

Model-Driven representation of the Infrarium Serious Game

From the Network of Puzzles concept to the Unified Modelling Language notation



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Language notation

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Preface

All models are wrong, but some are useful

George E. P. Box

The following thesis is the result of the long process of finding myself in such a beautiful and fascinating world of science. After a long but still too short journey full of ups and downs into the complex socio-technical systems, starting from my fascination with aviation and ending with the love-hate relation with modeling, I can, with no hesitation, claim proudly that I know who I am, who I want to be and where is my place on Earth. Today, this place is here at TPM faculty, next to the Infrarium container, surrounded by the people I love, admire, and respect... people for whom I am grateful the most and without whom the completion of my thesis would not have been possible.

First, I would like to thank my supervisors for not only professional guidance and inspiring meetings but also for your support in discovering the realm of abstract concepts, evolving infrastructure, wicked problems, deep uncertainties, system nestedness, path dependencies, and many, many more. You never let me doubt myself and continuously challenged me to be a better researcher. Igor, thank you for showing me that modeling is not about perfection but often about messing up with the “spaghetti” of your own thoughts and ideas. Geertje, thank you for your perspective that broadened mine and for the introduction to the intriguing field of serious gaming that completely drew me in.

Second, I would like to thank Aarthi, Nourian, and the Infrarium team for your patience and help in catching up with the theory, design, and simulation. I hope to work with you soon again!

Finally, I would like to sincerely thank my family and friends. My husband Michal, for believing in me at the moments I needed it the most. I could not imagine a better partner in crime than you. My sisters, for long talks about everything and nothing. My parents, for always pushing me to be the best version of myself. My friends and Makerspace Delft community, thanks to whom I feel like home every time I am back in the Netherlands!

Paulina Zurawska-Grendysz

Delft, November 2023

Abstract

Serious Games can be used for many purposes, including studying complex, socio-technical systems. They are claimed to provide new opportunities by bringing different knowledge and fields of expertise to the table. Combined with simulations that allow for observation of the evolving infrastructure under deeply uncertain conditions, they have the potential to be an effective research tool. An example of such a serious game is Infrarium - an adaptive cyber-physical game that addresses the challenge of collective decision-making toward emission neutrality in the energy transition process within the port. The enormous space of paths that players could follow and the complexity of interactions available raise the question of whether it is possible to create such an intervention method that would allow for steering the gameflow. This research addresses this question by introducing the concept of a Network of Puzzles based on which the Infrarium model is built. After concept evolution was done while searching for a suitable tool, the System Modelling Language (SysML) was chosen. The game was successfully represented in the conceptual model that captures the system's complexity sufficiently enough to provide the coherent structure of the game within which the clarity and traceability of connections provide a design space for future development as a tool for shaping the game flow. The results are presented in the form of SysML diagrams followed by a discussion about SysML as a supporting tool in model-driven game design, within which the possibility of further vertical elaboration with requirements and limitations is justified. We have proven that further development of the game elements should not jeopardize the existing functional level of the model. The SysML model in the presented form could be used to design an intervention method to shape players' experience during gameplay.

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List of abbreviations and acronyms

AD	Activity Diagram
ABM	Agent-Based Model
BDD	Block Definition Diagram
CoSEM	Complex Systems Engineering and Management
EA	Enterprise Architect
ER	Escape Room
GO	Grid Operator
MRQ	Main Research Question
OAM	Organizational Accident Model
PM	Port Manager
SCM	Swiss Cheese Model
SM	State Machine
SMD	State Machine Diagram
SysML	System Modelling Language
TO	Top Oil
UML	Unified Modelling Language

1. Introduction

1.1 Context and motivation

The energy transition is an example of a complex, uncertain socio-technical process. It can occur along infinite paths, determining future-proof decisions embedded in the deeply uncertain problem extremely difficult to make (GridMaster, 2020). According to the GridMaster project partners, those challenges can only be solved by the collective effort of involved stakeholders.

However, these stakeholders often have different understandings of the problem, knowledge about the system, and means to tackle it. Moreover, the system evolves under the influence of the decisions made within it. On the other hand, those decisions need to happen to run the energy transition process, which can be defined by de facto all the actions performed and interactions that happened within and to the complex socio-technical system over time.

All that can be experienced by the players during the Infrarium gameplay. Infrarium is a cyber-physical serious game which one of the goals is to enhance collaboration between players. During the gameplay, the knowledge and expertise of different parties are combined to make a collective decision towards a more robust infrastructure during the energy transition in the port that the game represents.

The game infrastructure¹, knowledge of the players, their experience, and the game status² within the gameplay continuously evolve and adapt. A controlled environment with visualization of the complex nature of the material that Infrarium provides creates a safe space that enhances learning and testing. Thus, increases awareness of the energy transition challenges and broadens the horizon, which serves another purpose of serious games: to educate about the problem the game refers to (Sawyer & Smith, 2008) as occurred in Cagiltay et al. (2015), Mayer (2009), Freese et al. (2020), and Hartevelt et al. (2010).

Moreover, serious games, like Infrarium, that combine adaptive simulations with the triadic game design can embrace the deep uncertainty caused by multiple paths that the decision-makers could follow. The participation of the players might provide a real-world connection that emerges

¹ The game infrastructure consists of all the physical game elements.

² The state of all the game elements in the given timestep determine the game status.

during the game sessions. Players interact with each other, changing the game, so the evolution of their experience and the game infrastructure could be observable, which makes Infrarium a potential research tool on behavioral aspects of learning, understanding, and collective decision-making.

