyadh Development Authority to build a new center for the city. A conceptual framework was introduced to explore the use of digital twins in supporting urban development projects in Saudi Arabia [21].

The Saudi Electricity Company (SEC) was formed as the largest corporation in Saudi Arabia for electricity generation, transmission, and distribution. The company is also considered to be the largest trading company in the Middle East and North Africa. It performs operations relating to electricity generation, transmission, and distribution, and it also fully owns four companies in the operation of networks in six regions. It also holds the majority stake in other networks under a separate entity for public investment [35].

Saudi companies have considerably increased their investments in emerging technologies, prominently including digital twin applications. These firms have introduced innovative products that leverage digital twin technologies, such as AG5 and BITE Satellite software [8]. They have established a strategic partnership with the Saudi Arabian Oil Company, aimed at integrating predictive analytics and digital twin technology within the Kingdom. The company's Ist-1 enterprise IoT solution presents various digital twin technology options tailored for the Saudi Arabian market, with a primary focus on facilitating maintenance planning and scheduling. This initiative also underscores the commitment to enhancing workplace safety through digital twin technologies in the region [27].

The Saudi Electric Company has been pioneering digital twin solutions for its distribution network, utilizing a unified model that encompasses a broad spectrum of geographic and design data. This approach facilitates the consolidation of insights from nearly all independent grid systems, thereby enhancing operational efficiency. Additionally, Zamil Steel has distinguished itself as the first company in the HVACR industry within Saudi Arabia to initiate a virtual twin platform, integrating IoT functionalities and AI-driven contract capabilities [36].

Engie has adopted digital twin technology to optimize energy management within industrial contexts, reflecting the increasing reliance on advanced technological frameworks in the energy sector. Furthermore, the Saudi Chamber of Commerce has conducted extensive studies on the implications of Smart Cities, emphasizing their critical role in the evolution of digital twin simulations and real-time analysis as essential components for the future development of the Kingdom.

The exploratory study conducted by Hassanain et al. [37] has revealed that a variety of digital twin implementations, such as the SRO National Cyber Range (SNCR) for SCADA systems and the SRO Rail Operations Digital Twin (SRO ROT), are actively operational across several sectors, including clean technology, assembly, aviation, utilities, and oil and gas. Noteworthy implementations also include the Chlorine Digital Twin at the RC Jizan Chlorine Operations and the Smart Industrial Digital Twin in Yanbu Industrial City.

Significant opportunities for the application of digital twin technologies in Saudi Arabia exist, particularly in the realms of smart infrastructure and smart cities. Moreover, industrial digital twins and the industrial Internet of Things (IIoT) present numerous avenues for both private and public sector investments. However, it is important to note that the application of digital twins in sectors such as finance, hospitality, entertainment, and service remains underdeveloped [38].

Also, a digital twin was applied to a profitability analysis in partnership with a Saudi company called Aljazirah Vehicles Agency. A case study was performed at the customer's request to run a profitability analysis, emphasizing the dynamics of the bill of resources needed to run the simulation. The case owner provided the bill of resources for each of their services and key inter-resource activities to deliver the product. They currently run their factory based on demand. They start their planning process with a customer's order, and then they calculate the delivery date based on the promised delivery time. Then, they turn to their ERP system to check the status of each resource, considering that there will be no hiccups. If all goes well, they will start production. If they experience a shortage of resources, they identify the bottleneck and shuffle resources, thereby upsetting the resource planning of all affected products [39].

As shown above, there are many DT applications in Saudi companies, and this is a strong indicator of the Saudi awareness of the DT significance and benefits, in the meanwhile, these applications are still initial experiments to explore the new technology, and its challenges and benefits, so the application need to be more active, wide scaled, and deeply examined, especially with the scope of the integration between various digital technologies to process data.

4.2. Findings of the Qualitative Case Study

4.2.1. Background of the Case Company

Aramco is one of the largest integrated energy and chemicals companies globally and serves as the state-owned petroleum and natural gas company of Saudi Arabia. As of 2022, it ranks as the second-largest company in the world by revenue and is headquartered in Dhahran. The company's mission is to create value throughout the hydrocarbon chain while delivering societal and economic benefits to communities worldwide that depend on the essential energy it provides. Aramco is also committed to playing a leading role in the energy transition, recognizing its responsibility to help the world achieve a net-zero economy and address sustainability challenges [40].

