Closed-loop Supply Chain for Seawater Desalination: A Performance Measurement Model

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Abstract

The expansions of global population, increasing water demand, along with recent climate changes and scarceness of natural water sources, have caused the increment need of seawater desalination worldwide. Much attention has been paid in the water desalination literature to optimize the unit processes of a single desalination plant and its operations. Nevertheless, there are few researches considered evaluating the desalination supply chain as a whole, more particularly closed-loop supply chain. Examining the water desalination process as a closed-loop supply chain allows decision makers to evaluate the performance of water desalination operations end to end. Thus, the purpose of this study is to develop a performance measurement model for closed-loop supply chain in water desalination industry. The research methodology is based on literature analysis concerning performance measurement in closed-loop supply chain to be applied for companies belonging to the water desalination industry. Since the study focuses on a specific industry, this could be seen as a limitation. The proposed model could serve as a reference for the desalination industry to establish applicable performance appraisal indicators. It is believed that both researchers and practitioners would benefit from the model developed.

Keywords
Supply Chain, Desalination, Closed-loop, Performance Measurement.

1. Introduction

Water is one of the most significant substances in earth. Although water covers almost 75 percent of the earth's surface, yet the lack of drinkable water is one of the major challenges to be resolved globally (Al-Nory & Graves 2013). It is essential that the water which people drink and use for different purposes is fresh water. The number of the population who resides in regions where physical water accessibility is restricted, as in arid areas, exceeds 1.2 billion (United Nations, 2015). In addition, the number of the population who resides in regions where they do not have the monetary means to extract an adequate portion of fresh water exceeds 1.6 billion (United Nations, 2015). Therefore, finding an appropriate method to face this water shortage dilemma is critical nowadays.

Desalination has been considered globally as a feasible solution to the scarcity of fresh water shortage problem. Different forms of water, such as seawater, brackish water and ground water, can be pe processed through desalination. The seawater desalination sector has been developing progressively for the recent decades with plenty of additional desalination plants constructed every year. The overall capacity of desalination plants worldwide reached 80.9 million m^3/d by the end of 2013. This showed a dramatic increase since the desalination capacity was appraised by 52.8 million m^3/d in 2008 and only 5 million m^3/d in 1980 (Ghaffour et al., 2013). Furthermore, the overall desalination market surpasses USD 31 billion in 2015 with more than 16,000 desalination facilities worldwide (Menichetti et al., 2019).

The management of supply chain (SC) activities focuses on the question of how best to match supply to demand (McCormack et al. 2008). The value of SC perspective comes from the capability of planning or assessing at a system level rather than at a component or unit level. In essence, the SC perspective aims to go beyond sub-optimization.

Various studies developed performance measurement models for SC in diverse industries such as hospital laboratories SC (Hamid Abu Bakar et al. 2009), construction SC (Wibowo et al. 2015), food SC (Shafiee et al. 2014), dairy SC (Khalili-Damghani et al. 2012), furniture SC (Robb et al. 2008), Pharmaceutical SC (Zarenezhada et al. 2013), and automotive SC (Gopal & Thakkar 2016). In addition, technical, economic, social and environmental performance of different scales of WDSC options such as truck distribution, wastewater treatment, desalination and rainwater tank were investigated in the literature through a range of different quantitative and qualitative techniques (Balfaqih et al., 2016; Shahabi et al. 2014).

Although water desalination industry can take advantage of the developed performance models in supply chain management, the differences between process industry such as water desalination industry and discrete part manufacturing industries creates the need for performance measures specific to the closed-loop of water desalination supply chain. Hence, it is indispensable to develop a performance measurement model that can evaluate the performance of the closed-loop of water desalination supply chain (WDSC). This is to guarantee that safe drinking water is provided within an adequate quality and at an appropriate cost through effective and efficient manner.

2. Closed-loop supply chain for water desalination

The fabulous success of supply chain management concept in manufacturing and service industries makes it attractive to be implemented in water desalination industries (Balfaqih et al., 2016). By considering the water desalination operations as a SC, this delivers a comprehensive view, which assist the decision makers to improve the water desalination processes holistically. The closed-loop water desalination supply chain stages, as shown in Figure 1, include:

1. Obtaining feed water and chemicals required for the desalination processes.
2. Desalination operations.
3. Storage of the desalinated water.
4. Fresh water distribution to the customers.
5. Collecting used water for further treatment.

