Analysing the Requirements of a Digital Twin for Multimodal Transportation at Port of Twente

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Requirements Engineering (RE) has traditionally been employed to analyze software project requirements, but there has been a shift towards Goal Oriented Requirements Engineering (GORE), which captures requirements through high-level stakeholder goals. This paper applies GORE to analyze the goals and requirements of a Digital Twin for the multimodal transportation ecosystem. Utilizing the *i* 2.0* framework, it provides a comprehensive view of stakeholder needs, mapping out their goals and requirements to facilitate effective system development.

Additional Key Words and Phrases: Goal Oriented Requirements Engineering, Digital Twin, Multimodal Transportation

1 INTRODUCTION

In recent years, reliability and performance of multimodal transportation in the Netherlands has been under risk and pressure due to ecological disruptions and climate change. Cascading events prove to be a threat for the stakeholders involved in the multimodal corridors and can cause reverse modal shifts for inland water shipping. This modality has emerged as a cornerstone of goods transportation in the Netherlands, accounting for just over 17.5% of total goods transportation in 2023 [5].

For example, in August 2022, the reverse modal shift caused cascading events due to severe droughts. During the period, many inland vessels became unusable, resulting in a demand for 13.119 trucks for transport. This sudden shift led to transport costs increasing from 108€ to 360€ per km/ton and significant increase in road congestion and carbon emissions [7]. After this period, the Ministry of Infrastructure and Water Management (*Ministerie van Infrastructuur en Waterstaat*) emphasised on the significance of the inland shipment to the Dutch transport sector and provided their long term goals for improving the future of inland transport [11].

To mitigate the risks posed by climate change and disruptive events, the University of Twente, in collaboration with the Port of Twente and several other partners, initiated a project on October 18, 2023, to develop a Digital Twin. This innovative project aims to monitor and enhance the resilience of canals, support the transition towards synchromodal corridors, and prevent reverse modal shifts and cascading effects of disruptions.

Currently, the project is still in its initial stages, but emphasises the critical importance of chain coordination and stakeholder collaboration in developing resilient, climate-adaptive multimodal corridors. Effective chain coordination requires active engagement from all stakeholders, including shippers, logistics service providers, and public partners, to maximise network utilisation and mitigate the risk of a reverse modal shift.

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Understanding these needs is crucial for tailoring the functionalities of the Digital Twin to meet stakeholder objectives and ensuring an effective ecosystem. By addressing potential conflicts early on, this research will facilitate the development of a Digital Twin that enhances canal resilience, supports the transition to synchromodal corridors, and mitigates the risks of reverse modal shifts and disruptive events.

The aim of this paper is to identify and analyse the goals and requirements of stakeholders involved in the multimodal ecosystem of Twentekanaal. Then, create a model illustrating the tasks, goals, and relationships among the stakeholders of the ecosystem.

To realise this model, the paper will first analyse the requirements and goals of the stakeholders involved in the ecosystem. Then, using the *i* 2.0* [3] framework, it will create a refined model that aims to minimise conflicting goals.

2 RESEARCH QUESTIONS

In order achieve the aim of the project, the following research question will be posed: **What are the goals and requirements of a digital twin for the stakeholders of a multimodal transportation?** To answer this question, the following sub questions will be asked:

- What are the effects of digital twins on multimodal transport logistics?
- What are the functional and non-functional requirements of the stakeholders from the Digital Twin?
- How can these requirements be analysed?
- Are there any conflicting requirements between stakeholders? How can we refine/solve them?

3 RELATED WORK

This section will go over relevant literature concerning a requirements elicitation of a digital twin for multimodal transportation.

3.1 Digital Twins

Digital twin is defined as an accurate portrayal of a physical entity in [9]. driven by data, a digital twin can be programmed to perform monitoring, prediction and more. Brochado, Rocha and Costa [2] propose in their paper assessing logistics performance monitor and facilitating real time scheduling through modular Internet of Things (IoT) architecture. The proposed solution, applied in Portugal, is able to provide real-time insights and optimise transport processes. Jin and Choi [12] investigate the impact of a digital twin on regional economics and logistic development. With their results, they argue that digital twin models significantly improve logistic efficiency, economic growth and reduced costs.