Aramco has significant interests and investments in deploying various Fourth Industrial Revolution (4IR) technologies across its operations. The company states, “We aim to meet the world’s energy needs while enhancing productivity, reducing CO2 emissions, and creating next-generation products and materials” [41].

The top management at Aramco is acutely aware of the applications and benefits of Digital Twin technology. They have remarked that “Digital Twins enable us to transform many of our business processes, including project engineering design, construction execution planning, supply chain and materials handling, as well as facility operations and maintenance” [42]. The company has already implemented Digital Twin technology in the Hasbah field and intends to expand its use across its engineering and project management divisions.

In 2023, Aramco Ventures, the venture capital arm of Aramco, invested in Aize AS, a provider of digital twin software for heavy-asset industries, acquiring a 7.4% stake in Aize Holding, the parent company [41].

For all the justifications mentioned above, Aramco was chosen as a case study to explore the relationships between digital twins, MA practices, and competitive advantage achievement in the Saudi context. Therefore, the researcher sent an email about the research details to the selected respondents in Aramco, a Saudi petroleum refinery company, to explain the main purpose of the research, interview questions, and the possible involvement of the managers and accountants. The email was sent to the senior managers in the Aramco accounting and operation departments, with definitions of MA practices, digital twins applications, and competitive advantage. Additionally, the response requirements were clearly stated. At the same time, the interviewees were informed confidentially.

Table 1.
Interviewee’s Details

Details	**Interviewee A**	**Interviewee B**	**Interviewee C**	**Interviewee D**
Position	Senior Manager	Accounts Manager (Manufacturing Account)	Senior manager	Senior manager
Department	Accounts Department	Accounts Department	Operations management	Information systems and data analysis
Years of experience	20 years	15 years	15 years	10 years
Interview method	Phone call	Zoom Meeting	Zoom Meeting	Phone call

Data were collected to investigate the relationships between digital twin usage, MA practices, and competitive advantage achievement in the study case corporation, so the questions in the interviews were designed to explore the following main variables of the study:

- Awareness of digital twins’ technology and its advantages and opportunities
- Applications of digital twins in Aramco and the stage of implementation
- The assessment of digital twin implementation in the case company
- The impact of the integration between the digital twin’s system and the other information systems in the company, including MA and decision-making support systems
- Barriers and challenges arose during the early implementation, and plans were made to enhance and address the deficiencies.
- The role of the digital twins’ application in creating added value for the company.

4.2.2. Discussion of findings of the qualitative study:

4.2.2.1. Awareness of the importance of digital twins’ applications

There have been numerous efforts and various pilot projects developed, executed, or initiated by Saudi Aramco in the field of Digital Twin technology. The large number of ongoing Digital Twin projects highlights Saudi Aramco's strong belief in the Digital Twin's ability to improve the design of the asset [43]. These cases looked at the entire asset lifecycle, including initial design through to operation and maintenance, and built on both historical and real-time data. Saudi Aramco believed that real-time data would add significant value to the integrity of the model when incorporated into the Digital Twin. The

implementation of Digital Twin technology has become an essential and defined process for Saudi Aramco's digital transformation strategy. By integrating the thorough knowledge of geology, reservoir, well, and facilities into one model, the Digital Twin enables the company's engineers and operations staff to create the best asset management plan at an enhanced level of understanding [44].

The deployment of Digital Twin technologies is key to making Saudi Aramco an intelligent organization. The Digital Twin approach will continue to broaden the capabilities of megaprojects and existing ones, introduce automation into routine planning and operation integration, and increase the quality and creativity achieved in deploying advanced systems and solutions. Therefore, it is a logical step that with the powerful digital tools available today, we develop and continue to improve Digital Twins using these data models. The Saudi Aramco digital twinning framework for value creation is a living set of essential components and metrics adapted on a case-by-case basis. The "Digital Twin Imperative" focuses on operational and customer impacts in a "Connected Services" digital economy and the long-term elements for sustainable Digital Twin business success. The senior operations manager’s answer.

