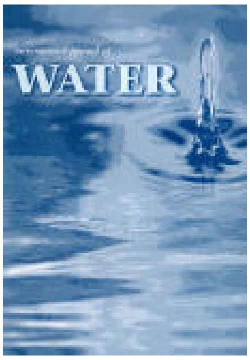

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Water management technologies using Industry 4.0 tools

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Abstract: The fourth industrial revolution facilitates the realisation of integrated ICT technologies as tools for water management. The key challenge is the design of the multilayer network, including enterprise (and in some cases inter-enterprise), operational level (known as the manufacturing execution systems), and the sensor network (known as the control network). The secondary considerations are the testing and integration of a variety of technologies into this network. This paper proposes a global best practice, a hierarchical network of systems for data optimisation and total digitalisation of the water sector. This provides for technology integration by testing and integrating three control network systems integrated into the multilayer network. The system impacts, data impacts, and overall business automation as a result of the integration of automated data are illustrated as results. The digital impacts of the technologies are modelled and illustrated as outputs.

Keywords: digital; fourth industrial revolution; water resources planning; water management; optimisation; water; smart planning.

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His research projects strive to unearth technologies and implementation methodologies that enable the digitising of the technologically challenged industrial and mining sectors.

1 Introduction

The water services sector is complex, crucial, and a contributor to the growth of any economy (Lombardi et al., 2019). Multifaceted, complex issues such as ageing infrastructures, urbanisation, resource constraints, climatic changes, and technological advancements have influenced and affected the water sector. The interest in planning and managing water resources has significantly increased over the last decade with an increasing rate of research that significantly impacts customer satisfaction levels. Water resources incorporate complexities such as "miscommunication; disruptions in data; inaccurate demand forecast; obsolete and excess inventory, real-time value capacity; independent orientation; costly, and effective tracking". Water resource planning and management encompass a wide diversity of structures and strategies aimed to conserve, and balance demands inclusive of social, financial, economic, and environmental impacts (Groenfeldt, 2019). Water resource planning and management have been affected by unpredicted events influencing productivity, sustainability, and profitability. This is especially evident in the urban areas as a result of continuous migration consequently increasing demand (Atkinson et al., 2019). Conventional water resource planning and management interventions that include qualitative and quantitative approaches are not sustainable. Stakeholders are interested in sustainability strategy measures suitable to mitigate impacts caused by the related risks. Current best practices relating to water resource planning and management advocate for instantaneous or proactive decision-making promoting the need for a Digitalised Water Management Model (DWMM) to address associated risks.

1.1 Research objective

This paper propositions a smart and sustainable approach to water resource planning and management by developing a DWMM suitable as a decision-making tool in real-time. The DWMM developments are achieved with the tools provided by the Fourth Industrial Revolutions (4IR).

2 Literature review

Several authors argue that the robustness of the 4IR results in a paradigm shift for digitalisation and automation of systems for easy decision-making (Vaidya et al., 2018). The intricacies of this paper are addressed with emphasis on the tools of the 4IR. The inception of the 4IR is necessitated by the desire for greater productivity and sustainability (Dalenogare et al., 2018). The 4IR context evolved in Europe predominantly in Germany around 2011 as a tactical business innovation that offers a greater demand for effective business integration, management, and growth (Liao et al., 2017). The advancements offered by related technologies of the 4IR inform its application to develop an integrated DWMM (Oztemel and Gursev, 2020). The technologies, tools, and approaches that fall within the 4IR spectrum as detailed in the literature (Oztemel and Gursev, 2020; Zaidi et al., 2018) include cyber-physical systems (CPS), Internet of Things (IoT), machine learning (ML), Internet of Services (IOS), big data analytics, cloud computing, and service-oriented computing. These tools facilitate smart and sustainable water resource planning and management.

The 4IR technologies are numerous, motivating the research team to classify for this investigation with emphasis on its ability to:

- digitally model the water resources (end-to-end modelling and integration)
- support mathematical techniques and optimisation (proactive and real-time monitoring/control)
- allow the discrete event modelling, interaction, and simulation of each element.

Several publications provide insights into applications of 4IR tools for business integration and automation in the health, automotive, robotic, and manufacturing sectors (Nikolakis et al., 2019; Wang et al., 2015; Chen et al., 2012; Lee and Sokolsky, 2010; Cardenas et al., 2008). 4IR tools provide a confluence between water resources and digitisation. Conducting an extensive review of established literature, not a single publication attempts to plan and manage water resources under applications of the 4IR tools.

The proposed DWMM consists of crucial elements that enable effective planning and management of water resources. An initial desktop review highlights business processes (activities in a water network) and variables as the crucial elements that capture all key protocols in a water network. Business processes are a sequence of structured activities executed by humans or machinery (Chofreh et al., 2016). Variables describe the factors with significant impacts on the effective planning and management of interrelated activities.

The literature review is structured with an emphasis on 4IR enablers, water resources (business processes and variables), digitisation, and business modelling.

2.1 Industry 4.0 enablers

The Industry 4.0 enablers are suitable to integrate water resources for smart and sustainability interventions. The enablers are a collection of predictive drivers unified to represent the physical world and suitable to change a business logic (Nikolakis et al., 2019). Literature details the key enablers to include integration, virtualisation, decentralisation, and real-time capability (Lee et al., 2015). The proposed DWMM is developed with the 4IR enablers as a theoretical basis that serves as predictive and operational drivers. Predictive drivers are crucial in investigative analytic research (Tett et al., 1991). The applications of the 4IR enablers for business digitalisation, planning, integration, and management are evident across the literature as captured in Table 1.