Nonetheless, there are several challenges considering the usefulness of the serious game as a research tool. There are a few empirical studies that evaluate Serious Gaming as a research tool (Lukosch, Bekebrede, Kurapati, & Lukosch, 2018; Noy & Raban, 2006; Freese, Lukosch, Wegener, & König, 2020). The last one is specifically useful for the case of Infrarium. Freese et al. (2020) specify relevant issues that occurred during the design, development, and use of the game as a transportation research tool. One of them is to balance the game mechanics and flow to increase the game's efficiency and usefulness. To address this challenge, the paper states that one of the solutions is to adapt the game to the player (Freese, Lukosch, Wegener, & König, 2020).

Knowing the high level of interdependencies of evolving structure and players' game experience that characterize Infrarium, the point brought up by Freese et al. (2020) to adapt the game to the player could be addressed by shaping the game flow that would inevitably influence the players' experience.

What would it mean for the Infrarium? Observing and Monitoring player's experience is crucial to understand better the forces that influence the decision-making process and, thus, the energy transition. As stated before, every decision followed by the action taken determines the change of the system and the transition towards a more sustainable, emission-neutral landscape. Every intervention made in gameplay could change the player's experience, emotional state, behavior, and thus, learning and thinking processes. Infrarium as an adaptable game to player's needs or the gameplay purpose addresses the challenge indicated by Freese et al. (2020). Hypothetically, this change also leads to increased efficiency and usefulness not only as a research tool (Freese, Lukosch, Wegener, & König, 2020) but also as an educational game and a supportive tool for decision-maker while tackling the wicked problem nature of the energy transition.

Therefore, the proposed research investigates whether it is possible to create such an intervention design tool that could shape the game flow and thus make Infrarium more adaptable to players' conditions and researchers' needs.

1.2 Research Scope and Main Research Questions

1.2.1 Core concepts and Research Objectives

Serious gaming can increase consciousness and broaden horizons (Sawyer & Smith, 2008). One of their main goals is to give people new insights and thus help them understand the complexity of the real world and experiment without consequences in their real lives by offering a safe space (Freese, Lukosch, Wegener, & König, 2020). It can be done even more efficiently by adapting the game to the players' needs and the purpose of the gameplay, as indicated in the previous section. In the case of Infrarium, this can be realized by shaping the gameflow in a desired way. This chapter introduces core concepts that are used in this research to achieve that goal.

The Infrarium game is about adapting over time. That makes the information gathered and held – the logic state of the game – even more critical. Every step ends with a changed system and gained experience, which determines the importance of learning and building, similar to the concept of a puzzle in escape rooms (Nicholson, 2015).

Escape Room is a type of collaboration game where players solve puzzles by discovering and collecting clues to reach the game's goal, usually to escape the room in which players are locked (Nicholson, 2015). In the ER literature, the term *puzzles* is used for all the activities that players need to pass, mostly using logical thinking and observation skills, from a challenge through a solution to a reward (Veldkamp et al., 2020). Nicholson (2015) identifies different designs of escape rooms based on different puzzle structures, as presented in Figure 1-1.

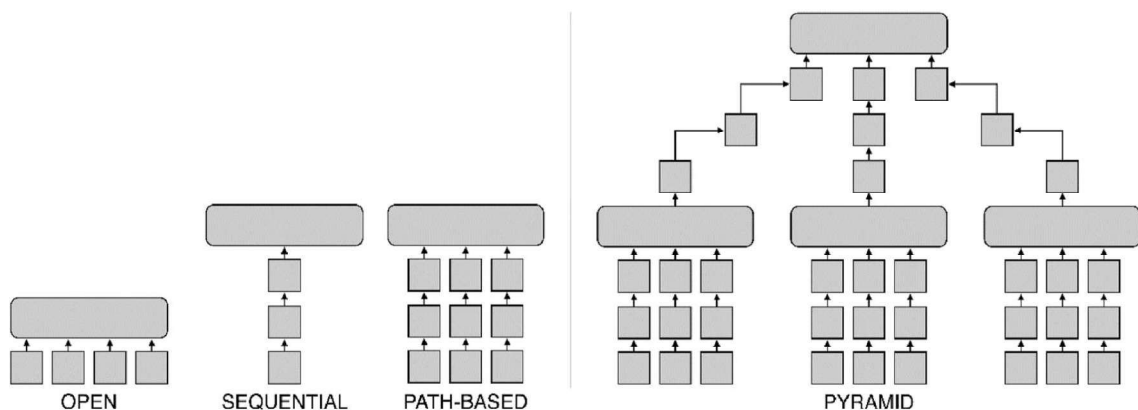


Figure 1-1: Puzzle structures based on Nicholson's way of organizing the puzzles in ERs (Veldkamp et al., 2020)

As depicted above, all the structures are organized in a way that outcomes from solving previous puzzles (squares) contribute to a meta-puzzle in which the final solution is reached either for the whole game or the certain game phase (rectangles).

However, in the Infrarium, players adapt to the changing environment, and their actions continuously drive the change of the logic state and game infrastructure. This phenomenon could be visualized more like a tree-based network of limited paths that the players can follow, as depicted in Figure 1-2.

