Assessing and Prioritizing the Requirements of a Digital Twin for the Port of Twente

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A long period of drought in the Twente region in August 2022 caused a reverse modal shift in the Twente corridor. The period of drought resulted in delivery delays, disruption of planning and operational processes, reduced production capacity, and even led to factory closures. To address these issues, a digital twin is being designed for a resilient multimodal corridor that can support the transition to a synchromodal corridor that can utilize the most appropriate modality at any time. This paper aims to analyze, validate and prioritize the requirements for this digital twin, as well as create a model that shows which resources the system requirements depend on and the dependencies between the digital twin and the stakeholders. The requirements were identified based on an analysis conducted on the documentation of previously performed interviews with stakeholders. And verification and prioritization are done by surveys submitted to the same stakeholders. Finally, the model was created using the identified requirements and updating a previously created Goal model. The outcome shows that the system requirements were validated and prioritized at the foundation level and dependencies of digital twin and system requirements were identified.

Additional Key Words and Phrases: Digital twin (DT), Goal Model, Requirements Specification, Requirements Validation, Requirements Prioritization

1 INTRODUCTION

The logistics industry has always been an important contributor to the Dutch economy. Many products from abroad are transported through the Netherlands to the inland regions of Europe and other regions of the world, and vice versa. The Dutch logistics industry has developed a strong transit and warehouse sector and related value-added services and other activities [17]. In 2020, a total of 1.9 billion tons of goods were transported in Dutch territory and Dutch waters, of which 291 million tons were transported by inland navigation, equivalent to about 15% [8]. Therefore, it can be said that inland shipping is a very important part of the corridor.

Climate change in recent years has caused significant pressure on coastal shipping. Climate change leads to droughts, flooding, infrastructure failures, and downtime, revealing the vulnerability of the corridor and significantly impacting its performance, as well as the negative impacts on direct stakeholders. The disruption that began in the Twente port caused problems in many aspects, as can be seen in the example of the reverse modal shift caused by the drought in the Twente region in August 2022 [14]. Vulnerabilities in multimodal corridors have serious consequences and need to be addressed. As a solution, a digital twin (DT) is being designed that can collect real-time real-world information, such as operational data, environmental data, etc., and monitor and simulate those states and situations. It allows, for example, to predict when reverse modal shifts will occur, improving the resilience of transportation. Implementing such a DT would support the transition to a synchromodal corridor and prevent the cascading effects of reverse modal shifts and disruptions.

In the development process of such software, requirements specification, validation and prioritization play an important role. Requirements validation is used to determine the correct requirements, avoiding inconsistencies, incompleteness, inaccuracies, and other defects, and to validate that the requirements are reasonable as a description of the system to be implemented [12]. It reduces the risks associated with software projects by helping to detect and correct errors and mistakes that may occur unintentionally [16]. Requirements prioritization is the process of defining the relative importance of the requirements for the stakeholders and is a key step in making critical decisions that enable the software under consideration for development to function as expected and increase the economic value of the system. Prioritizing requirements before architectural design and coding will significantly help implement software systems that are prioritized by stakeholders [2]. These techniques assist in implementing the project according to schedule, budget, and desired features.

The transportation process in multimodal corridors involves multiple stakeholders, and it is crucial to consider the requirements of all stakeholders involved and to validate their requirements while taking into account their priorities in designing the DT.

Therefore, this paper aims to identify the requirements of stakeholders in the Port of Twente multimodal corridor and to validate and prioritize those requirements. Furthermore, a model that has been previously created is updated in this paper with more detailed information about the DT requirements, relating these requirements to the goals and tasks, and showing the dependencies between the stakeholders and the DT.

2 RESEARCH QUESTION

While interviews have already been conducted with several stakeholders in the multimodal corridor of the port of Twente, the most important step in the design of the system has not yet been taken, which is to identify the detailed requirements the stakeholders are looking for and confirm the validity of those requirements.