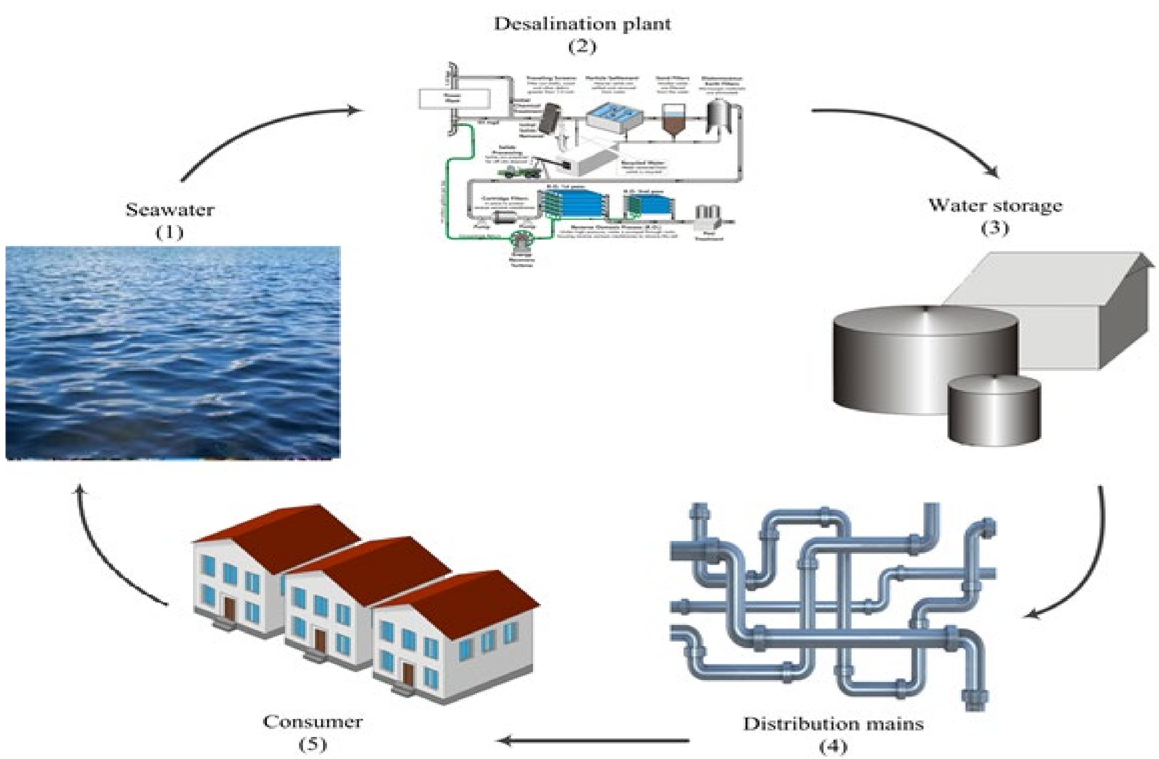

Figure 1. Closed-loop Water desalination supply chain stages

3. Methodology

Exploratory review of the literature was conducted to understand the background of the closed-loop water desalination supply chain and supply chain performance measurement systems. The literature is a source of secondary data and comprises refereed articles, presentations as well as technical and governmental reports (Fink, 2019). The literature review focused on two aspects which are water desalination supply chain and supply chain performance. Thereafter, the collected performance measures and metrics were allocated into the four balanced scorecard model (BSC) dimensions which are the financial, customer, internal processes, and learning & growth as well as the environment dimension since it is essential aspect for the closed-loop processes.

4. Results

After conducting extensive literature review of available performance measures for SC, four perspectives of the BSC model and environment are adopted as the first-level measures of the proposed PMF of WDSC. They are financial, customer, internal processes as well as learning and innovation perspectives. The BSC model was adopted because it guards against sub-optimization. It maintains a balance between short and long terms goals, between financial and non-financial measures, between lagging and leading indicators, as well as between internal and external performance aspects (Hansen and Schaltegger, 2016). Moreover, it allows decision makers to observe whether improvement in one perspective have been achieved at the expense of another perspective or not. The performance measurement model for the closed-loop of water desalination supply chain developed in this study is presented in Figure 2 below.