3.2 GORE

Requirements engineering (RE) has become a critical stage of software development, with multiple sub-tasks, such as identifying stakeholders and their goals/requirements [1]. However, the traditional RE approaches could not deal effectively with complex software systems. These approaches treat requirements as processes and not considering the possible high-level concerns of the systems [4]. Lapouchnian then provides an overview of why Goal Oriented Requirements Engineering (GORE) came to be, and then goes over the common GORE approaches used in the scientific world.

3.3 Multimodal Transportation

Definition of multimodal transportation is the transportation of goods, by a sequence of at least 2 different modes of transportation [8]. SteadieSeifi et al. then provide in their paper a literature review on planning problems: strategic, tactical, operational planning.

4 METHODOLOGY

In this part, the structured approach to writing this paper will be discussed. First, the paper will detail how the data for the requirements are collected. Then, the process of formulating the goals and requirements from the data. Finally, the tools and frameworks used in creating the models.

4.1 Data Collection

The Digital Twin will be tailored to the needs of the companies who are in collaboration with this project. In order to understand their demands of the companies, interviews have been conducted. The interviews were semi-structured, allowing both the interviewer and interviewee to explore different ideas during the interview.

4.2 Creation of goals and requirements

Following the interviews, participants' responses were systematically coded into identified problems, high-level goals, and requirements. These goals and requirements were then prioritised based on the frequency with which topics were repeated in the interviews. This method ensured a focused framework for addressing the most critical areas and strategic objectives.

4.3 Representation of requirements with *i* 2.0* framework

To visualise the goals and requirements, the *i* 2.0* [3] framework will be used. This framework will also facilitate the refinement of these goals and requirements, ensuring a clear and structured representation of the system's strategic objectives.

4.4 Visualisation using *piStar*

piStar [6] will be used to create the models for the requirements. This tool will aid in visualizing and refining the goals and requirements using the *i* 2.0* framework.

4.5 Evaluation of the models by experts

Finally, a qualitative questionnaire will be sent to experts in the project, and their evaluation will be used as a validation tool for the model.

5 *I* 2.0* FRAMEWORK

Understanding the domain and intentions/goals of the stakeholders have been an important aspect of software engineering since the nineties. There have been many frameworks developed to help engineers formulate the goals with different levels of abstraction and perspectives. In compare in their paper the different GORE frameworks, namely *i** [13] and *KAOS* [10], and concluded that *i** models represent goals and soft goals efficiently, dependencies can be detailed in an explicit way, however the models can get complex and huge.Therefore, *i** framework was chosen for the modelling.

As mentioned in the introduction, *i** framework [13] developed by Yu provides a solution for the formulation of properties of stakeholders involved in an organisational context. Currently, his work is one of the most common frameworks for goal and agent oriented modelling in the area.

Throughout the years, many developments have been made on top of Yu's work.In order to explain the basic concepts and core concepts of *i**, Dalpiaz et al. have developed a *i* 2.0* core language [3]. Next, the paper will describe the core components of the *i* 2.0* framework, taken from the language guide of Dalpiaz et al.[3]. Then, in Section 7, the models made in *piStar* [6] will be introduced.

5.1 Actors

Actors are depicted as circles or ovals. They represent entities with strategic goals. In the case of *Actors*, a straight line is added in the top part of the actor circle. For a *Role*, a curved line is added in the lower part.

5.2 Dependencies

Goal Dependency: Illustrated with an lines with letter *D* going from the depender (the actor who depends) to the dependee (the actor who is depended upon), labeled with the goal.
Task Dependency: Similar to goal dependency but labeled with the specific task.
Resource Dependency: Depicted with an arrow labeled with the resource needed.
Softgoal Dependency: Shown with a cloud-shaped label, indicating the softer, qualitative nature of the goal.

5.3 Intentional Elements within Actors

Goals: Represented as ovals within the actor boundary.
Tasks: Illustrated as hexagons within the actor.
Resources: Shown as rectangles within the actor.
Softgoals: Depicted as clouds within the actor.