To achieve the objective of this research, the following research question was formulated: **What is the valid final set of requirements to guide the development of the Port of Twente's Digital Twin?** This research question can be answered with the following sub-questions:

(1) What initial requirements may be specified through inspection of the documentation resulting from the stakeholders' interviews?
(2) How can the captured requirements be analyzed with the support of goal models and associated requirements table?

TScIT 42, January 20, 2025, Enschede, The Netherlands

(3) Which of the initial requirements are considered valid by the stakeholders?
(4) How are the valid requirements prioritized by the stakeholders?

3 RELATED WORK

3.1 Digital twin (DT)

DT refers to a virtual copy or model of a physical entity (physical twin) interconnected by real-time data exchange, allowing real-time monitoring, design/planning, optimization, maintenance and remote access over the Internet [15] and can directly help create a lean, flexible and smart logistics and supply chain environment, and can greatly help optimize logistics. For example, information on canal water levels could be collected by sensors and other physical devices to analyze and predict water level fluctuations over the next two weeks to support transportation planning and other decision making. In addition, simulation models can be run on the DT to test processes in different scenarios. This will allow the organization to test the feasibility of the model settings against possible logistical scenarios that may occur in the future [1].

3.2 Requirements analysis, validation and prioritization

Analyzing, identifying, validating, and prioritizing software requirements of stakeholders is one of the important and fundamental processes of requirements engineering and is used to find out the needs of stakeholders [3].

Requirements validation minimizes inconsistencies, ambiguities, and defects through the detection and correction of errors in requirements, and contributes to project success by ensuring the accuracy of requirements, reducing defects correction costs in the later stages, and helping the project stay on schedule [6], [7], [12], [16].

Similarly, requirements prioritization helps eliminate unnecessary requirements and focus on those that are truly necessary, facilitates consensus building among stakeholders, and provides a foundation for creating maximum value with limited resources, which can lead to greater stakeholder satisfaction, more efficient use of resources, and increased project success rates [2], [11], [13].

3.3 Goal-oriented Requirements Engineering

Goal modeling is a key element of Goal Oriented Requirements Engineering (GORE) as a tool for requirements analysis of software systems and includes methods and tools that use the concept of goals to elicit, model, analyze, and verify requirements [10]. The goal model is created by using one of the most prominent frameworks in GORE, the i^* framework. Goal model is intended to visualize the interests of stakeholders, such as requirements, and supports understanding and analyzing problem domains in the early stages of system modeling [19]. Within the model, actors, tasks, resources, and goals and their relationships are represented, and it allows to visualize: *What does each actor want? How do they achieve what they want? And who do they depend on to achieve what they want?* [18]

4 METHODOLOGY

4.1 Interview analysis

The analysis in this study was based on interviews with relevant stakeholders to identify system functional/non-functional requirements for the development of the DT. The project team has already conducted these interviews and the analysis of system requirements was based on a summary of those interviews. Interviews were conducted with key stakeholders associated with the Port of Twente multimodal corridor, a total of nine stakeholders were interviewed, and the following types of business were included:

- Port of Twente
- Rijkswaterstaat (Executive organization of the Ministry of Infrastructure and Water Management)
- Logistic Company
- Transporter

The interview analysis process includes the following steps:

(1) **Organize interview data**
Organize the main problems and opinions from the interviews with each stakeholder. Focus particularly on problems that arise frequently and opinions that are common among stakeholders.
(2) **Categorization of data**
Based on the organized interview data, an analysis is performed to create large, abstract requirements categories.
(3) **Identification of detailed requirements**
Based on the abstract requirement categories and the results of the analysis, identify and clarify the specific functional/non-functional requirements that stakeholders are looking for in the DT.