Table 1 Applications of 4IR tools

Authors	*Descriptions*
Wang et al. (2015)	The authors demonstrate the applications of 4IR tools in manufacturing for implementing cyber-physical production systems (CPPS) in process control and automation
Nikolakis et al. (2019)	The authors propose and discuss an approach for safe human-robot integration in a shared workplace, highlighting the value add of 4IR tools for effective digitalisation
Chen et al. (2012)	The authors discuss a detailed desktop study of the 4IR technology applications based on its capacity to provide intelligent and digitalised services driven by smart devices, enormous wireless networks, and knowledge from the surrounding physical world
Cardenas et al. (2008)	The authors advocate for the integration of computing and communication capabilities with control, planning, management, and digitalisation of entities in the physical world driven by protocols of the 4IR tools
Lee and Sokolsky (2010)	The authors discuss the opportunities offered by the 4IR technologies towards increasing reliance on software to deliver innovative functionalities, critical integration of medical networks, and broader use of network connectivity in a member of the college of physicians and surgeons

Source: Extracted from authors captured

2.2 Water resources

Water resources can be represented as business processes (activities in a water network) and quantified by variables. The water resources are crucial elements of the proposed DWMM and are suitable to model and represent real-world water resource implementation (Zheng, 2012). The business processes are sequentially connected and suitable to indicate distinct physical activity in the water value chain and collaboratively represent all operations conducted in the business.

The business processes are enabled via three control network systems and constitute a succession of activities in a network from the planning, operations to the control floor (Chofreh et al., 2016). The Purdue reference model (Williams, 1994) propositions the enterprise resource planning (ERP), manufacturing execution systems (MES), and plant elements network (PCN) as the current network of systems applicable to enable the activities in a network.

The research team propositions the water network of systems to function concurrently with integrated applications and tools that connect, manage, automate, and control the water resources. Each network of the system covers all levels obtainable in a modern business ranging from strategic, management, operational, and control protocols. Each network of system functions across business levels detailed from the Purdue reference model as:

- *Level 0* (*Business area*): High-level tasks capturing the core functional domain of the water network.
- *Level 1* (*Process group*): Logical flow of tasks belonging to the same domain of functionalities.

- *Level 2* (*Business process*): Consists of sub-activities combining business-oriented steps to a unit.
- *Level 3* (*Process variant*): Comprises key events of each business-oriented step aggregated in a unit.
- *Level 4* (*Task*): Activities accomplished by a single individual and connected to a single functional domain.

The business processes are often extracted in a repository deploying tools such as Accuprocess Modeler, Metastorm provision BPA, Savvion process Modeler, iGrafx process, Enterprise Architect, ARIS business architect, Holocentric Modeler, System architect, Casewise corporate Modeler suite, Lucidchart, Bonitasoft, Lombardi blueprint, Microsoft Visio, Process maker currently dominating in recent research (Murali, 2013). These toolsets are incorporated with different functionalities and are suitable to serve as an analysis structure (Islay et al., 2007).

The water resources constituted as crucial elements of the proposed DWMM support the pre-development (planning), post-execution (monitoring), and workflow analysis (management) for smart and sustainable water management.

2.3 Digital business and technologies for water

The proliferation of sustainable digital technologies has been substantial across businesses globally (Jewitt, 2013). A digital business refers to the leveraging of optimum technologies and data to transform operational practices, innovativeness, and enhance competitiveness (Bharadwaj et al., 2013). The digital agenda fosters improvements in decision-making, communication, efficiency, working conditions, interoperability, security, and productivity (Gray, 2019). This paper identifies and defines benchmarks as captured in Table 2 suitable to measure a business digital drive.

Table 2 Benchmarks to measure digitalisation

Digital benchmarks	*Descriptions*
Ubiquity	Measures the extent to which stakeholders in a business have collective access to digital applications and services
Affordability	Assess the extent to which digital applications and services are valued sufficiently to make it available to all stakeholders
Reliability	Checks for the quality of the available digital applications and services
Speed	Estimate the extent to which the digital applications and services can be accessed in real-time
Usability	Investigates the use of digital applications and services and the interest in the local ecosystem to encourage its adoption
Skill	Assess the ability of stakeholders to incorporate digital applications into the business through continuous training and education

Source: Karim et al. (2012)

The surge in digital applications enabled with 4IR tools is not limited to any business sector rather it cuts across various corporations. Table 3 captures some of these applications.

Table 3 Digital applications enabled with 4IR tools across business sectors

Sectors/Authors	*Descriptions*
Healthcare/ Baines et al. (2020)	Real-time implementations, detection, and treatment of patients deploying sensors and data analytics tools that improve diagnoses
Automotive/ Bysko et al. (2018)	Real-time preventive analytics enhancing operations, purchases, inventories, and client experiences
Banking/ Mekinjić (2019)	Real-time fraud detection, identifying investment opportunities, and classifying high-risk profiles using cyber-surveillances
Marketing/ Ardito et al. (2019)	Real-time taxonomies of price fluctuations, customer experiences, and product recommendations
Petroleum/ Stokkeland (2019)	Real-time data analytics of operations to save costs, time, and improve safety
Manufacturing/ Frank et al. (2019)	Changes and improves product and value chain design, usage, and services
Transportation/ Ivanov et al. (2019)	Real-time prediction of climatic conditions, price, and potential failures delivering effective route management and services
Agriculture/ Trivelli et al. (2019)	Real-time plant and animal management based on historical trends of climatic conditions, price, irrigation systems, and soil moisture
Education/ Coşkun et al. (2019)	Real-time and personalised learning applications and platforms that improve teaching efficiency, scheduling, and management

Source: Extracted from authors captured

The water sector has keyed into the robustness of the digital applications and achieved advanced levels of digitalisation over the years by deploying sustainable technologies. Digital technologies have changed the way operational practices are conducted (Xu et al., 2018). This paper propositions similar applications captured in Table 3 to develop a DWMM. Several applications of Artificial Intelligence (AI) are visible in the water sector for smart and sustainable water management as detailed in the literature (Weisbord, 2019) and captured in Figure 1. AI is a transformation in the 4IR technology that demonstrates the intelligence of machines in contrast to human intellect (Kamaruzaman et al., 2019).