6 INTERVIEWS

6.1 Structure of the interviews

The interviews were conducted to have a deep understanding of the current operations of the stakeholders and what their goals are from this digital twin. During the interviews, it was aimed to explore current challenges in logistic operations and how the stakeholders prefer the challenge to be solved. The interviewees were selected based on their representative role in their company and the possibility that they will be using the digital twin. Scheduling the interviews were done by the project responsible person of the

Port of Twente. Semi-structured format was followed for the interviews, as it allows flexibility to explore while maintaining focus on the main topics. Meetings lasted around 1 hour to 1 hour 15 minutes, usually at the company of the interviewee.

6.2 Limitations of the interview

Scheduling interviews were proven to be difficult in short notice and external circumstances of the companies. During the period, only 3 companies were interviewed, which represents the logistic companies, but unfortunately there were no interviews conducted with associations or governing bodies, who also play a role in the ecosystem

6.3 Reflection

Conducting the interviews provided valuable insight to the experienced difficulties companies have with their logistic operations, and their goals from the project.

7 REQUIREMENTS MODEL FOR THE DIGITAL TWIN

7.1 Requirements

The interviews helped establish high-level goals, which were then refined into detailed low-level software requirements. This process ensured that the software's design aligns closely with user needs and expectations. Below is the list of goals.

- Simulating scenarios like water levels, disruptive events etc.
- They want to know best modality for the situation
- Real-time monitoring of ships and infrastructure on the canals
- Prediction of water levels
- Better collaboration mechanisms for communication
- Knowing the optimal (synchro)modality for transportation
- Overview on vessel availability and their specifications (for future scheduling)
- Weather monitoring
- Operational data of canals (disruptions, repairs, obstructions etc.)
- Max load/ height for transport based on water levels and infrastructure
- Queue management for vessels
- Vessel scheduling optimisation based on lock waiting times, congestion
- Suggestive actions for logistic operations

7.2 Goal Based Models

In order to show the impact of the digital twin on the ecosystem, the paper provides two main diagrams, in different views: *Strategic Rationale (SR), Strategic Dependency (SD)* and *Hybrid SD/SR* which will be explained in detail in the following subsections.

Strategic Rationale (SR): This view shows all the details to be captured in the models, where all actors, dependencies, actor links and details of each actor [3].

Strategic Dependencies (SD): Compared to the *SR*, this view only represents the actors and the dependencies between each other [3].

Hybrid SD/SR: This view incorporates the previous views together, but helps emphasise on the strategic rationale of a particular set of actors [3].

7.2.1 Current Situation. This section represents a generalised overview on the current ecosystem, the high-level objectives of the roles in the ecosystem, dependencies of the roles on each other.

Figure 1 in Appendix B presents the *SD* model of the current situation, highlighting the dependencies of *Logistics Companies* and their reliance on external entities to achieve their goals. According to the model, *Logistics Companies* heavily depend on *Rijkswaterstaat* (RWS) and *Transporters*. *Transporters* are individuals or companies that provide resources to transport the goods for *Logistics Companies*.

Further examining the dependencies, Figure 3 in Appendix B details the specific aspects on which *Logistics Companies* rely to accomplish their scheduled transportation of goods. The figure outlines several general soft goals that these companies aim to achieve, such as MINIMIZING TRANSPORTATION COSTS, ENSURING SUSTAINABLE TRANSPORTATION, ACHIEVING EFFICIENT TRANSPORTATION, and FAST DECISION-MAKING. Although these soft goals are general and not specific to any one company, they represent common objectives within the industry.

The tasks that *Logistics Companies* undertake to achieve these goals impact the aforementioned soft goals. These tasks require numerous resources from external parties, introducing potential instability in decision-making for *Logistics Companies*. The reliance on external resources means that any disruption or unavailability of these resources can obstruct or hinder the *Logistics Companies*' ability to meet their goals and soft goals.

In conclusion, there is a clear dependency on external parties for *Logistics Companies*, and the fulfillment of their goals and soft goals is highly contingent on the availability and reliability of resources provided by these external entities.

7.2.2 Future State. This section visualises the impact of the digital twin on the ecosystem, with the requirements derived from the companies.

Figure 2 and 4 in Appendix B demonstrates the *SD* and *Hybrid SD/SR* models. In the new models, *Digital Twin* acts as a comprehensive data hub for multiple stakeholders, helping various roles within the ecosystem achieve their goals more efficiently by providing accurate, real-time information and optimizing decision-making processes.