4.2 Requirements visualization

In order to allow stakeholders to easily validate the identified system requirements and to visualize the relationship between the system requirements and stakeholders clearly, this study visualized the requirements in the following two ways:

- System requirements table
- Goal model

4.2.1 System requirements table. The system requirements table was created through a process of organizing the requirements of each stakeholder and eventually building an integrated initial system requirements table. The following steps were taken to create the table:

(1) **Organize requirements for each of the stakeholders**
Based on the analysis of the interviews with each stakeholder, a system requirements table was created for each stakeholder. This clarified the requirements to reflect individual specific needs.
(2) **Integration of each interview**
Based on the total of nine stakeholder requirement tables that were created, a further detailed analysis was conducted to organize and integrate the requirements into a single table. This process produced a single 'Initial Requirements Table'.

This initial requirements table was used in the survey with stakeholders conducted during the verification and prioritization of requirements in later steps.

4.2.2 *Goal model.* Using the *i*2.0* framework, goal models were created that clearly show the system requirements, which resources those requirements need, and how stakeholders depend on the DT. This process uses a tool called piStar[1], which is capable of creating models of the *i*2.0* framework. The creation of the model was based on a model already created by Arda [4], who had previously worked on this project, and was an upgrade of that model.

The representations used in the model are following [9]:

Actors
Actors are represented graphically as circles. The intentional elements of an actor and their interrelationships are represented by actor boundaries. Elements and relationships are shown within a gray area [Fig. 1].

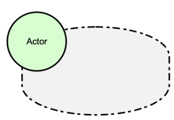

Fig. 1. Representation of actor and actor boundary

Intentional elements
The intentional elements that appear inside the actor boundaries represent what the actor wants or desires [Fig. 2]:

- Goal: An objective that the actor wants to achieve.
- Quality: an attribute that the actor desires to achieve to some degree.
- Task: an action that the actor desires to perform, a task necessary to achieve some goal.
- Resource: A physical or information source that the actor needs to perform the task.

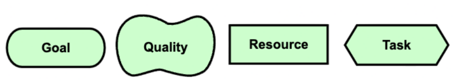

Fig. 2. Representation of internal elements

Social dependencies
Dependencies represent social relationships. There are two types of dependency relationships used in our model:

- Goal dependency: The individual or entity that is relied upon is expected to accomplish a desired outcome, and they have the flexibility to decide the method or approach they will use to achieve it.
- Resource dependency: The individual or entity that is relied upon is expected to provide an asset or material that the reliant individual or entity needs to use.

[1] https://www.cin.ufpe.br/ jhcp/pistar

The D on the line link serves as an arrow “>” and indicates the direction [Fig. 3].

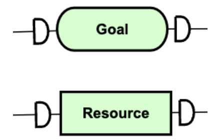

Fig. 3. Representation of dependency types

And link
One of the refinements that links goals and tasks in a hierarchical manner. An intentional element can be the parent of at most one refinement relationship. It is represented as a set of links directed from a sub-element to the parent element. A T-shaped arrow serves as an arrow directed to the parent element [Fig. 4].

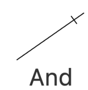

Fig. 4. Representation of and link

4.3 Requirements validation and prioritization

A survey was conducted with stakeholders to confirm the validity of each identified system requirement and to assess the importance of these requirements.

The survey was constructed by extracting the requirements directly from the initial requirements table and maintaining the structure of the table. The link to the survey can be found in A.2. The stakeholders responded by selecting a linear scale of 1 to 4 for each requirement, and the survey was conducted via Google Forms. Stakeholders were asked to evaluate the requirements using the following criteria:
1: "No need to have" that requirement
2: "Could have" that requirement
3: "Should have" that requirement
4: "Must have" that requirement
In addition, an open section was included at the end of the survey to allow stakeholders to describe features that are not listed in the requirements table but that they expect from the DT.
The data collected were analyzed by the following steps:

(1) **Calculation of priority score**
The average priority score for each requirement was calculated by summing each priority score, dividing that score by the number of respondents, and finally rounding that score to the nearest integer. This average score is used as the final priority score for each requirement
(2) **Priorities for not needed requirements**
Requirements that are rated 1: “No needed to have” by all stakeholders are not eliminated from the table due to the small number of stakeholders involved in this survey, but are

listed as not-important requirements in the table. In addition, new system requirements proposed by stakeholders through this survey will not be prioritized but will be added to the table as 'Suggested by stakeholder'.