4.2.2.2. Benefits and Advantages of Using Digital Twin in Aramco

In engineering, the digital twin concept has become popular through cross-industry smart factories. They currently refer to a digital copy of an asset, e.g., plant equipment, that can be used for various purposes, including data preparation. Besides monitoring and assessing performance due to conditions in real-time, already in the operational phase [45].

Nowadays, we can have access to some different technological solutions used in the oil & gas industry, but receive comparatively less attention outside of it. Accordingly, in the oil and gas industry, we are addressing directly the question "What is a Digital Twin?" for a better understanding of why we should use Digital Twin. If you asked this question to many IT developers or many industry application users, you could probably listen to many different "answers" because they could be inspired by many different keywords. In the most general form, indeed, a far-from-uniformed consensus exists, just implying that a digital twin, the senior operation manager’s answer.

4.2.2.3. Applications of Digital Twin in Aramco

One of the valuable companies that successfully utilizes digital twin technology is Aramco Company in Saudi Arabia. Saudi Aramco is a pioneer in digital technology and has successfully implemented digital twin technology in one of its biggest plants [46].

The current applications of the digital twin in the physical system of the Aramco company, as referred to by the senior operational manager and data analysis managers, are:

- The application of digital twins is to develop a cybersecurity digital twin for oil and gas offshore processes. Cybersecurity attacks on simulation and data using the twin; if the integrity of the twin is maintained, it can predict failures.
- The application of digital twin to simulate and restart Amine treatment for WAG, "Water Alternating Gas," is a method used in the oil and gas industry to enhance oil recovery. It involves injecting water and gas in alternating cycles into the reservoir to improve the displacement of oil. The term "slug" refers to a volume of liquid or gas that is injected into the reservoir in a single phase. In the context of WAG, it typically refers to a large volume of gas that is injected into the reservoir to drive and push the oil toward production wells.
- The use of digital twins to separate the GOSP (Gas Oil Separation Plant) for the Offshore Brat platform. The digital twin helps to predict the future state of the GOSP after it has stopped, reduces the time needed to restart it, and maintains stability during the restart.
- The fourth use of the digital twin is to develop an architecture that defines the capabilities of the digital twin.
- The application of digital twins in asset performance monitoring and predictive maintenance
- Affected by the large-scale equipment with high risk and the heavy maintenance tasks in the petrochemical industry, the demand for digital twin technology-based predictive maintenance has become particularly urgent. The ultimate goal is to enable factory equipment to perform self-diagnosis and real-time monitoring of component health. The online asset performance management and predictive maintenance solutions of Huawei and Bentley companies have a wide range of applications in petrochemical companies. In the field of petrochemicals, damage to production facilities will result in the release of toxic gases and oil spills. The closed production facility often prohibits the independent operation of instrumentation and equipment in terms of computing capability and power consumption. With the continuous advancement of artificial intelligence, the petrochemical industry is also starting to introduce Edge AI solutions into its closed control during digital twin construction to provide support and intelligent health diagnosis services for this equipment.

Based on all the mentioned applications of digital twins in Aramco, it is obvious that the proposed digital twin was expected to provide a series of meanings, including data-based state prediction, multi-scale digital synchronization, intelligent equipment health status, and intelligent state transition management, to help future petrochemical operations. Although stunning advances in mathematical statistics, computer vision, learning theories, and cognitive analytics have been made, the current conceptual operation and advantage optimization in making predictions and forecasting remain uncertain and not systematically organized [47].

4.2.2.4. Challenges and Limitations of Implementing Digital Twins in Aramco

In a discussion about the challenges of digital twin implementation, organizational barriers were mentioned as a problem. This included an unclear framework for commercial and profit & loss (PML) wherein different departments, such as Engineering, Procurement, Supply Chain Management, and External Affairs, have unclear interfaces with an internal Digital Twin supplier [10].