The model demonstrates that the *Digital Twin* acts as a central hub, integrating and coupling various dependencies from different actors. This centralization of resources and information reduces opacity between companies and governmental or regulatory bodies, fostering more effective collaboration. Additionally, the *Digital Twin* streamlines operations for *Logistics Companies* by decreasing the tasks required to achieve their goals, offering the most suitable and optimal choices for each situation. Equipped with predictive software, the *Digital Twin* provides crucial insights, enabling logistics companies to plan more effectively for the future. Furthermore, regulatory bodies like *Port of Twente* no longer need to rely solely on reports from companies and other entities, as they can obtain relevant information directly from the Digital Twin.

8 VALIDATION

The models have been validated by 2 experts overseeing the project, and through a qualitative questionnaire their analysis has been recorded.

8.1 Experts and Evaluation Criteria Selected for Analysis

The experts selected for the evaluation of the models are the experts overseeing the project, namely the principal researcher of the multi-year project mentioned in Section1 and Engineering Doctorate (EngD) student involved in developing the Digital Twin, and were present during the interviews.

8.2 Evaluation Criteria and Questions

The evaluation criteria were centered on assessing the overall completeness and accuracy of the models in representing the ecosystem. This included evaluating how well the models captured the various elements and interactions within the ecosystem, as well as their ability to accurately reflect real-world scenarios and dynamics. The questions were directed into understanding the accuracy of the components of the i* 2.0 framework and the completeness of the model representing the ecosystem.

8.3 Evaluation Process

The experts were asked to complete a form using a Likert scale to evaluate the models' accuracy and completeness. They assessed statements like, "The model accurately covers the actors involved in the multimodal transportation ecosystem," indicating their level of agreement or disagreement. This approach provided a clear measure of the models' coverage and representation of the ecosystem.

8.4 Evaluation Results

Unfortunately, there were no feedback received from the principal researcher. So, only the evaluation of the EngD student's evaluation will be used.

Overall, the responses from the EngD student indicated strong agreement with the accuracy and completeness of the model. Their main addition on the models were on also covering the *recreational use of the canals*, and adding another requirement mentioning *alternative routes for transportation to logistic companies.*

9 DISCUSSION

9.1 Limitations

Interviews play a crucial role in this research as they are the sole data source. Unfortunately, due to external circumstances with the companies, not all intended interviews were conducted. Specifically, interviews with governmental bodies and associations overseeing the canals and the logistical operations of the companies were not completed. Consequently, this has resulted in a limited understanding of their roles within the ecosystem and their specific goals.

9.2 Quality of the models

The models were aimed to capture the high-level objectives of the digital twin by comparing the different scenarios: the current ecosystem and the future scenario where a digital twin is acting as a central hub for data and operations. Additionally, the models help create a common ground for understanding how each requirement supports the overarching goals, and an overview of requirements for future developers of the digital twin. However, there are possible areas of requirements that might not have been included in the models. Therefore, this paper can be regarded as a initial step for a more refined model in the future.

10 CONCLUSION

In this paper, the high-level goals and the requirements of a digital twin for multimodal transportation ecosystem have been discussed. Overall, *i* 2.0* provides an overview not only the requirements, but also the dependencies on each other to achieve their goals, making it a reliable framework for requirements engineering. Regarding the models, it is hoped that they provide a sufficient overview for the development of the digital twin, and act as a building block for the project.

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A APPENDIX A: AI TOOL USE

During the preparation of this work the author used ChatGPT in order to consult the academic language and structure of the work. All supplied content to ChatGPT was made by the author. The tool was used for assisting in ensuring coherent and correct academic language, and document structure. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