Finally, after the average priority for all requirements is identified, a new column is added to the right side of the initial requirements table, where the priority for each requirement is listed.

5 RESULTS

5.1 Requirements analysis

After organizing and analyzing the interviews with each of the stakeholders, several common major problems were identified. The major problems most often raised were:

- Fluctuations in water level: Transportation plans are negatively and significantly affected by changes in canal water levels.
- Ship monitoring: Lack of accurate real-time information on current locations and estimated arrival times of ships.
- Bridge and lock management: Real-time information on the operational status of bridges and locks is lacking.
- Information sharing: Limited information sharing between organizations and with the government.

To solve these problems, many stakeholders specifically mentioned "implementation of highly accurate water level fluctuation prediction" as a function they would like to see. Many other problems and opinions raised were analyzed, and categorized (See categories in 5.2).

Based on these categories, the specific needs of each stakeholder were analyzed and detailed system requirements were identified for each stakeholder. Based on the requirements identified for each stakeholder, requirements tables were created for each stakeholder. The table can be found in the Github repository [5].

5.2 Initial requirements table

The requirements tables created for each stakeholder were integrated to create a single initial requirements table [5]. This process involved sorting out common or similar requirements among the various stakeholders. The requirements table contains two types: Functional requirements and Non-Functional requirements. Functional requirements are requirements that describe the specific functionality that the system should provide, which stakeholders can directly see as the deliverables of the system. Non-Functional requirements are requirements that describe overall system characteristics and qualities such as performance, security, etc. These are often not directly visible to stakeholders, but are important to the success of the system.

The table consists of three columns, 'ID', 'Requirement', and 'Comment'. The Requirement column in each row describes a specific function, and the comment provides a simple description of the requirement or additional information about the requirement. The requirements are also grouped by the following categories:

- Water information: Requirements related to real-time information about water and predictions of water level fluctuations.
- Weather information: Requirements related to weather forecasts.
- Operational plan management: Requirements related to the operational plan.
- Ship information: Requirements for real-time ship information and other ship-related information.
- Facilities management: Requirements related to canal facilities.
- Bridge and lock management: Requirements related to bridges and locks, including real-time status of bridges and locks.
- Cost management: Requirements related to the tracking and optimization of transportation cost.
- Fuel/CO2 emission management: Requirements related to the tracking and optimizing of fuel consumption and CO2 emissions.
- Storage management: Requirements related to storage management.
- Communication channel: Requirements related to communication channels that support efficient communication.
- Information hub: Requirements related to information providing platforms.
- Account: Requirements related to accounts within the system.
- Payment: Requirements related to the payment process at the canal facilities.

As mentioned in the previous section, the major problems raised by almost all stakeholders were water level fluctuations, ship monitoring, bridge and lock management, and information sharing, and the requirements identified to address these issues are represented by the following requirements:

- 1.1.3: System calculates and displays predicted water level/depth for next several weeks.
- 1.1.4: System alerts users when predicted water level/depth is lower/higher than certain level
- 2.2.1: System displays an overview of available ships and its information
- 2.2.2: System displays real-time vessel navigation status
- 2.4.2: System displays real-time waiting time at the locks and bridges
- 2.4.3: System displays real-time operational status of lock/bridge
- 4.1.5: System provides communication channel for emergency communication with government and carriers
- 4.2.2: System provides information hub to share information from government
- 4.2.4: System provides contact information for ports, locks, and related companies

Among these requirements, one of the most frequently raised problems was the need for an accurate prediction of fluctuation of water level. According to a stakeholder, there are already simple systems for predicting water level fluctuations, but they are not accurate and can only predict water level fluctuations for a few days. To address this, the development of a system that can accurately predict fluctuations in water level over a period of several weeks is one of the key functions of this DT development project. In addition, the real-time waiting time information at the lock and bridge is also very important, as it significantly affects the transportation plan.