Figure 1 Current applications of AI in the water sector (see online version for colours)

Source: Weisbord (2019)

2.4 Water model

Modelling of business structures, processes, and strategies for current and future evaluation of operational practices has improved significantly in recent literature from business practice, academia to researchers. Business process modelling is an effective approach for extracting, developing, and identifying improvement opportunities (Bocken et al., 2013). A business process model elaborates where and how the activities in a business can be effectively optimised (Geissdoerfer et al., 2016). An effectively developed business process model facilitates a structure for detailing, analysing, and presenting improvement prospects of operations (Massa and Tucci, 2013). The innovative advancements offered by business process models inform the research team to employ a DWMM in configuring crucial elements of a water network for smart and sustainable planning and management of water resources (Kastalli and Van Looy, 2013).

3 Research method

This paper propositions a smart and sustainable approach to water resource planning and management driven by the 4IR tools with a focus on the development of a DWMM. The DWMM is predictive and constituted based on a mixed research method. The suitability of the mixed-method approach in developing business process models is detailed in the literature (Spiegel et al., 2016). The mixed-method approach adopted in this research combines both qualitative and quantitative approaches for data collection, analysis, and research (Creswell and Creswell, 2017). The research team employs the mixed-method to identify and develop suitable elements of a DWMM for smart and sustainable water resource planning and management. The mixed research method adopted, to address the objective of this paper, is segregated into approaches detailed in steps below:

3.1 Develop a database for water as a business

The water value chain operations referred to as business processes are sequentially connected and suitable to indicate distinct physical activity in the water network. The constituted business processes collaboratively representing all operations conducted in the business are captured in a suitable repository to form an integral element of the proposed DWMM. The literature review section indicates business processes can serve as a suitable model to represent a business. The business process development initiates from level 0 and expands into level 4. The definition of each business process level is detailed in the literature review. The water value chain operations across each level are extracted from (APQC, 2015; ISA, 2000) and modelled using the Microsoft Visio tool. Based on an extensive evaluation based on criteria detailed in the literature (Medoh and Telukdarie, 2017; Murali, 2013; Islay et al., 2007), the research team selects the Microsoft Visio tool and Accuprocess Modeler for investigations. The criteria include cost, availability, support and maintenance, functional requirements, active content, general features, training, technological requirements, version control, integration, reference sites, and user interface.

3.2 Develop a database for predictive model via simulation

Simulation is a stochastic optimisation approach that describes the approximate imitation of real-world operations, processes, and systems over time in a controlled environment such as a model. The suitability of the simulation to develop a predictive model is detailed in the literature (Jia et al., 2016). The modelled business processes from a previous step are developed into a predictive model with the Accuprocess simulation toolset. Key considerations in developing a predictive model via simulation are crucial resources essential to execute each business process activity.

Variables: Each task in the water value chain is influenced by factors such as people, environment, cost, escalation, energy, turnaround time, and automation systems. The variables enable a quantification basis to test and validate the impacts of the model.

Decision nodes: Some activities in the configured water value chain require countless decision-making resulting in decision blocks requiring multiple pathways or interdependencies. Decision nodes determine the business process step execution path. To address the unpredictability of the decision nodes, each decision block is randomised via simulation resulting in multiple pathways of the flow of activities in the comprehensive business processes. The randomness of decision nodes is conducted until a negligible change in the standard error mean. This resource captures the comprehensive business processes in its real-life practical state enabled with continuous changes.

Numeric metrics: Each factor is assigned a numeric metric (unit cost and people count) defined based on the average hourly rate obtained from (payscale.com/research/ZA/Job).

3.3 Conduct impact analysis

To quantify the impacts of the proposed DWMM, the resources detailed above are captured in the simulation model via distinct activity with each resource configured. The databases detailed are crucial indicators for comparative analysis and to quantify the impacts of the proposed DWMM. The DWMM development in the simulation model concludes the methodology and delivers a model capable of proactive functionalities and quantifying the impacts of change. The results of the DWMM seeks to demonstrate the suitability and sustainability to quantify and predict optimum solutions of the different investigative scenarios. The outputs aim to stimulate and validate the usefulness of the DWMM as a 4IR toolset suitable to represent the water sector and applications for effective water resource planning and management. The optimum solutions obtained from the impact analysis are segregated into:

- *Cost impact analysis*: Conducts a run cost graph measured in minutes based on maximum, average, and minimum usage.
- *Time impact analysis*: Conducts a run time graph measured in minutes based on maximum, average, and minimum usage.
- *Resource utilisation impact analysis*: Conducts a worker average utilisation (%) run graph.

Where “Maximum = Maximum cost/time among all runs”; “Average = Cumulative cost/time divided by the number of runs”; and “Minimum = Minimum cost/time among all runs”.

4 DWMM developments

Developing and navigating a DWMM is quite a complex activity. The proposed DWMM is suitable to effectively streamline, improve interactions, and operational practices of the water resources. The DWMM offers a water resource planning and management solution that suitably demonstrates the correlation between related water resource elements.

4.1 Develop a database for water value chain activities

The International Water Association (IWA) details the system input volume of revenue and non-revenue international standard water balance. Table 4 captures each international standard water balance indicator adopted from the literature (Kanakoudis et al., 2012).