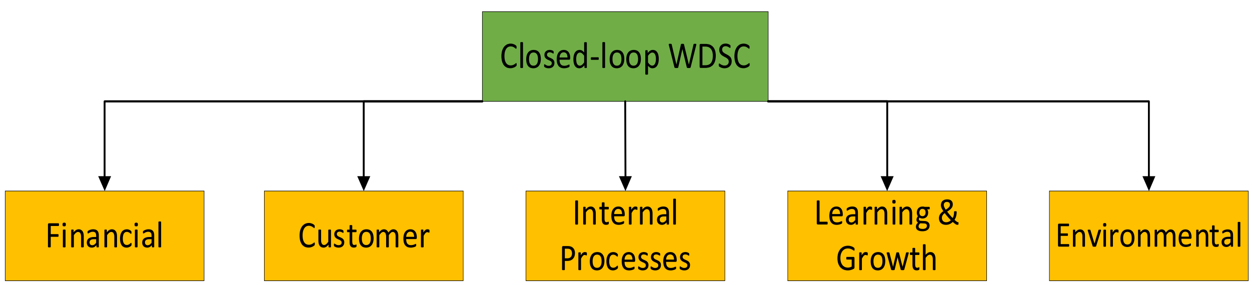

Figure 2. The closed-loop WDSC performance measurement model

4.1 Financial

The financial aspect indicates the strategic goals of an organization and it integrates the tangible outcomes of strategy in traditional financial terms (Kaplan & Norton, 1996). The financial perspectives of the WDSC PMF contains cost, revenue, investment, leverage, liquidity, profitability, average water charges and economic water losses. The proposed performance criteria and metrics for the financial perspective is shown in Table 1 below.

Table 1. Performance criteria and metrics for Financial perspective

Perspective	Criteria	Metrics
Financial	Cost	F1: Depreciation costs (%) F2: Net interest costs (%)

		F3: Internal manpower costs (%) F4: Electrical energy costs (%) F5: Abstraction and treatment costs (%) F6: Transmission, storage & distribution costs (%) F7: Water quality monitoring costs (%) F8: Water recycling cost (%)
	Revenue	F9: Unit revenue (USD/m³)
	Investment	F10: Unit investment (USD/m³)
	Leverage	F11: Debt service coverage ratio (%) F12: Debt equity ratio (%)
	Liquidity	F13: Current ratio (%)
	Profitability	F14: Return on net fixed assets (%) F15: Return on equity (%) F16: Return on capital employed (%)
	Average Water Charges	F17: Average water charges
	Economic Water Losses	F18: Non-revenue water by volume (%) F19: Non-revenue water by cost (%)

4.2 Customer

Customer perspective considers the strategy of delivering value to WDSC customers. The selected criteria include service coverage, customer complaints, continuity of supply, quality of supplied water and water meter reading as indicated in Table 2 below.

Table 2. Performance criteria and metrics for Customer perspective.

Perspective	Criteria	Metrics
Customer	Service coverage	C1: Households and businesses supply coverage C2: Population coverage
	Customer complaints	C3: Service complaints per connection C4: Service complaints per customer C5: Billing complaints and queries C6: Response to written complaints
	Continuity of supply	C7: Population experiencing restrictions to water supply C8: Water interruptions (%)
	Quality of supplied water	C9: Tests carried out (%) C10: Aesthetic tests compliance (%) C11: Microbiological tests compliance (%)

		C12: Physical-chemical tests compliance (%) C13: Radioactivity tests compliance (%)
	Water meter reading	C14: Customer reading efficiency C15: Residential customer reading efficiency C16: Operational meters (%) C17: Unmetered water (%)

4.3 Internal Processes

This perspective attempts to figure out how well is the performance of WDSC's internal processes and strive for achieving shareholders and customers' satisfaction via excelling at these processes. As shown in Table 3, the performance criteria include desalination plant utilization, water storage, transmission and distribution, inspection and maintenance, operational water losses, pumping and service connection

Table 3. Performance criteria and metrics for Internal Processes perspective.