However, information sharing regarding waiting time is currently lacking, so the development of this system is also an important function of the system.

5.3 Goal models

Based on the initial requirements table created and the model created by Arda [4], two goal models were created to visualize the overall relationship between DT, stakeholders, and system requirements, as well as other organizational background around DT. One shows the DT's goals, tasks, and the sources on which those tasks depend. The other model shows how stakeholders depend on the DT.

5.3.1 *DT Strategic Rationale Model.*

This model shows the goals of DT, the tasks, and the dependencies of these tasks [Fig. 6]. This model is built under the DT's parent goal of *"Optimise logistics and supply chains"*, which is refined into several child goals, and ultimately the system requirements are presented as detailed tasks necessary to achieve each goal. For example, there are goals that could be viewed as quality, such as: *"ensure efficient transportation modes"*, and *"minimize environmental impact"*. These were originally qualities, but by relating the specific functional requirements listed in the initial requirements table to these qualities, they will have clear cut satisfaction criteria. Therefore, these can be labeled as goals.

Paying attention to the final level of the tree within the DT, it can be seen that most of the requirements depend on external actors for the resources needed to accomplish their respective tasks. Dependence on external resources means that if these resources become unavailable for whatever reason, it will have a significant negative impact on the achievement of the DT's goals. Therefore, understanding and re-examining the dependence on these external resources is an important topic for future systems risk management.

5.3.2 *DT and Stakeholders Strategic Dependency Model.*

This model shows how stakeholders depend on DT [Fig. 7]. It can be observed that basically all stakeholders depend on DT to obtain some information/resources. In particular, it is significant to obtain information that requires immediate response from the DT, such as Real-time Operational Information and Congestion Alerts, which improves the information sharing that has been a major problem, and is often unclear. In addition, the information required for transportation planning, such as prediction of water level fluctuations, can be shared collectively within the DT, which improves the efficiency of transportation planning.

The centralization of information and resources in DT allows each stakeholder to greatly improve operational efficiency by sharing predicted information, facilitating real-time information sharing, and improving the efficiency of inter-organizational communication and information sharing.

5.4 Survey analysis

A survey with stakeholders was conducted based on the initial requirements table that was created to validate each of the identified system requirements and to evaluate the priority of those requirements. A survey was sent to nine stakeholders and responses were received from three stakeholders within the deadline for survey responses. The three stakeholders consist of two logistics companies and the Port of Twente. The validated table with priority based on the survey results can be found in the Github repository [5]. After analyzing the survey results, a new priority column was added to the far right side of the table [Fig. 5]. The priority score can be interpreted as follows.

- 4: "Must have" that requirement
- 3: "Should have" that requirement
- 2: "Could have" that requirement
- 1: "Will not have" that requirement
- N: Not important
- S: Suggested by stakeholder

In addition, each requirement category has been sorted in order of priority, and the requirement IDs have been changed accordingly.

In the functional requirements table, eleven requirements received the highest priority of 4: Must have, with high percentages of *Must* in the *Water information* and *Bridge and lock management* requirement categories. In the non-functional requirements table, four requirements received a *Must* rating.

Across all requirements, the lowest rating received was *3.1: System allows users to manage inventory information for their warehouses*, which received 1: No need to have, from all respondents. In the table, a priority of *N* is given. However, it is important to consider that, due to the insufficient number of responses, what may seem unimportant to some may be important to others who have not yet responded.

The respondents proposed two new requirements:

- 2.1.14: System provides comparisons based on water level predictions, by ship vs. truck or other transportation methods
- 5.3.1: System provides 3D visualization simulation tool

These were given priority *S*.