Table 4 System input volume for international water balance

System input volume	Authorised use	Billed authorised use	Billed metered use	Revenue water
			Billed unmetered use	
		Unbilled authorised use	Unbilled metered use	Non-revenue water (real losses)
			Unbilled unmetered use	
	Water losses	Apparent losses	Unauthorised use	
			Customer meter inaccuracies and data handling errors	

Source: Kanakoudis et al. (2012)

Comprehensive aspects of the water value chain activities should be considered in constituting a DWMM suitable to proactively quantify the impacts of the all-inclusive water value chain in real-time. This includes, human resource, planning, maintenance, administration, quality, value chain, finance, logistics, research, diagnostics, and customer relationship management. The research team develops a high-level database for water value chain activities (Figure 2) with a focus on non-revenue water to present an illustrative investigation for this paper.

The thin slice high-level database (level 0 – level 2) for water value chain activities are extracted from the water systems (ERP, MES, PCN) based on the literature (APQC, 2015; ISA, 2000). The high-level processes across each water management system (ERP, MES, PCN) considered to present a case in this paper are classified into functional domains “Human resources, Logistics (planning), Maintenance, Quality, Finance, and Customer relationship management”.

4.2 Develop a database for DWMM via simulation

The simulation set-up is based on a discrete-event simulation approach. Each operational step in the integrated high-level database specific to non-revenue water (real losses) results in a complex structure with each step having a significant impact on the total non-revenue water management cycle. The simulation database development is facilitated with conditions (factors, decision nodes and numeric metrics). The factors selected for investigation are identified from the literature (Jin and Luo, 2017; Guo et al., 2015; Petro and Gardiner, 2015; Subramanyam, 2012). The literature detailed establishes the efficiency of a business process is dependent on the effective handling of the following factors:

- *Process timing*: Process timing is essentially the total execution time it takes for the singular or collection of activities to be performed.
- *Cost*: The DWMM must support a structure facilitating the execution of the water value chain at a minimal or optimised cost. Cost is estimated in the value of South African Rands (R).
- *Resource utilisation*: The DWMM must support the holistic (integrated) networking and minimal energy/people usage in the water value chain which optimises the resource utilisation of operational practices.

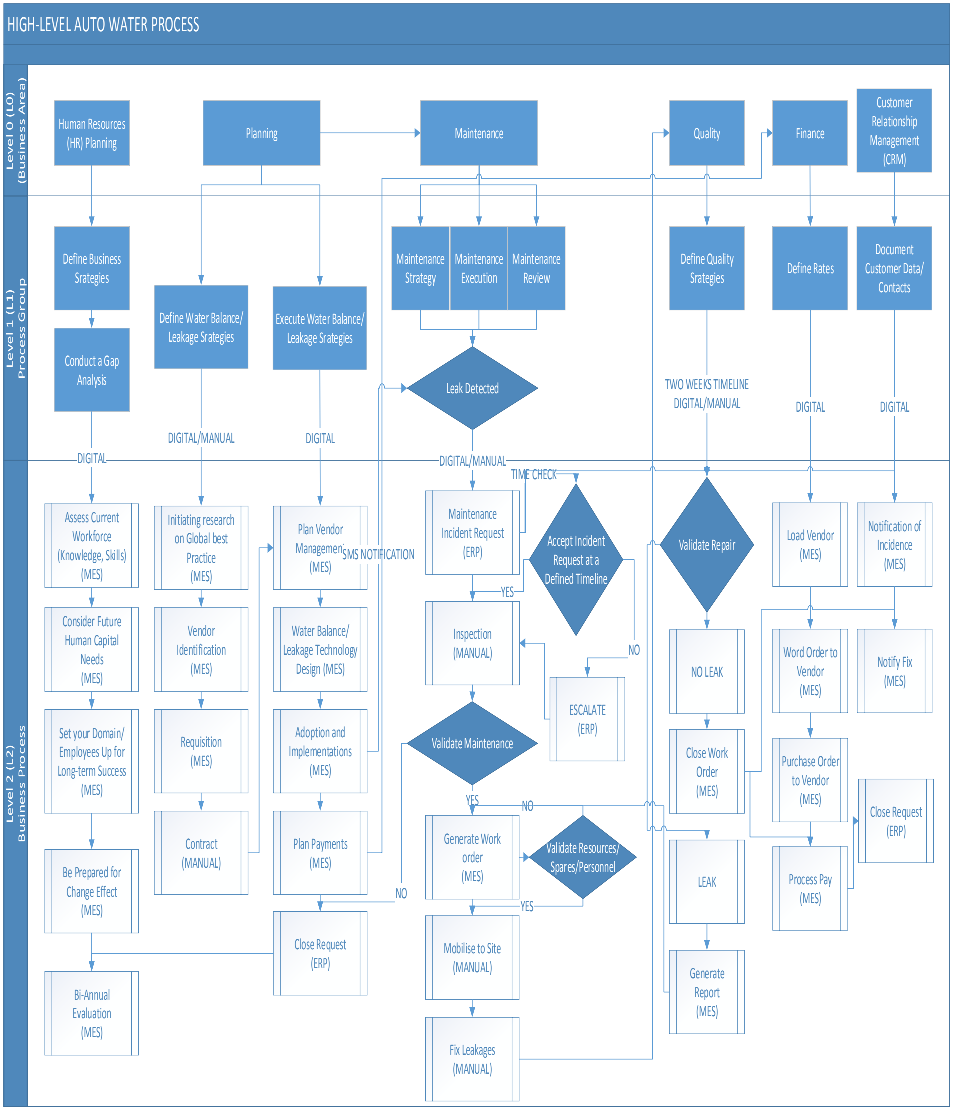
To quantify the impacts of the DWMM in real-time based on the output factors discussed, the simulation approach is used. The simulation steps are detailed.