The Executive team lacks the necessary knowledge to provide and manage the required silos effectively. Capability assessments were still conducted based on the job descriptions. An effective governance model is crucial for the long-term performance of a Digital Twin application and to minimize potential conflicts between the Asset Owner, Digital Twin vendor, and Data Science Center [45].

Cross-collaboration between different domains, such as predictive maintenance, asset risk analysis, and process optimization, is essential for timely decision-making. Culture change is a challenging and long-term task, which is traditionally difficult to influence. Leadership needs to develop and execute a targeted change declaration and implementation plan, including raising awareness of the company vision, capacity development, communication, and establishing new processes and policies. Firmly anchoring policies and procedures is crucial, and the Digital Twin infrastructure controls important elements. Additionally, the R&D strategy for building internal capability and leading the technology application is key [36, 48].

Regarding the challenges of data integration and interoperability issues, the information systems and data analysis manager refers to the following:

Data integration is one of the main challenges facing digital twin promoters. Bringing together multiple data sources from heterogeneous systems, such as CAD systems, BIM modeling, LIDAR frequency scanning, ERP data, and IoT systems, and fusing this information accurately with real-time data for different objects at different levels of abstraction is a challenging issue. The big challenge of the integration of various information in the digital twin applications does not lie in creating a unified repository for the various information types. Research works, such as the development of ontologies, help to structure the information to be managed through the digital twin system. However, other challenges, such as the integration of data from the real world continuously, or the accuracy of the available information.

In addition, the data source might be important for some applications of digital twin systems, such as environmental assessment applications, and might be unreliable for developing predictions for others.

Finally, the reality of business is often complex because managers deal with incomplete, distributed, and unstructured data. Visual analytics tools can deal with this important business data and offer a reliable solution for providing decision-making information to business managers. To connect the database and BI segments, the PE smart dashboard effectively integrates with all data stored in any object (e.g., files, disks) in the Virtuoso server-side graph database as well as most third-party databases (such as MySQL, SQL Server, and Triple store). Therefore, users can effectively eliminate the boundaries related to the problems. Furthermore, the PE smart dashboard is not just a regular type of BI sales tool; rather, a circulatory database is at the center of the development tools [49].

Smart decision support systems are based on graph theory, Verdantix, ERP, and accounting software (e.g., Adept Sage), and thus, they can take advantage of existing formulas and can simply view and control any data as a series of graphs. According to operational logic and standardized authentication, the graphical director can immediately transform any graph into a report or report RPC (Format, RDF, plain JSON, HTML, etc.) and send any transformation to the business manager. For the above reasons, smart decisions are useful for offering succinct and insightful descriptions of the data, ensuring that all business users can be involved in the review of the company concerning any smart operational graph uses [6, 50].

4.2.3. The impact of DT applications on MA(MA) practices

In recent years, digital technologies have significantly raised the expectations of how companies are managed in practice. Digital technologies have played a crucial role in decision-making in organizations, such as intelligent data analytics, artificial intelligence, cybersecurity, blockchain, and the Internet of Things. Lately, digital twin applications work by integrating most of the other digital technologies efficiently [51].

A digital twin provides a model of the actual system to help achieve goals such as better understanding, interpretation, prediction of outcomes, and detection of system problems, among others. There is still an opportunity to investigate the potential of digital twins for practices in helping organizations achieve their strategies. It is also important to identify whether these advances work for MAs and enable them to act in areas of appropriate complexity [26].

Management accounting (MA) is a vital discipline that plays a significant role in organizations by providing a well-structured framework of practices and processes to handle economic information. With the ever-evolving business landscape, MA needs to constantly adapt and embrace various emerging trends. This includes keeping pace with mixed economics, digitalization, and the integration of new technologies. Recently, the impact of information technologies (ITs) on MA practices has gained significant attention. However, a limited number of studies have specifically delved into the influence of digital technologies on MA practices. These technologies include big data, the Internet of Things (IoT), artificial intelligence (AI), and digital transformation (DT) [21].