B APPENDIX B: MODELS

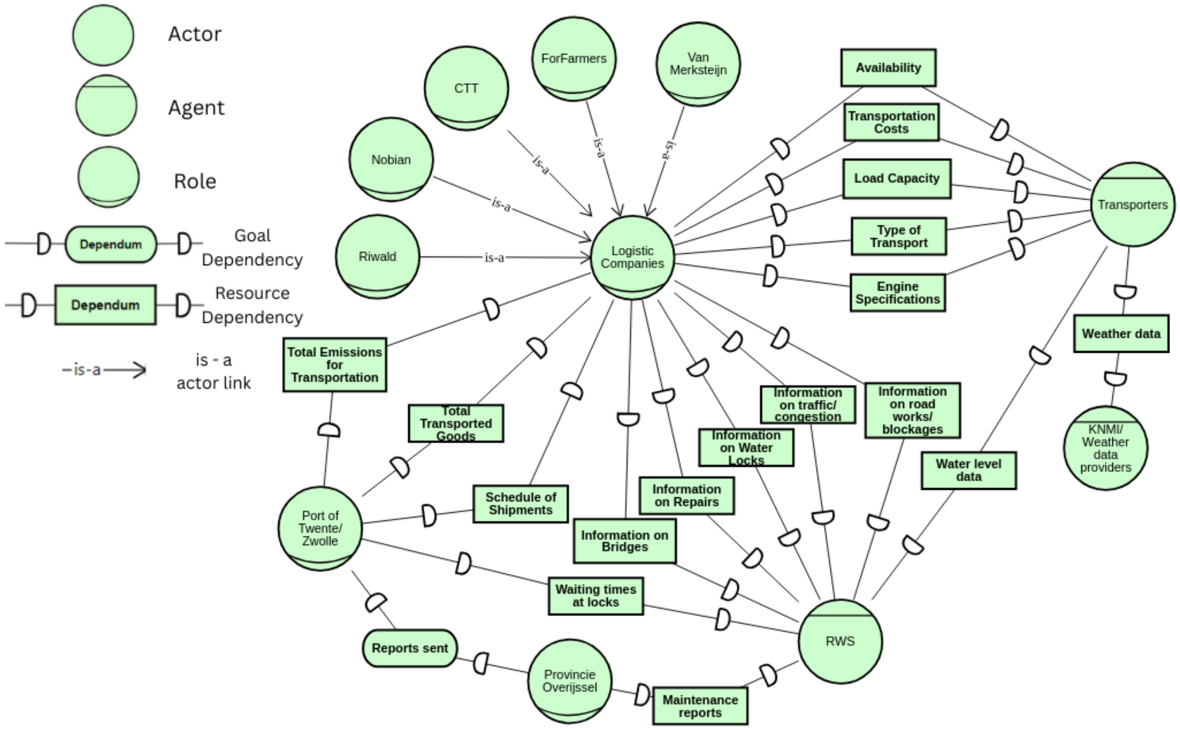

Figure 1: *SD* of Current State

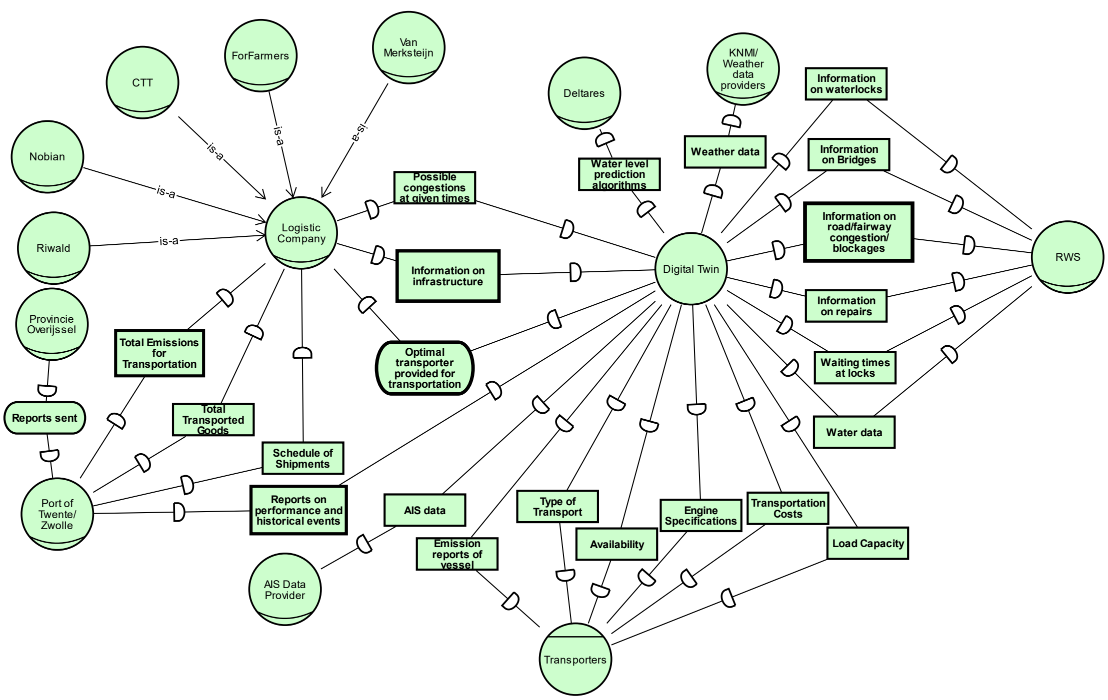