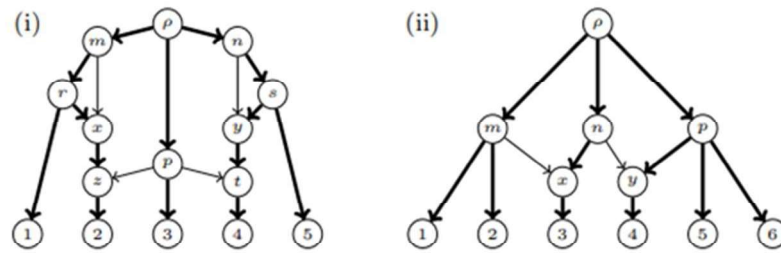


Figure 1-2: (i) A binary tree-based network and (ii) a nonbinary tree based network (Pons, Semple, & Steel, 2018)

The main difference between the presented figures is the direction of the flow within one path. As visible in Figure 1-1, there are three basic ways to organize the puzzles in ERs that could be further combined in the more elaborated structure of a pyramid. No matter which structure is used, the flow of action always goes from the bottom puzzles to one upper meta-puzzle that ends the game.

The tree-based network is more about expanding the number of paths that go from one node to another, starting with the one starting node.

In the case of Infrarium, the node could represent the game state. Starting conditions are set at the start of the game, and the rest of the paths emerge over time when players and the infrastructure change. Such a model of path dependency is more accurate for the Infrarium, even though the puzzle concept seems to suit better the game state than the node in the network. The activity that needs to be performed is more like solving a clue rather than a pre-defined guide that leads to the node with the same attributes.

Therefore, the idea of the escape rooms with puzzles combined with not typical for the ERs path dependencies and interdependencies that fit nicely with the structure of a tree-based network led to the network of puzzles concept, as shown in Figure 1-3, which was chosen as a core for the thesis and is elaborated further in chapter 4.

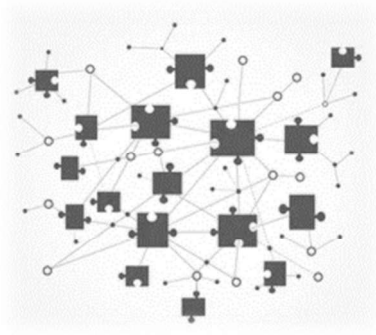


Figure 1-3: High Level Visualization of the Network of Puzzles Concept

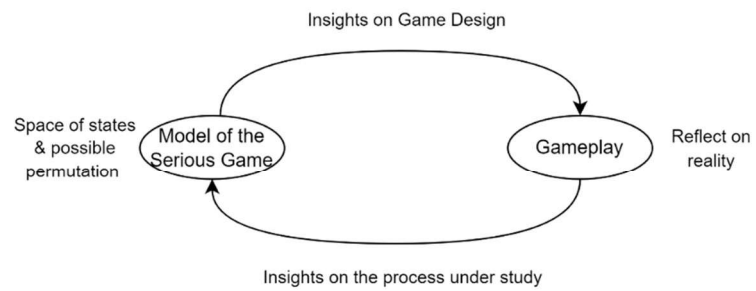


Figure 1-4: Joint concept of the game and its model

Such a representation of the game in the form of a networked model might allow for better control over the game flow by creating a design of states in which all the permutations of the game logic, player, and infrastructure states are defined, as depicted in Figure 1-4.

1.2.2 Research Deliverable

Previous sections present motivation with the core concept that inspires the design of the high-level conceptual model based on the network of puzzle concept. Although the origin of the concept of the Network of Puzzles was presented, how the puzzle could be defined in the Infrarium case and how to adapt this concept and develop further into the functional conceptual model is part of the conducted research.

To claim the model is functional sufficiently to fit the purpose of being a method to design intervention for the gameflow, the model needs to satisfy two requirements: coherence and descriptiveness.

The first one refers to the design space of all possible paths that the gameflow could follow each timestep. To use the model as an intervention tool, those transitions between all possible game states must be easily traceable and determine connections compliant with the game mechanics so that the future designer will gain insight into when and where the transition is done. On the other hand, the second requirement ensures a clear structure that would allow for identifying who or what has influence on who/what and how.

Consequently, two main aims of this research are stated: 1) to build a coherent, descriptive conceptual model of the Infrarium Game on the chosen level of functionality and 2) to adapt it so that it could be used to design an intervention method for the game flow.

Therefore, the main research question is formulated as follows:

How could the Network of Puzzles concept be used for developing the model-driven conceptual representation of the Infrarium game and further a design tool for shaping the game flow?

To answer the main research question, the network conceptual model of the Infrarium game needs to be built. By using the Network of Puzzles concept, it will be possible to provide designers and researchers with the space of game states and paths within which players can move. As a result, all possible permutations of the game states could be investigated. Thus, the model could be used to shape the game flow in a way that increases and directs the players' game experience. Moreover, adequately designed intervention could provide meaningful insights for further research on patterns observed during game sessions and thus open the way for more elaborated research in the serious gaming field.

1.3 Outline

The research plan is done using the bathtub model, presented in Figure 1-5 below. This ensures that the research addresses the challenge embedded in a real-life socio-technical complex system and thus is analyzed by more detailed theories and tools. In the upward path, the structure goes from a model itself to its translation to the context of the real problem's chosen scope. As shown in Figure 1-6, each layer of the bathtub model has sources to use (data, concepts, theories) and the expected outcomes, which are the needs required to answer the main research question.