4.3 Identify resources

Resources comprise a collection of crucial factors that facilitates the quantification of the variables that govern the business process implementations. The functionalities of the resources are dependent on the instructions assigned. Table 5 defines the following resources that facilitate the simulation database developments based on the assumptions that:

- A large business with an estimated 500 employees spends an average of R 450 per employee monthly for office supplies (bizjournals.com).
- An average cost to rent an 8259+ sq ft suitable to accommodate 100+ employees is R 200 per square metre estimated at R 1,650,000 monthly (businesstech.co.za).
- An average cost of R 354,572 for an ERP consultant (payscale.com/research/ZA/Job).
- An average cost of R 530,394 for a Senior Business Analyst (payscale.com/research/ZA/Job).
- An average cost of R 257,728 for a Big Data SQL Analytics (payscale.com/research/ZA/Job).
- An average cost of R 360,215 for a Financial Expert (payscale.com/research/ZA/Job).
- An average cost of R 323,854 for an Information Technology (IT) Specialist (payscale.com/research/ZA/Job).

Figure 2 High-level steps of the integrated water auto-processes/systems (see online version for colours)



Source: Authors own compilation)

Each business process scenario (impact analysis) is simulated to obtain responses based on the factors and associated numeric metrics highlighted above.

Table 5 Resource set for simulation database developments

Output factors/input factors/definition/numeric metrics					
Cost	Direct resource	The costs are credited based on the execution of a business process step. The direct resources include office supplies incurred by each unit for distinct business process activity. Examples include papers, printers, copiers, etc.	*Item*	*Office supplies*	
			Unit used	500	
			Cost/unit	R 450	
			Total cost	R 225 000	
	Indirect resource	The costs comprise fixed expenses incurred by the enterprise irrespective of the execution of a business process activity. Indirect resources include utilities, rent, and insurance.	Item	Rent	
			Cost	R 1, 650, 000	
			Unit	Month	
	People resource	The costs cover labour expenses incurred based on the execution of a business process step. The people resource include wages, taxes, and salaries.	ERP consultant	5	R 354,572
			Information Technology Specialist	5	R 323,854
			Big Data SQL Analytics	6	R 257,728
			Financial Expert	4	R 360,215
			Senior Business Analyst	4	R 530,394
Process timing	Cost impact analysis		Conducts a run cost graph measured in minutes based on maximum, average, and minimum usage	Distribution	Constant
				Value	2.0
	Time impact analysis		Conducts a run time graph measured in minutes based on maximum, average, and minimum usage	Unit	Minutes
				No of runs	100
	Resource utilisation impact analysis		Conducts a workers average utilisation (%) run graph		
Resource utilisation	Tier 1 escalation rate		Process steps with medium critical factor		1.5
	Tier 2 escalation rate		Process steps with very high priority critical factor.		2.5

4.4 Define timing information

The next step after identifying sets of resources is to assign execution time in each business process step for a distinct impact scenario defined. This includes allocating numeric metrics (cost, escalation potential, critical factors) for each impact scenario to expatiate the method in which the steps will proceed from the queue. A 30 days timing period is propositioned for the water value chain cycle and defined for simulation runs. The research team considers daily estimation insufficient and yearly valuation intense. The constant distribution indicates a constant value ranging over a period.

4.5 Assign probabilities to decision nodes

Probabilities are assigned to each node in the water value chain. To obtain values assigned to each node, the simulation and design of experiments (DOE) methods (Mark and Patrick, 2007) are used. The suitability of the simulation and DOE optimisation method to investigate optimum solutions of differentiable functions is detailed in the literature (Anderson and Mclean, 2018; Weber and Skillings, 2018; Kumar, 2017; Jia et al., 2016). The decision nodes estimate the probability and sequence of flow of an activity in the water value chain occurring. The decision nodes are dependent on the exact business conditions at an instance and complexities in decision-making. The decision nodes are randomised using a random number generator integrated with distribution probabilities such as Poisson, Normal, and exponential algorithms based on a discrete event simulation approach. The discrete event simulation method, which is time-based, dynamic, and supports linear modelling is used to execute a large number of simulations runs resulting in sets of random numbers suitable for each decision node. The baseline random numbers used are defined under constraints "ten discrete-event simulation runs set at a '2σ' (95%) statistical significance". The research team settles for ten discrete-event simulation runs after incremental iterations conducted based on mean analysis of total value chain response time (minutes). The baseline random numbers (%) are integrated into each of the five decision nodes relating to the high-level steps of the integrated water auto-processes/systems captured in Figure 2.

4.6 Define simulation scenarios

A scenario comprises sets of data used for simulation impact analysis based on business states with associated numeric metrics defined. In each scenario defined, business process step(s) can be excluded or included to obtain different statistics.