ID	Requirements	Comment	Priority
1	***Environmental Information***		
1.1.0	**Water information**		
1.1.1	System displays real-time water level, depth and flow	Ijssel River, Twente Canal, around locks and bridges	4
1.1.2	System alerts users when water level is lower/higher than certain level	Such as When the IJssel River water level is lower than possible water pumping water level, it alerts users	4
1.1.3	System calculates and displays predicted water level/depth for next several weeks	Based on past data, weather forecast, etc.	4

Fig. 5. Part of validated table

The full table can be found in the Github repository [5].

6 DISCUSSION

This research plays an important role in facilitating the analysis of system requirements in the development of a DT for multimodal transportation at the Port of Twente. Through the analysis of interviews with stakeholders, each system requirement was identified, capturing what each stakeholder expects from the system. The requirements identified for each stakeholder were then analyzed for similarities and inconsistencies and a single DT system requirements table was identified. Then, Goal models were created, which aimed to understand the organizational context associated with the system requirements, thereby identifying the sources on which each requirement depended, as well as the dependencies between the stakeholders and the DT. This identified key dependencies that could be used for future risk management. Finally, the identified requirements were validated and prioritized by stakeholders. This process ensures the certainty of requirements in system development by minimizing inconsistencies, ambiguities, and deficiencies in requirements and facilitates the building of consensus among stakeholders, which contributes significantly to system satisfaction, efficient use of resources, and higher project success rates. Although, due to the limited number of responses, the verification and prioritization of requirements was at a limited level, it did identify requirements that must be considered important at this point, and it also allowed for the identification of new system requirements. More responses are expected in the future, and the analysis of these responses is expected to identify and prioritize even higher-level system requirements. Thus, this paper can be seen as a basis for further refinement and identification of requirements in the future.

6.1 Limitations

In this research, the survey was the only method used to validate and prioritize system requirements by stakeholders, therefore, responses from as many stakeholders as possible were desirable. However, due to time constraints, only three stakeholders responded, and only a limited level of validation and prioritization of requirements was performed.

7 CONCLUSION

This research discussed the system requirements for the development of a DT for multimodal transportation at the Port of Twente. The research question, **"What is the valid final set of requirements to guide the development of the Port of Twente's Digital Twin?"** was divided into the following sub-questions, which were answered throughout the research:

(1) **What initial requirements may be specified through inspection of the documentation resulting from the stakeholders' interviews?**
Initial requirements were specified through the analysis of stakeholder interviews and added to the initial requirements table [5]. The initial requirements were categorized into functional and non-functional domains. In the functional domain, the requirements were categorized into thirteen categories such as *"water information", "operational plan management", "bridge and lock management"*, etc. A total of sixty requirements were identified, including *"System calculates and displays predicted water level/depth for the next several weeks"*. In the non-functional domain, the requirements were categorized into four categories, such as *"compatibility"*, and a total of five requirements were identified, including *The UI displays on Smartphone, Tablet and Desktop displays"*.

(2) **How can the captured requirements be analyzed with the support of goal models and associated requirements table?**
Goal models identified the resources on which system requirements depend, provided insight for future risk management, and provided a model for understanding the organizational and technical interrelationships of dependencies between stakeholders and DT.

(3) **Which of the initial requirements are considered valid by the stakeholders?**
The stakeholder survey validation found that while most of the initial requirements listed were rated as valid,*"the system allows users to manage inventory information for their warehouses"* was the only requirement that was not evaluated as valid. However, only a small number of responses were received to completely determine whether or not each requirement was valid.

(4) **How are the valid requirements prioritized by the stakeholders?**
In the prioritization based on the survey responses, many of the requirements categorized under *"water information"* and *"bridge and lock management"* received the highest rating of 4: Must have, including requirements about water level predictions and real-time wait time information at bridges and locks, highlighting functions that are critical to the success of the DT.

Finally, to answer the research questions, the valid final set of requirements created through sub-questions can be found in the Github repository [5]. However, it must be kept in mind that these requirements, as mentioned earlier, have only been validated by a limited number of stakeholders and may change in the future with responses from more stakeholders.

