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Decision Support System for Critical Infrastructure 2050 (BOS Model) †

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Abstract: In 2010, Vitens embarked on a strategic initiative to transition towards data-driven decision-making, with a primary focus on enhancing resilience through the identification of future infrastructure alternatives. This endeavor aligns with the overarching goal of fortifying Vitens' current and future operational capabilities. Facing significant uncertainties, we explored three areas: first, future water demand projections considering per capita consumption changes and potential regional population shifts; second, choices regarding our network topology; and third, the optimization priorities balancing costs, sustainability, resilience, and flexibility. Integral to this process, extensive consultations took place with diverse stakeholders (internal and external) to ensure the seamless integration of novel alternatives into the decision-making framework.

Keywords: critical infrastructure; decision support system; long-term planning

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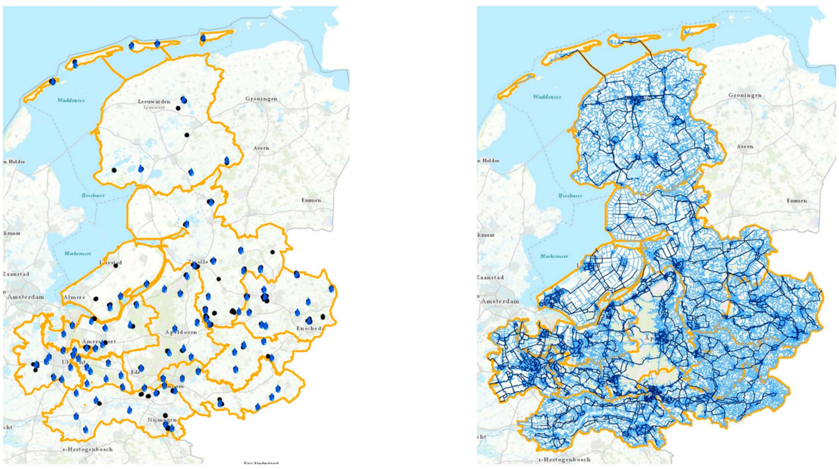
1. Introduction

Vitens, with 93 production locations and managing approximately 50,000 km of pipelines, delivers drinking water to five provinces and more than 5.6 million customers in a very complex water infrastructure (Figure 1). The company is slowly transforming into a data-driven-decision organization. For that reason, it is necessary to plan long-term investments such as new production locations and pipelines, while at the same time dealing with increasing climate variability and future country-related economic developments.



(**a**) (**b**)

Figure 1. Current infrastructure of Vitens (2022). (**a**) Production locations (as blue dots), (**b**) pipelines (as blue lines).

In 2010, it was decided that the main policy of the company's infrastructure would be its resilience enhancement. For that reason, a Long-Term Vision (LTV) was established in 2015, based on five different pillars answering different questions, as follows:

1. Robustness: What happens if parts of the system fail?
2. Flexibility: What happens if water demand and water availability mismatch?
3. Sustainability: How can the company produce water more sustainable?
4. Tolerance: Can we overcome extreme events (i.e., drought)?
5. Intelligence: Can we operate the whole system in a coherent way?

Facing significant uncertainties, the decision was to develop a system capable of taking into account three subjects of interest: first, future water demand projections considering per capita consumption changes and potential regional population shifts; second, choices regarding our network topology; and third, the optimization priorities balancing costs and the above mentioned resilience pillars.

The complexity of these challenges, compounded by the fragmentation of expertise across geographical regions and domains, has created a sophisticated decision-making problem. To address this, the authors have developed a Decision Support System (DSS), designed to aid decision-making in the face of numerous uncertainties (BOS-model in Dutch).

The DSS leverages cross-disciplinary insights and comprehensive data analysis, enabling informed, coherent decision-making processes regarding the network topology design options we are currently evaluating, as follows: whether to move to more centralized production locations; the effects of closing production sites that are relatively high in costs or that bring detrimental effects to their surroundings; and what happens when we connect regions that are currently disconnected.

2. Materials and Methods

The BOS-model is constructed iteratively. We started with a minimal viable product and iteratively enhance this tool. This section describes the tool in its state as it was at the start of 2024.

There are several data sources which have been steadily linked to the BOS-model. Most of the data sources correspond to other forecast or data-driven models. The details of such models are outside the scope of this article.

Strategic model. The strategic hydraulic model of Vitens is a composition of the main transport pipelines which are able to convey water from sources to large consumption areas. The selection of such elements has been made in collaboration as an abstraction of water allocation. In this regard, the strategic hydraulic model is thought to be a water balance transport model, Q-model (only flows are of interest), rather than a fully QH-model (flows and pressures model). This model is somewhat a skeleton of Figure 1b.

Future demands forecasting. Information on future demands is obtained based on an internal project of Vitens named PRIMOS. This project is an implementation of a long-term demand-forecasting model.

CAPEX and OPEX. At the moment, the costs of CAPEX and OPEX of each of the production locations is estimated based on averages per known production location. We have been working on a data-driven model named EURperCUBE. This costs model corresponds to an extensive analysis of the different treatment processes of each of the production locations. It is our ambition to incorporate this model into the next delivery of this tool.