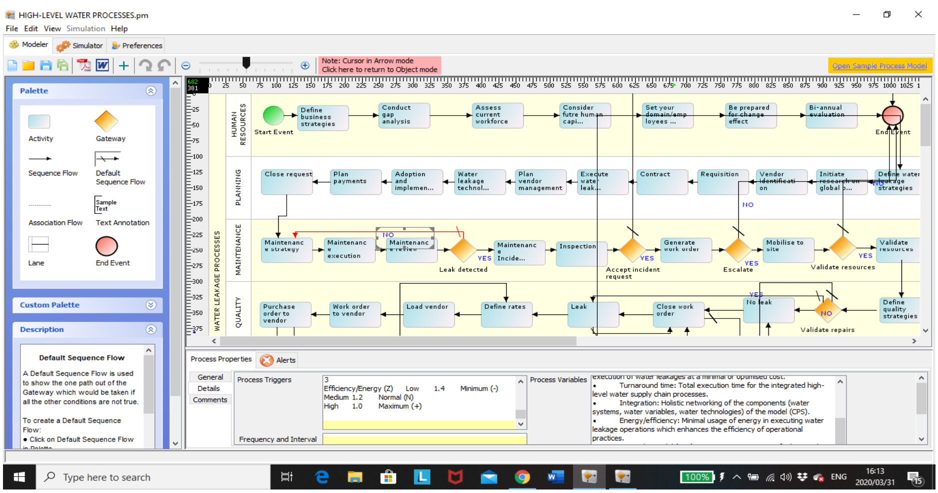
4.7 Analyse the simulation results

At the end of the simulation runs premised on the scenario impact analysis, the simulation results are analysed. Based on the simulation outputs, the DWMM can be improved such as the reassigning of resources, minimising delays, etc. The Accuprocess modeler is integrated with charts such as bar charts for simulation analysis which provides information on counts observed, queue size/processed steps, and resource utilisation. The consolidated outputs detail the cost, time, and resource utilisation impact graphical analysis.

5 DWMM applications

The research team infers from the collective literature reviewed that the most important issues in the water value chain are measures to reduce costs, increase efficiency, integrate and improve business process effectiveness. The Accuprocess Modeler is a suitable tool for capturing the business processes enabling the current processes to be analysed and potentially offer greater capabilities and improvements for the future. The High-level steps of the integrated water auto-processes/systems captured in the Accuprocess Modeler simulation tool are illustrated in Figure 3.

Figure 3 High-level steps of the integrated water auto-processes/systems captured in Accuprocess Modeler simulation tool (see online version for colours)



Source: Authors own compilation

The Accuprocess Modeler provides a simulation framework for an in-depth analysis of the factors identified which has significant impacts on the effective implementations of the water value chain. The impact analysis is segregated to understand the total expected business process performance based on the overall water value chain that includes:

- to quantify the average, minimum, and maximum cost of executing a process step in the water value chain
- to quantify the average, minimum, and maximum possible process timing in executing a process step in the water value chain.

To quantify resource utilisation which includes identifying bottlenecks in executing a process step in the water value chain. The bottlenecks include where the process step slows down in the comprehensive workflow.

5.1 Cost impact analysis

The resource set identified for cost impact analysis is based on high-level steps illustrated in Figure 3 and the cost input factor associated with numeric metrics detailed in Table 5. Figure 4 captures a thin slice of the resource set where:

- Unit cost refers to resources per unit applicable for direct resource only.
- Count indicates the number of workers applicable to people resources only.
- Cost per person denotes the cost for a single worker applicable to a single resource only.
- Usage unit indicates the duration of the cost per worker applicable to people resources only.

Figure 4 Thin slice resource set for cost impact analysis (see online version for colours)

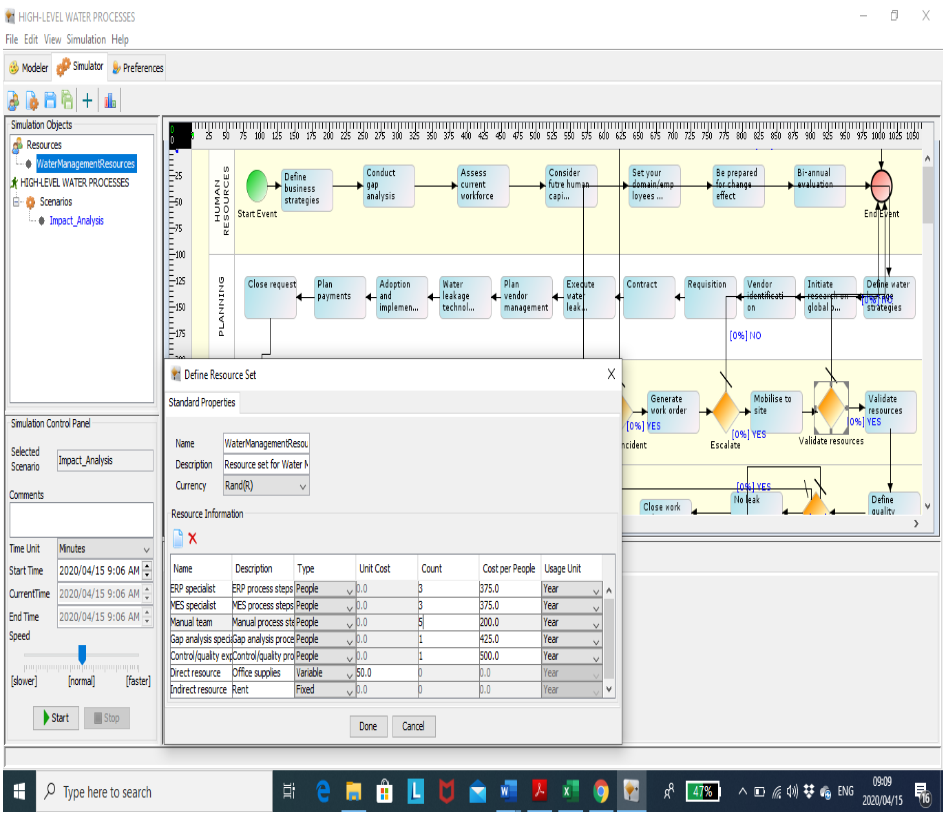


Table 6 captures the run cost data obtained from the cost impact analysis.

5.2 Time impact analysis

The resource set identified for time impact analysis is based on high-level steps illustrated in Figure 3 and time input factors associated with numeric metrics detailed in Table 5. Figure 5 captures a thin slice of the scenario set.