There is remarkable evidence of the impact of the new technologies on MA practices; for example, the advent of big data has revolutionized how organizations gather and analyze vast amounts of information. This has subsequently fueled the need for MA to adapt its practices to effectively capture and utilize such data. The IoT has further augmented the role of MA by connecting various devices and enabling real-time data collection. This interconnectedness enables a more comprehensive understanding of organizational processes, leading to enhanced decision-making [52].

AI, with its advanced algorithms and machine learning capabilities, has introduced automation into MA practices. This has resulted in increased efficiency and accuracy in tasks such as financial analysis, forecasting, and budgeting. Additionally, AI-powered systems can provide valuable insights by analyzing complex data sets and identifying patterns that may go unnoticed by human personnel [1, 15].

Since DT applications are defined as a combination of many digital technologies that are efficiently integrated, such as big data, AI, remote sensors, and IoT, it is expected that they can develop MA practices and functions to support data-driven decision-making. Based on our discussion, the MA senior stated that there are key advantages of DT implementation and its impact on MA practices, as it could lead to new, profound applications. Deep integration of both systems aims to generate synergies of benefits such as holistic process understanding, synchronized views of the real system, centralized control of actions, adequate value assessments for coercive decisions, and up-to-date knowledge usage. However, the simultaneous multiplicity of applications can reveal inconsistencies and cause significant challenges that need to be addressed and developed to achieve the target benefits.

It is obvious that digital transformation continues to shape the business world, and MA is not immune to its effects. Integrating digital technologies into every aspect of organizations has ushered in a new era of data-driven decision-making. This necessitates a shift in MA practices towards a more proactive and strategic approach, where real-time data analysis and predictive modeling are leveraged to drive business growth [53].

Academically, little understanding exists of the potential of new technologies within existing MA practices. The lack of research in the field of digital technologies, especially DTs and their implications on MA, creates a conceptual gap between the two important disciplines driving the development of an organization. As organizations strive to succeed in the digital era, accounting research should address challenges to the future of management accounting [45, 54].

4.2.4. Opportunities Of Digital Applications to Support Competitive Advantage

Currently, tremendous technological innovation has been ignited, which offers significant opportunities and new challenges to the world's business industries. It includes unfolding the transformative power of artificial intelligence, the Internet of Things, big data, cloud computing, digitalization, and mobile technology. These significant advances enable businesses worldwide to invest in and invent the digital combination of skills and knowledge for data-driven value creation. It leads to dramatic changes in business characteristics and can reinforce industry competitiveness. The response of the operational senior on this point.

Consequently, the business can gain digital innovation, which leads to the next industrial revolution. The ongoing advancement of digital information technology has encouraged businesses to transform their value creation model to create higher value. The digital transformation encompasses sophisticated digital infrastructure that allows companies to trial new and innovative experiences to access digital business competition. The data-driven economy is described as an ecosystem that exploits data to create value that derives a competitive economic advantage to benefit society's business value. The data-driven economy offers shattering economic implications, generating higher minimum productivity while driving sector shifts and business transformation. It also includes a paradigm shift in the exchange of outcome knowledge while the entire business collapses due to digital innovation [55, 56].

It is critical for companies embarking on a digital transformation journey to understand and leverage competitive advantage. By identifying their differentiators, aligning with customer needs, embracing digital technologies, collaborating with partners, and fostering a culture of continuous learning, organizations can position themselves for success in the digital age [20, 57].

4.2.4.1. Identifying competitive advantage

The first step in leveraging competitive advantage is to identify what sets the business model apart from others. This could be a unique product or service, a strong brand reputation, proprietary technology, a highly skilled workforce, an innovative mechanism to reduce costs while maintaining high quality, or a focus on a specific customer segment with unique services, sales, relationship management, etc. For example, Apple's competitive advantage lies in its ability to create innovative, easy-to-use products that seamlessly integrate hardware, software, and services. By understanding and leveraging this advantage, Apple has been able to maintain its position as a market leader in the digital age [23, 58].