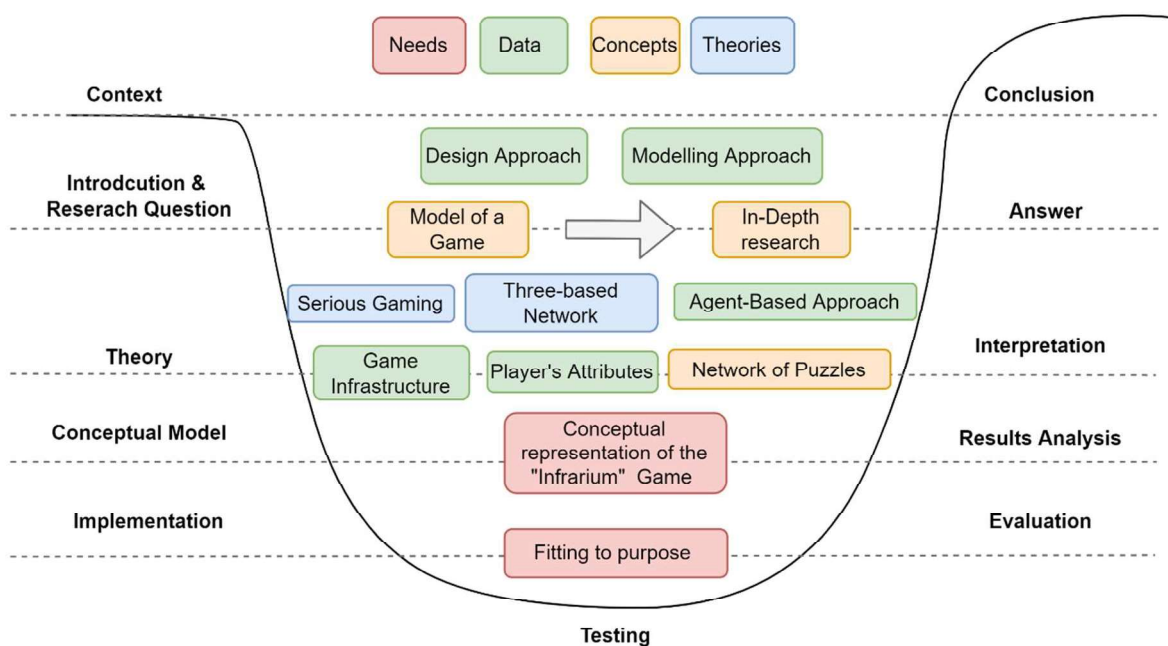


Figure 1-5: The Bathtub Model applied to Thesis Research

Following the idea behind the bathtub model, the research starts with a problem introduction and the main research question identification that are already presented in chapter 1. Other phases are shown in detail in the research flow diagram in section 2.2.

According to the model, the research can be divided into several parts, diving into the study and the corresponding parts while obtaining and analyzing results and drawing conclusions. The first part of the research is scoped down according to its context: [deep uncertainty of the decision-making process](#) towards emission neutrality of the port that Infrarium represents and the motivation behind [increasing the game's efficiency and usefulness](#) by [shaping the gameflow](#). This step determines the scope of the research conclusion: [the conceptual model of the game](#) fits the purpose of [supporting intervention design](#) to shape the gameflow. The second step introduces the problem and research question run by the context and chosen scope: how to build the conceptual model using the chosen Network of Puzzles concept. The corresponding phase is answering this question and drawing the conclusion that impacts the real world and refers to context. The third step concerns theories, concepts, and data used within the research that will further shape the conceptual model: [serious gaming](#), [tree-based network](#), [escape room puzzle design](#), and [Network of Puzzles](#). The choice of research approaches, with its motivation, is presented in the following section 2.1. Corresponding results analysis and interpretation will reflect the theoretical lenses used in the study and lead to the answer to the main research question. It implies that the way the theory is presented and chosen influences the scope of discussion, and the conceptual model determines the interpretation. Implementation of the conceptual model is the final phase corresponding to the evaluation driven by fitting to purpose check. This structure is used to create a research flow diagram and layout for the thesis report presented in the next section.

2. Methodology

2.1 Research Approach

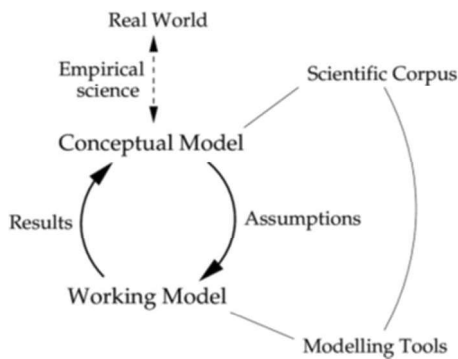


Figure 2-1: The cycle of enquiry in scientific modelling within the context of scientific investigation (Bryden, 2007)

In Bryden's (2007) cycle of enquiry, depicted in Figure 2-1, conceptual models are based on scientific corpus and empirical studies of the real world. As a result, they are one of the fundamentals to creating working models. In the context of the proposed research, it motivates the usage of two research approaches already depicted in Figure 1- 5: design and modelling.

The first one is taken while identifying and analyzing the system to formulate relevant assumptions and requirements for the model based on the empirical studies on the Infrarium Game. The modeling approach is used to create the conceptual model of the Infrarium SG based on the Network of Puzzle concept.

One of the essential driving factors for the conducted research is that interactions between players themselves and game elements in SG are crucial. Hence, the modeling part is scoped down to focus mainly on the players, which at its core is similar to the agent-based perspective. This approach allows for observing patterns occurring due to interactions between agents themselves and the environment. Furthermore, it enables answering the questions about coexistence and synergy between different elements by providing insights into complex systems (Wilensky Uri & Rand William, 2015; Nikolic, Dam, & Kasmire, 2013), in the example of which the Infrarium game is embedded into. Consequently, the AB approach allows for the identification and understanding of those interactions and mechanisms under them to further design accurate interventions during the gameplay.