Table 6 Run cost data

Activity	*Average people cost*	*Maximum people cost*	*Minimum people cost*	*Total people cost*
Enterprise resource planning	R 166,779.8	R 353,146.5	R 116,518.5	R 16,566,039.7
Information technology protocols	R 151,618	R 321,042.3	R 105,925.9	R 15,060,035.5
Big data SQL protocols	R 120,331.7	R 254,795.5	R 84,068.1	R 11,952,409.1
Financial management	R 151,368	R 213,441.6	R 89,633.6	R 15,203,876.8
Define strategies and conduct gap analysis	R 223,128.3	R766,466.4	R 85,834.9	R 22,340,946.5

Figure 5 Thin slice scenario set (see online version for colours)

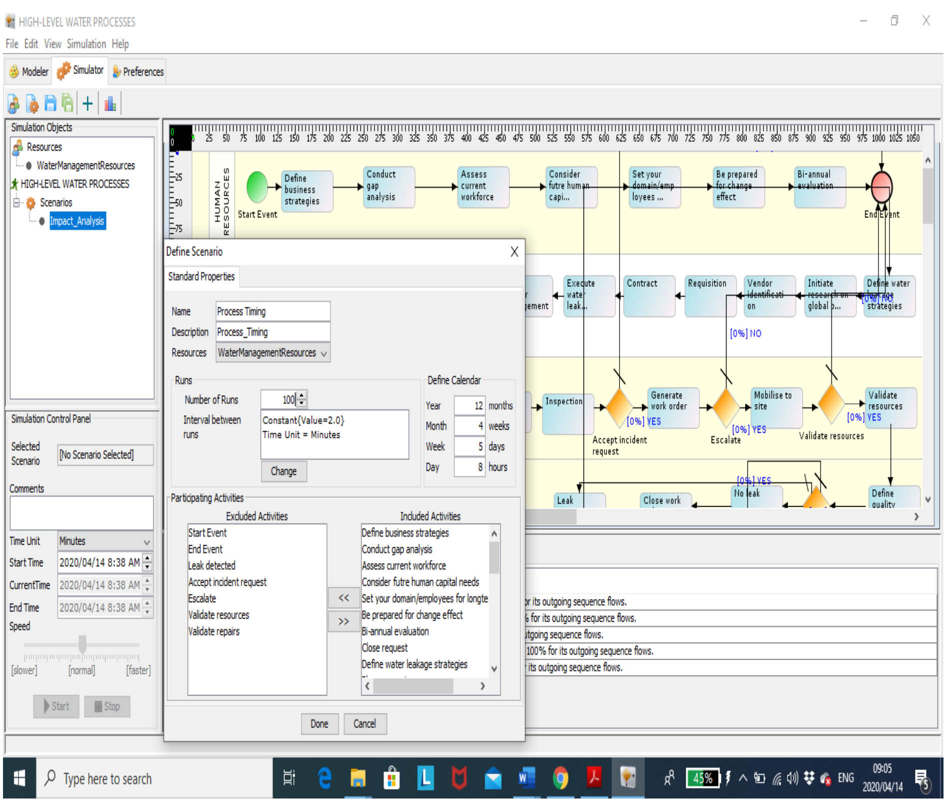


Table 7 captures the run time data obtained from the time impact analysis.

5.3 Resource utilisation impact analysis

To perform a resource utilisation impact analysis, the research team conducts a workers' average utilisation (%) run graph. Table 8 captures the workers' average utilisation (%) data.

Table 7 Run time data

Activity	*Average execution time* (min)
Enterprise resource planning	82.8
Information Technology protocols	110.6
Big Data SQL protocols	137.5
Financial management	33.1
Define strategies and conduct a gap analysis	139.1

Table 8 Workers' average utilisation data

People name	*Count*	*Activity*	*Average idle time* (minutes)	*Average busy time* (minutes)	*Utilisation* (%)
ERP consultant	5	Enterprise resource planning	1734.5	5166.9	57.5
Information technology specialist	5	Information Technology protocols	1221.5	6899.4	71.3
Big Data SQL analytics	6	Big Data SQL protocols	836.6	8343.4	83.4
Financial expert	4	Financial management	3160.4	3306.1	19.7
Senior business analyst	4	Define strategies and conduct a gap analysis	2306.8	4297.9	38.2

To provide a synopsis of the holistic and integrated analysis capability of the DWMM, the research team considers the illustrative impact analysis example above as scenario 1. A second scenario following similar steps discussed above with changes in the number of people count is simulated to obtain the cost, time, and resource utilisation impact analysis. The combined cost, time, and resource utilisation data are captured in Table 9.

Management can deploy the DWMM to view current operational practices facilitating optimum responses at different instances (scenarios 1 & 2). The following deductions are defined premised on the combined cost, time, and resource utilisation data for Scenarios 1 and 2.

i Big Data SQL Analytics resources with the highest number of people count have the highest average busy time. The combined outputs indicate as the number of people counts increases; the average busy time reduces as tasks are completed promptly. However, this results in increased costs. The research team deduces water sectors are optimised using the minimum (if the cost is a priority) and maximum (if the turnaround time is a priority) number of people count to execute the water value chain. The research team infers an average balance of the number of people count to accommodate a mix of priorities as both factors are inversely related or proportional.

ii The Big Data SQL Analytics has the highest resource utilisation (%) with the lowest total people cost. The combined output indicates as the number of Big Data SQL Analytics people counts increases; the average idle time increases while the average busy time decreases. This consequently decreases the resource utilisation (%) with an increase in total people cost.

iii Defining strategies and conduct gap analysis takes longer average execution time. The combined output indicates as the number of people counts increases; this results in a minimal decrease in average execution time. The high average execution time is a result of longer average idle time which indicates an increase in people count does not necessarily result in significant changes.

iv Financial management takes the least average execution time. The combined output indicates as the number of people counts increases; this results in a further decrease in average execution time but with longer average idle time. The research team deduces an increase in people count does not necessarily result in significant changes as the long average time is as a result of this resource being dependent on other resources completing respective activities.