4.2.4.2. Align with Customer Needs

To fully leverage competitive advantage, it is essential to align with the evolving needs and preferences of your target customers. This requires a deep understanding of their pain points, desires, and expectations. By staying abreast of customer feedback and market trends, businesses can adapt their strategies and offerings to meet these evolving needs. For example, Netflix recognized the shift in consumer behavior toward online streaming and invested heavily in developing a robust digital platform. This strategic move allowed them to gain a competitive advantage over traditional video rental stores and dominate the market [30, 59].

4.2.4.3. Embrace Digital Technologies:

Digital transformation inherently involves leveraging technology to gain a competitive advantage. This could include adopting advanced analytics, artificial intelligence, cloud computing, Internet of Things (IoT) solutions, and digital twinning. By adopting digital technologies, businesses can boost operational efficiency, improve customer experiences, and drive innovation. Take Amazon, for example, which has revolutionized the retail industry by leveraging advanced analytics and machine learning algorithms to personalize product recommendations and streamline its supply chain operations [60].

4.2.4.4. Collaborate with partners:

In the digital age, collaboration is key to unlocking competitive advantage. By forging strategic partnerships with complementary companies, organizations can leverage each other's strengths and capabilities. This could include partnering with technology providers, startups, or industry experts to drive innovation, expand market reach, or enhance customer experiences [61].

4.2.4.5. Continuous learning and adaptation:

It's important to recognize that competitive advantage is not static but rather a dynamic concept that requires continuous learning and adaptation. The digital landscape is constantly evolving, and companies must remain agile and proactive to remain competitive. This includes investing in ongoing employee training and development, staying abreast of emerging technologies and industry trends, and fostering a culture of innovation and experimentation [32].

4.2.5. DT and MA are Important in the Strategic Thinking Toolkit for Two Main Reasons

The potential of digital twins as a decision-making tool: Digital twins can help organizations better understand their physical systems, enabling them to make evidence-based decisions. By simulating scenarios and predicting outcomes, digital twins can help organizations improve their operations and prepare for the future.

The impact of digital twins on innovation and efficiency: Digital twins can facilitate innovation by enabling organizations to test new ideas and technologies in a virtual environment. They can also improve efficiency by reducing the need for physical testing and enabling real-time adjustments to systems [50, 62].

4.2.6. Determinants of Competitive Advantage Support from DT–MA Integrated Perspective

The environment of DT applications and MA-involved practices can provide companies with a significant competitive advantage, Ukko et al. [20] in multiple ways, including:

- Improved operations: Digital twins enable real-time monitoring and analysis of physical assets and processes. This continuous monitoring allows for rapid identification and resolution of anomalies, reducing downtime and improving operational performance.
- Predictive maintenance: By predicting when equipment or systems are likely to fail, digital twins enable companies to implement proactive maintenance strategies. Not only does this reduce the risk of unexpected failures, but it also extends the life of assets, resulting in cost savings and improved reliability.
- Enhancing Product Development: In product-centric industries, digital twins support the entire product development lifecycle. From design and prototyping to testing and iteration, companies can use digital twins to create and improve products more efficiently, reducing time to market and ensuring higher quality [63].
- Improving Decision-Making: The comprehensive insights provided by digital twins help decision-makers make informed and strategic choices. Whether it's optimizing processes, allocating resources, or responding to market changes, companies can act with greater confidence and speed.
- Reducing Costs: With data-driven insights, companies can identify areas of waste, duplication, or inefficiency, leading to cost savings. Predictive analytics also helps optimize resource utilization and reduce unnecessary expenses.
- Innovation and Agility: Digital twins facilitate experimentation and innovation by allowing companies to simulate different scenarios without impacting the physical environment. This fosters a culture of continuous improvement and adaptation to changing market conditions.

4.2.7. Key findings

The current article highlights the growing adoption and application of digital twin technology in various sectors in Saudi Arabia, with a particular focus on the implementation and benefits of digital twins at Saudi Aramco. It also explores the potential impact of digital twins on management accounting practices and their role in supporting competitive advantage, as shown in Table 2. The current study emphasizes the need for further research and understanding of the integration between digital technologies and management accounting disciplines.

Table 2.
Key findings.