What is worth noting is that the AB approach does not drive the ABM of the game. Instead, together with the system perspective, it was used to define the concept of the puzzle, adapt and define the network of puzzles concept, and build the conceptual model of the Infrarium game using the abovementioned approaches.

2.2 Research Flow Diagram

Based on the cycle of enquiry in scientific modeling within the context of scientific investigation proposed by Bryden (2007) and the bathtub model (Figure 1-6), research steps were formulated, each driven by different research approaches.

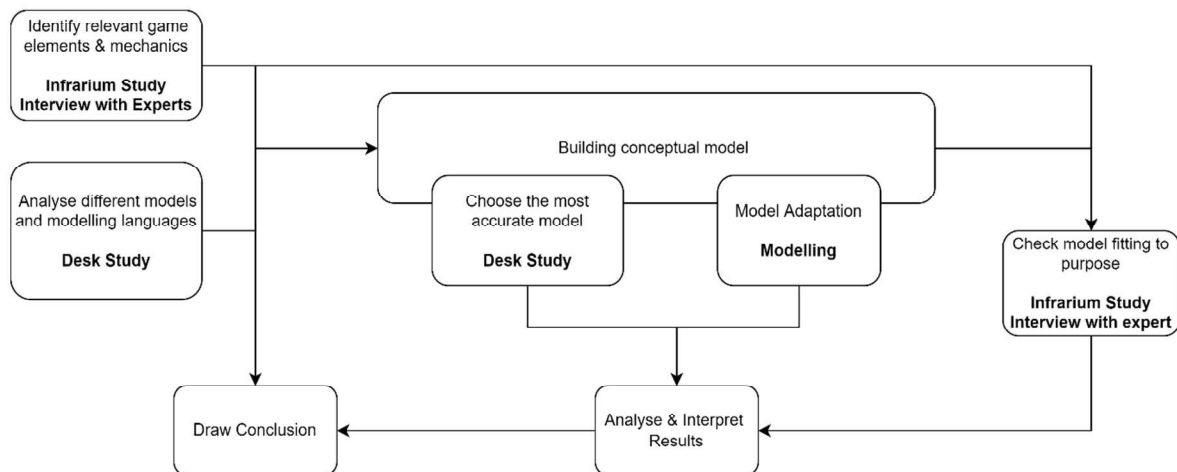


Figure 2-2: Research Flow Diagram

Each of the steps presented in the research flow diagram above needs to be followed to answer the main research question. The first two are about the Infrarium features and a choice of the accurate modeling tool to capture sufficiently all the critical elements and mechanics of the game and characteristics of the network of puzzles. To do so, first, the Infrarium Study was conducted. The main purpose was to get to know the game better from a different perspective so that all the relevant game elements and flows were identified. Simultaneously with the Infrarium study, the concept of the network of puzzles evolved, and as an outcome, the most relevant modeling tool was chosen. This phase is driven mainly by the design approach and is part of the theory level of the bathtub model.

The third part combines the results of the previous steps. It merges them into the model-driven representation of the Infrarium, which was obtained by following an iterative process driven by a feedback session with an expert and the evolution of the concept presented in chapter 4. Subsequently, the research goes down in the bathtub model to the implementation layer. It is fully modeling and creative work tested by multiple test runs conducted using the existing simulation of the Infrarium game and, once again, feedback sessions with experts due to time limitations.

Part four consists of a theoretical check of the model fitting to purpose. This part is elaborated on within the reflection and discussion part and provides valuable inputs for further studies on model-driven game design. The research flow visualizes those steps in Figure 2-2: Results Analysis, Interpretation, and Conclusion.

As described above, all the steps correspond to the previous parts of the research placed on the same layers of the bathtub model, which is also visualized in the research flow diagram's data & knowledge flow arrows. This way, the coherence of the study throughout the process is ensured, and the impact on the real world within the scope is motivated.

3. Infrarium Design

Analysis

The first step of the research, as depicted in the Research Flow Diagram, is to identify the relevant game elements of the physical player's environment and understand the mechanics that rule the gameplay. Understanding what is hidden behind bars and how the logic state of the game is determined is crucial for conceptual modeling. In this chapter, the basic mechanisms and game elements are introduced and briefly explained to ensure the final model is understandable for the reader. Nonetheless, getting to know the game from the inside, learning how it was designed and why was a pivotal base for the final model. Therefore, it is highly recommended for the modelers willing to work further with the presented model to also read Appendices A-C, where the detailed study with the more elaborated description and game pictures documentation is presented.

Infrarium, as indicated in previous chapters, is much more than a commonly known physical game in a container or a pure simulation-based virtual game. It combines the advantages of both physical environment, inspired by the escape room game design, where players can interact with the game and between each other, and simulation of reality hidden behind the bars that run the whole system, driving the evolution of player's experience and game infrastructure. This is much more than what is visible to the players. The information collected and the logic state are much broader and could be considered the heart of the game itself.

Nonetheless, the chosen agent-based perspective scopes down this study to the perspective of the player only. The game is investigated as an environment of different resources for the players with different roles: port manager, grid operator, and top oil station. However, important comments on certain relations between game elements that are not directly revealed to the players are separated in the section marked as **Unrevealed**. For modelers and interested parties, the source code with comments is available at <https://gitlab.tudelft.nl/inikolic/infrarium>.