The illustrative impact analysis example indicates the suitability of the DWMM for holistic and integrated modelling of water resources planning and management. The next section expands on the implications of the DWMM.

Table 9 Combined cost, time, and resource utilisation data for scenario 1 & 2

	ERP consultant	*Information technology specialist*	*Big Data SQL analytics*	*Financial expert*	*Senior business analyst*
People count (Scenario 1)	5	5	6	4	4
People count (Scenario 2)	7	7	8	6	6
Total cost (Scenario 1)	R 16,566,039.7	R 15,060,035.5	R 11,952,409.1	R 15,203,876.8	R 22,340,946.5
Total cost (scenario 2)	R 21,238,512.4	R 19,307,737.8	R 15,323,601.4	R 19,492,149.7	R 28,642,239.1
Average execution time (Scenario 1)	82.8 min	110.6 min	137.5 min	33.1 min	139.1 min
Average execution time (Scenario 2)	62.7 min	86.4 min	107.4 min	25.8 min	108.7 min
Utilisation (Scenario 1)	57.5%	71.3%	83.4%	19.7%	38.2%
Utilisation (Scenario 2)	44.8%	55.6%	65.0%	13.6%	29.8%

6 Research implications

This paper complements literature on water resource planning and management by developing a DWMM suitable for total business evaluation. The DWMM developments use 4IR tools and enablers to collaborate crucial elements for implementations of water resources. The theoretical and practical implications of the developed DWMM is detailed.

6.1 Theoretical implications

Water sectors focus on sustainability and improving competitiveness are aligning resources with opportunities provided by industry 4.0. Increasing publications emphasise the need for fully integrated operational processes when aiming to increase sustainability. This paper provides advancements to the current theoretical basis for capturing and evaluating implementations in water resource planning and management. The DWMM facilitates a holistic and integrated model for total business assessments that provides opportunities for the redesigning and optimising of processes in the water value chain. The theoretical deductions provided by the DWMM facilitate a framework for users to:

- Replicate a holistic structure of a real-world contemporary water sector.
- View, track, and measure the complex interrelationships between crucial elements in implementing the water value chain over time.
- Quantify a mix of optimisation options that enables the lowest operation abstraction with each experimental index (factors and numeric metrics).
- The DWMM is user friendly requiring minimal data inputs and intellectual efforts to evaluate impact analysis in the implementations of a water value chain.
- The DWMM is easily reproducible or modifiable to align with a specific water management value chain providing practical evidence that water resources can be modelled, simulated, and improved in real-time.

6.2 Managerial implications

This paper delivers a DWMM suitable to evaluate total water management implementations. The developments are based on similar model developments detailed in emerging publications but differ in results. The developments comprise crucial elements of the water value chain suitable for impact analysis and to quantify the effects of change. The research team conducts impact analysis of cost, time, and resource utilisation on a high-level water leakage processes as an illustrative example. The DWMM offers a viable analysis tool to assist the water sector to assess current operational implementations in water resource planning and management. Some key managerial implications relating to the DWMM developments are detailed.

- Delivers a tool suitable for total water management evaluation and optimisation with reduced user input requirements, efforts, and time-intensity to quantify change and predict demands in real-time.
- The developments demonstrate applications of Industry 4.0 tools for water resource planning and management advancements.
- *Single point data*: The development complements conventional methods of constituting a DWMM, which offers limited capability for proactive enablement,

monitoring, execution, and management. Dubey et al. (2016) emphasises the benefits of a single data point for ensuring sustainable business management.

- *Total business visibility/digitisation*: The DWMM identifies, defines, and configures a holistic collection of crucial water management elements suitable to facilitate optimum water management implementations. The benefits of overall business visibility/digitisation in model developments are detailed in the literature (Schreck and Raithel, 2018).
- *Effective deliverable timelines*: The DWMM facilitates escalation opportunities, real-time notifications, monitoring, and updates that enhance decision-making with reduced cost.
- *Total optimisation*: The DWMM validates the effectiveness of assuming a holistic and process-centric approach to modelling driven by transformations of Industry 4.0 to collaborate, predict, and ensure the seamless enablement of the water management protocols. The benefits of total business optimisation in model developments are detailed in the literature (Malihi and Aghdasi, 2014).
- *Scalability*: The development demonstrates the optimal effects and interactions of the factors investigated achieved on the viability of the simulation and DOE optimisation approaches.

7 Conclusions and limitation

The DWMM is a constitution of crucial elements that represent physical water management activities tested with viable optimisation approaches. This paper elaborates on the practical and sustainable benefits of providing business solutions based on a systemic, comprehensive, and process-centric approach to modelling. The holistic and integration capability of the DWMM based on enablers offered by Industry 4.0 serves as a theoretical drive in the developments. The testing and validation of the DWMM are based on best practice optimisation approaches that include simulation and DOE methods. The DWMM consists of two important elements that include business processes (activities in the water network) and factors with significant impacts on the execution of these activities. Both crucial elements are demonstrated in this research as essential for impact analysis to quantify the water resource planning and management implementations.

The DWMM represent real-world water resource operational strategies with the elements extracted from an extensive review of relevant and recent literature. The outputs obtained from the impact analysis establish and quantify sensitive changes (maximum, average, and minimum) of each factor impact. The results of this paper assist water management to develop alternative optimum strategies (modelling, holistic assessments, simulation) using the DWMM as guidelines for designing sustainable related water resource planning and management services. The DWMM developments are based on water value chain activities extracted from literature and on reliability testing of numeric values which are sufficient to demonstrate the intent of this paper. Future research considers the on-site practical testing of the DWMM.

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