Key Findings	Finding	Implication
1. Awareness and Adoption of Digital Twins	Digital twin technology is at varying stages of maturity and adoption across different industries in Saudi Arabia.	Increased investment and support from the government and universities can accelerate adoption.
2. Applications of Digital Twins at Saudi Aramco	Saudi Aramco has implemented digital twins for various applications, enhancing operational efficiency.	Other companies can learn from Aramco's experiences to implement similar technologies.
3. Integration with Management Accounting (MA)	Digital twins can significantly impact MA practices by enabling data-driven decision-making.	There is a need to address the conceptual gap in understanding digital twins within MA.
4. Opportunities for Competitive Advantage	Digital twins offer opportunities for businesses to transform value creation models.	Companies should align digital strategies with customer needs and foster a culture of continuous learning.

5. Conclusion and Implications

The exploratory study, as well as the qualitative case study, revealed useful insights about DT applications and their impact on MA practices to support competitive advantage in the Saudi Arabian context. The evidence from Aramco corporate indicated that they heavily invested in digital transformation technologies to benefit from them in real-time available about assets maintenance, operational process, supply chain, and other variables influencing the corporate strategies and performance, in the same context, the corporate case just started in 2023 to deploy the digital twin with many applications in cybersecurity, production processes, and maintenance, these applications created a new era of data-based decision making including data-based state prediction, multi-scale digital synchronization, intelligent equipment health status, and intelligent state transition management [64]. Despite significant advancements in mathematical statistics, computer vision, learning theories, and cognitive analytics, the current conceptual operation and advantage optimization that DT applications can provide to make predictions and forecasting remain uncertain and not systematically organized.

This study brings to light the level of awareness and application of Digital Twins in the Saudi environment, with a particular focus on distinct applications. It investigated how applications of Digital Twins assist practices in specific aspects of competitive advantage. Furthermore, it evaluated the impact of applications of Digital Twins on MA analytics that support data-driven decision-making. The findings reveal that there is a relatively good level of awareness and application of Digital Twin technology in Saudi organizations. Companies recognize the superiority of Digital Twin technology over conventional implementations, particularly in supporting smart manufacturing, smart cities, and the Internet of Things (IoT). However, most companies have little or no knowledge of the concept. Moreover, although referred to as its initial stages, large manufacturing industries, the energy and utility sectors, companies in the telecom industry, and large-scale transportation are already using some form of Digital Twin applications. Other industries lag far behind [35, 59].

The research contributes to academia by enhancing the body of knowledge in understanding how applications of Digital Twins can assist MA analytical relevant practices needed to formulate the value-added strategies that achieve competitive advantages, however, there is a very large gap to be filled by future studies about this topic, since the concept and scope of digital twins is combined of several interacting technologies such as big data, remote sensors, AI, IoT, and the prior studies in the domain of the impact of digital transformation on management practices focused only on the impact of only one of these technologies mentioned above on MA practices, and a lot of evidence is provided about the advances and the developments in MA analytic practices as a result of the integration with one digital application, so the interaction and the integration between many technologies in the same time as in the digital twin, need to be deeply studied and evaluated practically in various application environments to define the challenges and barriers, and its impact on MA practices as it is complex model based on huge unstructured data [11].

The findings of this research are subject to limitations as they are applied to a single company in the energy sector. The case company is one of the leading worldwide energy producers, with the highest production capacity and advanced strategies. This may translate into less uncertainty and less pressure from changes such as competition, customer preferences, and others. These circumstances present a special case. Hence, the findings cannot be generalized. Thus, future research can examine the association between the current study variables with wide-scale applications, different approaches, and in various contexts to enrich the findings.

6. Future Research Venues

The conclusion emphasizes the necessity for further exploration of the research topic, particularly in the context of different implementations of similar practices across various organizations. It suggests that the academic and professional communities engage in discussions regarding the benefits and drawbacks of DT applications and MA practices to support competitive advantage. Additionally, it highlights the challenges encountered in these implementations, advocating for a deeper investigation into the experiences of firms that have adopted these technologies over time. There is a call for more evidence and analysis to better understand the diverse approaches and business models that have emerged, which could provide valuable insights for financial and investment management.

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