Although each player's hardware environment is a separate physical space called a station, visible in Figure 3-1, players start with the same set of guidelines and information about the port, main goal, challenges to be faced, and type of physical connections that might be problematic for the players to plug or unplug during the game. All materials are attached and can be found at the end of the report in Appendix A.



Figure 3-1: Infrarium entrance, the view on the port manager station (left) and grid operator station (right)

After the briefing, players are assigned to the corresponding stations and are limited regarding resources to their surrounding environment and other players. Each of the stations has different artifacts that players can use, sources of knowledge, and information about the port, presented in Appendix A.2, needed by other players to address each of the three challenges presented in Appendix A.3. More detailed list of all game elements with their attributes is available at the project site: <https://gitlab.tudelft.nl/inikolic/infrarium>.

In Figure 3-2, the simplified structure of the Infrarium is presented. Solid line visualizes physical direct connection, like cables, between two game elements or social interactions between players. The dashed line represents information flow between game elements and usually is not revealed to the players. All these relationships and stations are further elaborated in subsections to present the isolated perspective of each player.

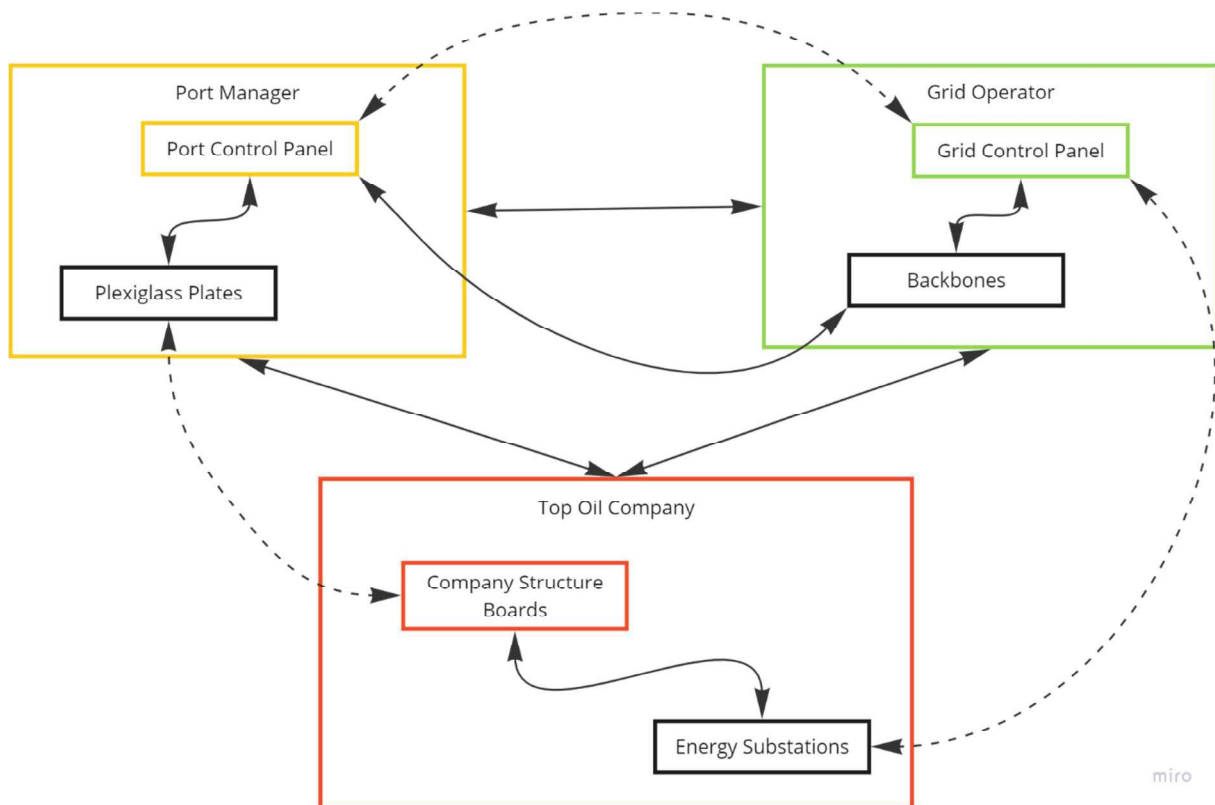


Figure 3-2: Simplified Infrarium Structure with chosen relations between the game elements

3.1 Port Manager Station

The Port Manager controls what type of energy source, electricity or/and hydrogen, is available for the port and decides which companies will settle in the port and which will leave. They can do that by adding new company plexiglass plates or removing the old ones from the control panel slots presented in Figure 3-3. Each slot can be occupied by only one company plate.



Figure 3-3: Port manager control panel and company plates.

At the beginning of the gameplay, the PM is in charge of connecting the whole port, with the cooperation of the grid operator, to the offshore windfarm farm that provides electricity (see Appendix A.3). Afterwards, he detached the coal factories and joints companies to the port with regards to their specifications. From the moment of settlement in the port, the company uses a given amount of energy from each source, generates declared revenue for the port, and emits pollution, if applicable. Similarly, the PM can invest in hydrogen plants or import hydrogen. All details about available companies, their requirements, and specifications are attached to the report in Appendix A.2

Unrevealed

1: As visible in Figure 3-3, the port manager control panel is divided into twenty-four slots. Each of the four slots corresponds to the one grid operator distribution panel sector presented in Figure 3-4. The energy consumption of each type is collected from every four PM panel slots, and the collective demand is sent to the grid operator, who needs to connect the corresponding sector to the grid. These connections are presented in Figure 3-2. If the demand is higher than the capacity of the infra cables, the grid is overloaded, and none of the companies placed in the four slots work. Players can notice that by monitoring the level of CO2 emission or revenue on the screens attached to each station. GO has the extra tool to identify the grid overload: capacity bars placed next to each backbone. All mentioned elements are documented and presented in Appendix A.