Water permits. The current and future permits of water for each of the water boards for which Vitens is a customer are available and are updated annually based on the information from the department of production and treatment (W&Z by its initials in the Dutch language).

Visualization. To enhance visibility and facilitate an effective comparison of the diverse criteria, a dedicated dashboard was developed using R-shiny. In the background, hydraulic simulations were performed using WNTR [1] (a python wrapper for EPANET 2.2 [2]), while many additional functions were created in Python. The graphs are displayed as *plotly*

(plotly is a Python library https://plotly.com/, accessed on 1 January 2023) objects, as this allows for the level of interactivity with the app that we need right now.

Consultation. Integral to this process, extensive consultations have taken place with diverse stakeholders (internal and external) to ensure the seamless integration of novel alternatives into the decision-making framework. This iterative approach allows for the continuous refinement of our strategies and ensures that Vitens remains at the forefront of resilience-focused infrastructure planning in The Netherlands.

3. Current Status and Headway

The current results and a long headway are to be further developed. Here, it is presented what the current BOS-model entails, as well as the future developments already in production.

3.1. Current Results

In Figure 2, the current dashboard of the BOS-model is presented. The dashboard shows different tabs for the user to inspect, related to the information the users need to be updated.

(**a**) (**b**)

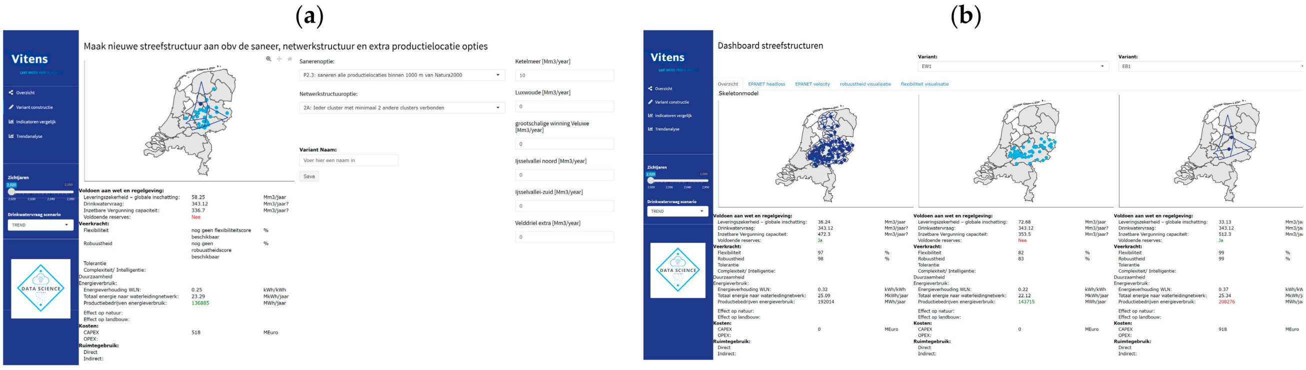


Figure 2. BOS-model interface (2022). (**a**) A dashboard where you can click different options that make a future network topology possible where you can instantly inspect the results for (**b**) a comparison of three alternatives.

The 'Variant Construction' tab features an interactive tool that allows users to select and configure various options for designing a prospective water distribution network. The intended users for this tab are—among others—Vitens management employees who need to quickly assess the impact of different network choices. Users can make decisions on the following: (1) Existing Production Locations: Choose which existing production locations to close based on costs or detrimental environmental effects; (2) new centralized production locations and determine their size; and (3) Interconnections: Decide on interconnecting currently disconnected regions (minimal connections or high interconnections).

The effects of these choices on key performance parameters are instantly visible. Once satisfied, users can save the newly designed prospective future network for later inspection in the Variant Overview tab.

The 'Variant Overview' tab displays the existing water distribution network (left) alongside two potential future networks (right). Policy makers are the intended users for this tab. These networks are previously constructed in the 'Variant Construction' tab. Users can compare different prospective water distribution networks based on defined key performance aspects.

Key Performance Indicators (KPIs): Both tabs show the performance of the displayed networks on key performance indicators related to the five previously defined pillars: robustness, flexibility, sustainability, tolerance, and intelligence (shown at the bottom of Figure 2). Additionally, the dashboard on the left incorporates uncertainty regarding customer demand, where the uncertainty regarding customer demand is incorporated into the dashboard. Here, the user can 'jump' into one of several predefined possible 'futures' based on whether the demand is expected to increase minimally, according to trend, or maximally.

3.2. Headway

Even with the current developed BOS model, there are certain aspects which still require improvement.

The calibration of strategic models is still a work in progress. For this, a new methodology has been proposed to the advisors of hydraulics and water allocation for the constant improvement of their base models.

The energy balance of the production locations is still hard to match with the calculated energy via BOS-model. This has to do with several issues which have been identified, such as the reduction in head losses after model skeletonization.

4. Conclusions and Future Work

This article presents the current developments of Vitens regarding its Critical Infrastructure 2050 with the help of a Decision Support System. The main goals of the project are established, and some of the future components currently under development are discussed.

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