Perspective	**Criteria**	**Metrics**
Internal Processes	Desalination plant utilization	IP1: Desalination plant utilization (%)
	Water storage	IP2: Raw water storage capacity (days) IP3: Desalinated water storage capacity (days)
	Transmission and distribution	IP4: Valve density (No./km) IP5: Hydrant density (No./km)
	Inspection and maintenance	IP6: Pump inspection (annually) IP7: Storage tank cleaning (annually) IP8: Active leakage control repairs (No./100 km/year) IP9: Mains rehabilitation (%/year)
	Operational water losses	IP10: Water losses per connection (m^3/connection/year) IP11: Water losses per mains length (m^3/km/day)
	Pumping	IP12: Pumping utilization (%) IP13: Standardized energy consumption (kWh/m^3/100m) IP14: Reactive energy consumption (%) IP15: Energy recovery (%)
	Service connection	IP16: New connection efficiency (days) IP17: Time to install a customer meter (days) IP18: Connection repair time (days)

4.4 Learning & Growth

Learning & Growth aspect considers the employee training and corporate cultural attitudes related to both individual and supply chain improvement. The selected performance criteria include personnel qualification, personnel training, automation & control and reused supplied water, as indicated in Table 4 below.

Table 4. Performance criteria and metrics for Learning & Growth perspective.

Perspective	Criteria	Metrics
Learning & Growth	Personnel Qualification	LI1: University degree personnel (%) LI2: Basic education personnel (%) LI3: Other qualification personnel (%)
	Personnel training	LI4: Internal training (hours/employee/year) LI5: External training (hours/employee/year)
	Automation and control	LI6: Automation degree (%) LI7: Remote control degree (%)
	Reused supplied water	LI8: Reused supplied water (%)

4.5 Environmental

Seawater desalination plants have high impact on the environment and can cause significant damage to the environment from different ways. The performance criteria include emissions, life cycle assessment, sustainability, recycling, and health & safety, as shown in Table 5 below.

Table 5. Performance criteria and metrics for Environmental perspective.

Perspective	Criteria	Metrics
Environmental	Emissions	E1: Airborne emissions E2: Waterborne emission E3: Emissions to soil
	Life Cycle Assessment	E4: Global warming E5: Ozone depletion E6: Acidification E7: Photochemical oxidation
	Sustainability	E8: Energy resources efficiency (%) E9: Energy consumption (kWh) E10: Sludge disposal E11: Sludge treatment quality E12: Brine discharge (mg/L) E13: Brine treatment quality (mg/L)
	Health and Safety	E14: Working accidents (No./year) E15: Medical treatment case (No./year) E16: Safety awareness (%)

		E17: Safety training (hours/employee/year)
	Recycling	E18: Water reuse efficiency (%) E19: Volume of water sourced from recycling (m^3) E20: Volume of the recycled water supplied (m^3)

5. Conclusion

Shortage of fresh water is one of the major challenges for life in earth planet. Even countries which do not suffer from water scarcity at the current time might experience water shortages in the near future due to population growth, climate change and desertification. Therefore, seawater desalination has been realized as a feasible solution to water shortage problem. It is important to assess the performance of water desalination operations holistically by considering the seawater treatment process by desalination plants as well as the process of providing the desalinated water to consumers. The focus on closed-loop SC is a step towards the wider adoption and expansion of sustainability, since the SC considers the product starting from its initial processing of raw materials up to the delivery point to consumers. This study has proposed a performance measurement model to evaluate and ultimately enhance the closed-loop SC performance in seawater desalination industry. Based on the literature review, the collected performance metrics were distributed into BSC model perspectives which are financial, customer, internal processes, and learning & innovation as well as environment to construct the performance model for the closed-loop water desalination supply chain. This research contributed to further understanding the nature of seawater desalination industry and allow for refinement of future research. Moreover, this research is likely going to help stakeholders of the industry by fostering a better understanding of the impact of SCM toward the closed-loop water desalination performance. The decision makers should be able to know the story of current performance through digits and graphs and how to enhance it in future.

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Biography

Hasan Balfaqih is an Assistant Professor in the Supply Chain Management Department at the University of Business and Technology, Jeddah, KSA. Dr. Balfaqih has extensive academic experience in the areas of Supply Chain Management, Performance Measurement, Operations Management and Engineering Management and has published several research articles in high impact factor journals as well as participated in several international conferences worldwide. Dr. Balfaqih is a qualified trainer and an active member in several academic as well as industrial organizations and communities.