7.1 Future research

Future research may involve: expanding stakeholder participation and further requirements validation to increase the comprehensiveness of requirements validation, developing a system to enhance DT functionality, including predictive analysis related to the identified requirements, and assessment of the social impact on stakeholders that the introduction of DT will have, based on the envisaged DT functionality.

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A APPENDIX

A.1 Use of AI Tools

During the preparation of this work, the author used ChatGPT and Grammarly to rephrase certain parts of the text for improved readability. After using these tools and services, the author reviewed and edited the content as needed and assumed full responsibility for the content of the work.

A.2 Survey

Below is a link to the survey:
https://forms.gle/i8gH5yaS64KK7y82A

A.3 Goal models

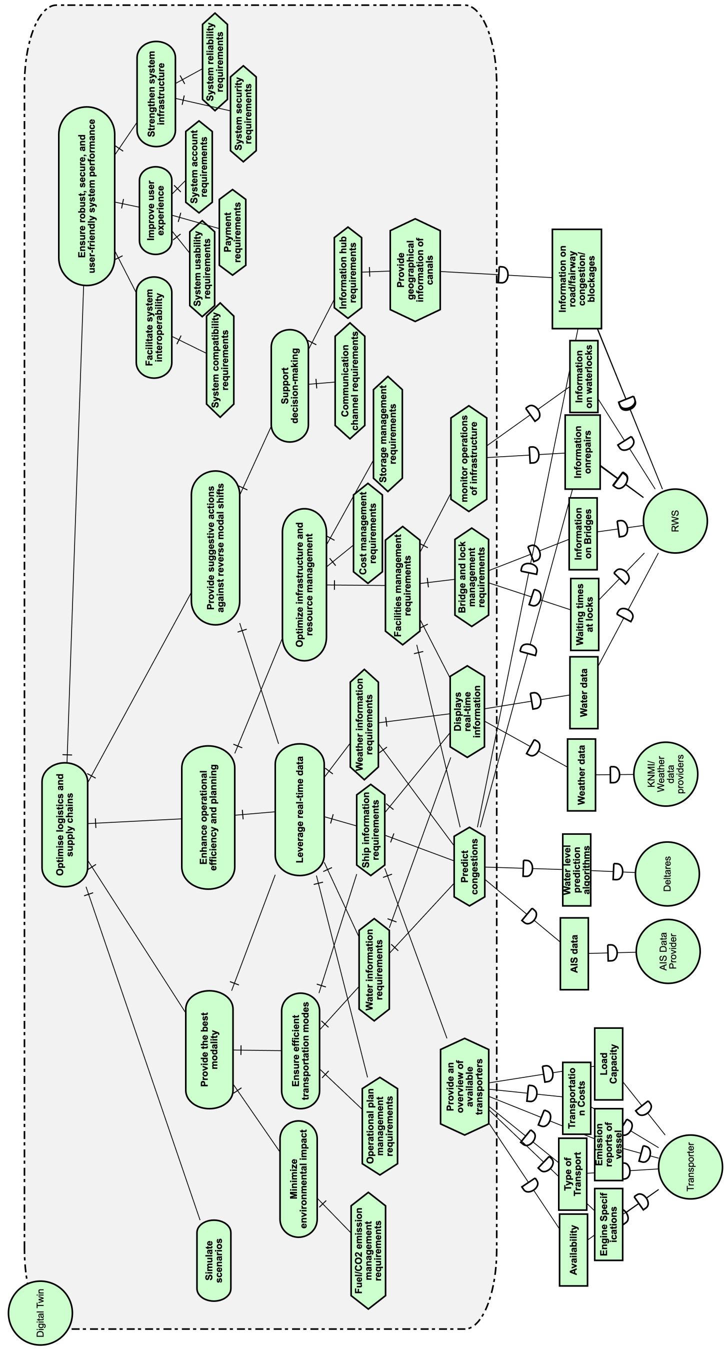

Fig. 6. DT Strategic Rationale Model

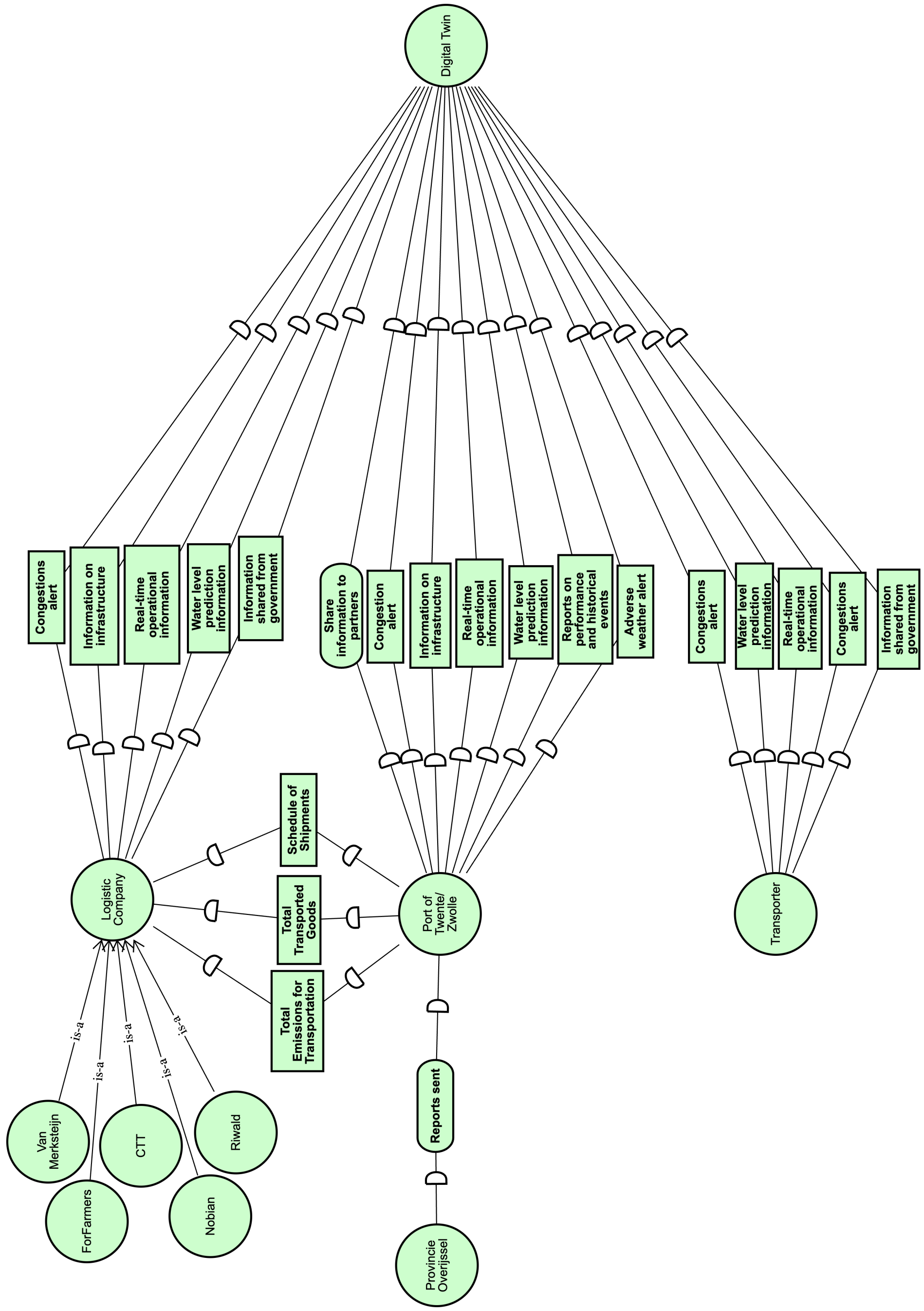

Fig. 7. DT and Stakeholders Strategic Dependency Model