2: Top Oil Company is assigned to the slot unless PM removes both plates. However, if the grid is overloaded, the demand will not be satisfied, and consequently, the company will not be able to operate. TO player can notice that as the whole company shuts down. However, this is only one of several options that end like this.

3.2 Grid Operator Station

The Grid Operator (GO) is responsible for the main energy infrastructure of the port. They can control the energy flow by connecting and disconnecting port sectors to the grid, as visible in Figure 3-4. The GO is the only player that knows the characteristics of the three main grid elements: cables, pipelines, and backbones (see Appendix A.2). They also monitor the capacity level of each backbone. During the hydrogen transition, the GO changes the gas supply infrastructure to the hydrogen by turning an adequate backbone while ensuring the grid is not overloaded. Backbones are partially visible on the right picture in Figure 3-1 and are represented by the large pipelines below the ceiling.

To maintain the grid, the GO uses three types of cables, gas, hydrogen, and electricity, while connecting the port sectors to the grid (corresponding backbone – gas, electricity, or hydrogen) and three types of pipeline, gas, electricity, and hydrogen, while connecting to the backbones to the power supply source. The grid operator distribution panel with connecting points and all three types of cable are visible in Figure 3-4 below.

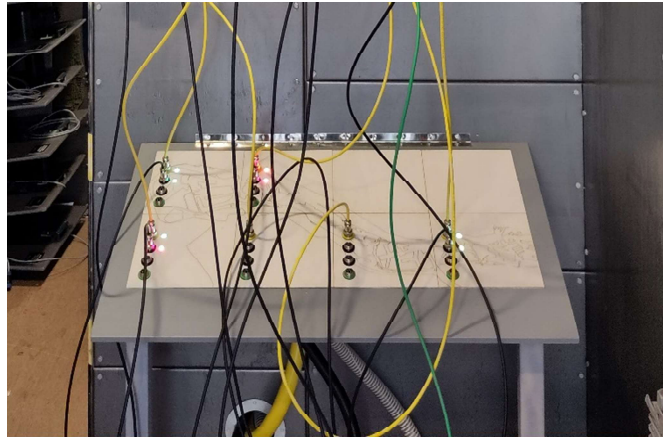


Figure 3-4: Grid operator distribution panel

Unrevealed

The GO control (distribution) panel is also a connection point for the Top Oil Company energy substation to the grid. Below the panel, there are three plugs for connecting three types of pipelines, each for a different energy source.

3.3 Top Oil Company

At the beginning of the game, the TO company is connected to the grid and activated by the plexiglass company plate placed in the PM control pane. The main challenge for Top Oil is to switch to the new office and transition towards sustainable energy while maintaining the steam kettle and furnace. The list of all the assets with picture documentation can be found in Appendix A. The examples of the asset and energy substation are presented in Figure 3-5 below.

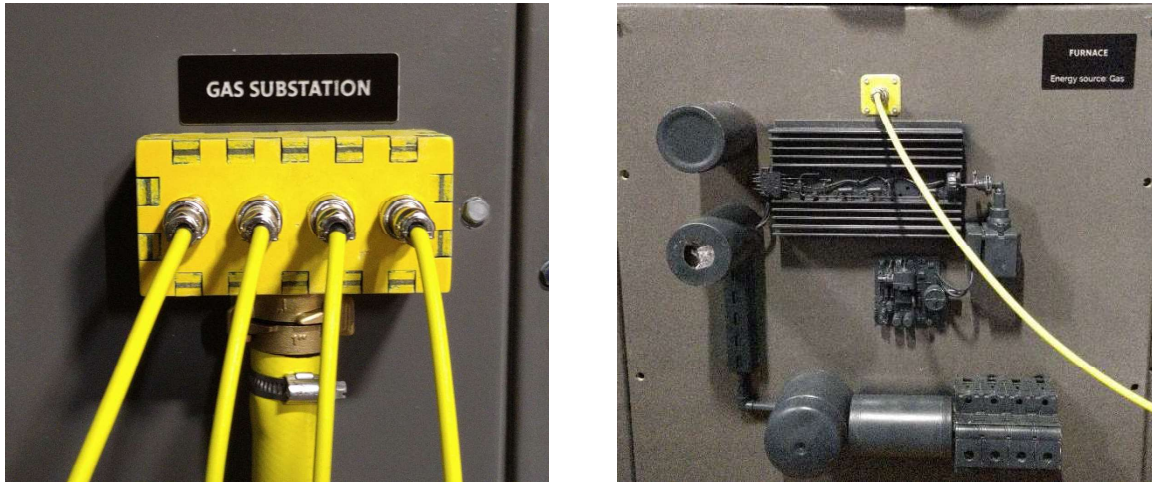


Figure 3-5: TO Company gas substation (left) and gas furnace asset (right)

The above-mentioned challenge can be addressed by switching all the gas-powered assets to electricity or hydrogen ones. However, it needs to be done by collaboration with other players as the TO player does not have direct access to the grid and cannot decide which type of energy is in use at a certain point of the game. Moreover, the company stays operational unless the PM detaches the company plates from the control panel. All the assets owned by the Top Oil Company, except for the office, could be changed from gas to electricity and hydrogen energy. The player has all the details needed to optimize the company, like investment costs, demand, and CO2 emission, which can be found in Appendix A.2.