Figure 2: *SD of Future State*

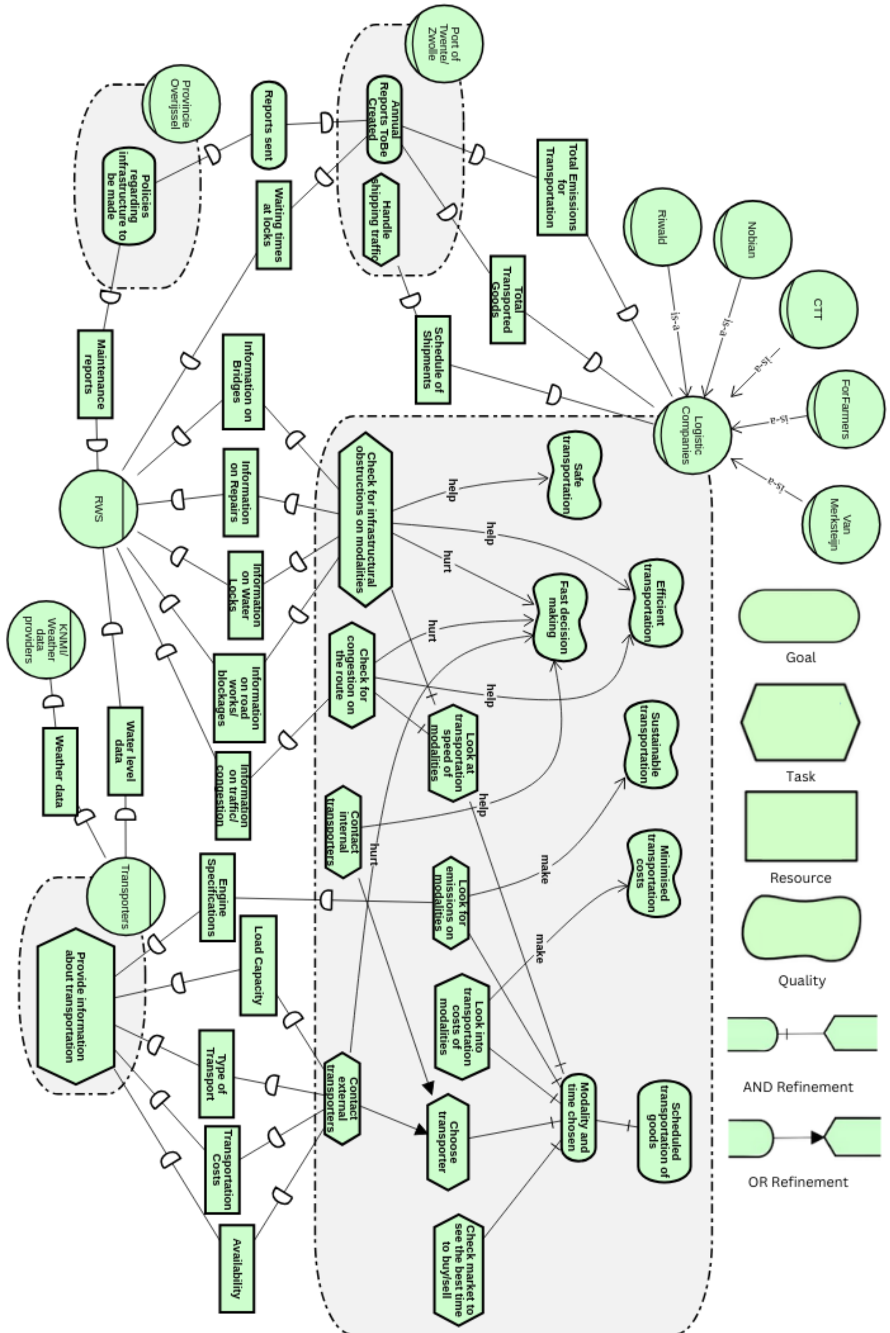

Figure 3: Hybrid of *SD* and *SR of Current State*

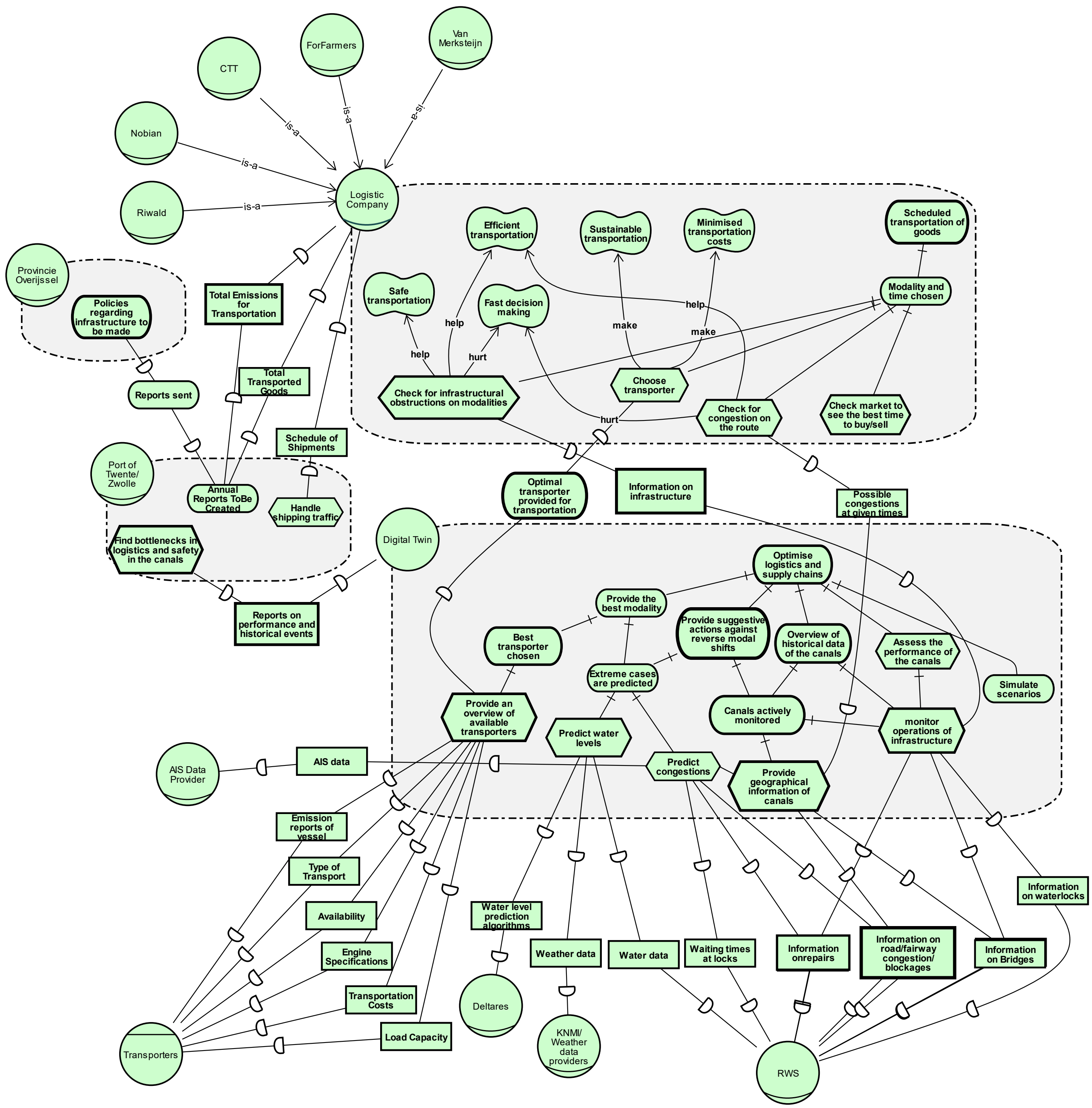

Figure 4: Hybrid of *SD* and *SR* of Future State