Unrevealed

As the Top Oil is already connected to the grid and to the specified port sector, tight cooperation with the grid operator is needed during company maintenance to not overload the grid during the energy transition process.

Although we did not capture all the connections, mechanisms, and relations in this chapter, the presented level of detail is assumed to be sufficient to follow the motivation and choices made while conceptualizing and building the final model of the Infrarium game. To gain more insights and details on the Infrarium design and used game elements, we strongly recommend reading whole Appendix A.

4. Concept Evolution

After the Infrarium game design analysis performed in chapter 3, we evaluate the Network of Puzzles concept presented in chapter 1.2 to check its accuracy and level of detail that can be obtained by applying it to the Infrarium conceptual model.

4.1 Multilayer Network of Puzzles

From Chapter 1.2.1, it can be stated that the network of puzzles concept imposes an interpretation of the game as a network of predefined game states that change over time, at a certain timestep of the gameplay called *a puzzle*. From the escape room game-type literature, the puzzle determines a fixed problem, a challenge to be solved that ends with a reward (Nicholson, 2015; Veldkamp, et al., 2020). In the case of the Infrarium, this concept needs to be modified and adapted. In a basic assumption, the puzzle is more about the decision that needs to be made to solve the challenge that emerges because of the specific game state the puzzle represents. It is more about what is going on at that specific moment of the gameplay: *who can do what with whom and to what*. The time aspect is excluded as the puzzle is “frozen” at that specific timestep. States transition that happens over time determines the change of the puzzle as the new state of one game element can reveal new possible paths or clues. Therefore, the puzzle itself consists of different entities and their states that can sufficiently describe what is happening at that specific point in time during the gameplay. The idea is that after the decision is made, other puzzles become available, and the transition between states occurs, creating the structure of paths that the gameplay could follow or the player could take, depending on what will be done within the original puzzle.

The first question arises: how to define those entities to capture game mechanics, elements, and logic state. Following the guideline of *who can do what with whom and to what*, three elements appear:

- Set of action that might, but does not have to:
 - reveal hidden resources;
 - be performed by the player;
- Player's attributes that might, but do not have to, influence the decision to or not to perform a certain action; note: the player is further considered as a game element;

- Resources that are available or hidden and might be used or must be used to perform certain actions.

The second question is how to represent the transition between puzzles that could be caused by more than one factor in a graph of edges and nodes when the edge is usually characterized by only its weight and direction, which is the case in three-based network presented by Pons et al. (2018).

So far in the literature, there are several examples that outline the need for establishing a more elaborated network in which the edges are defined additionally by their direction, weights (Barrat, Barthélemy, Pastor-Satorras, & Vespignani, 2004) or existence constraints (Holme & Saramäki, 2012) to better understand and describe the complexity of interdisciplinary systems (Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006). In the more current research, different terms have appeared, from the "network of networks" to "multidimensional networks" that are used to describe the network that consists of multiple networks or includes different interactions between entities (Kivela, et al., 2014). Kivela et al. (2014) differentiate those terms while proposing a standardized general definition of the multilayer network, which, for the purpose of this research, is adopted:

"Multilayer network consists of a set of nodes (...) that can be connected to each other in a pairwise manner both within the elementary layers [intra-layer edges] and across the elementary layers [inter-layer-edges] (...) [where] each elementary layer contains some subset of the node(...) and have number d of aspects such as a combination of elementary layers from all the aspects is called a layer $L = \{L_a\}_{a=1}^d$." Kivela et al. (2014)

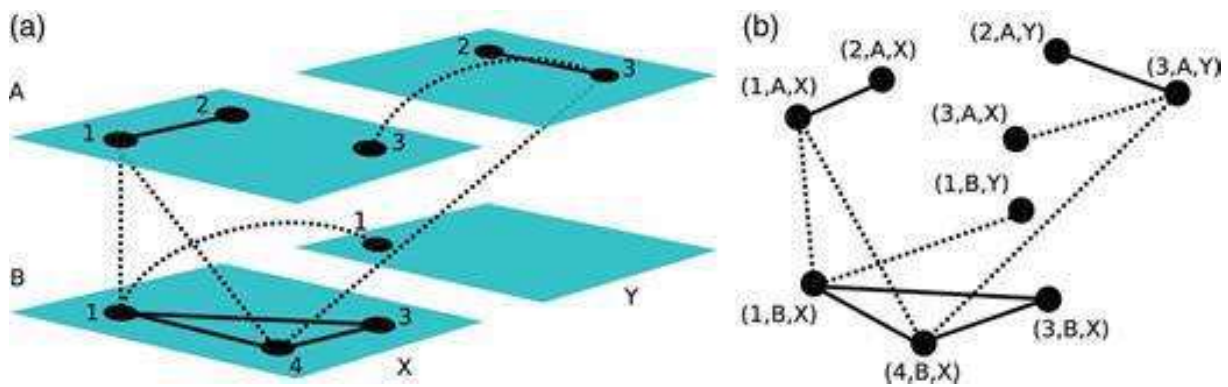


Figure 4-1: (a) General Multilayer Network M (b) graph representing Multilayer Network M (Kivela, et al., 2014)

Kivela et al. (2014) also provide a clear visualization of their definition. In Figure 4-1, the general model (a) and graph (b) of multilayer network M with two aspects is presented. In the graph, we can see that each node is determined by not one but three factors: the node itself in the overall set of nodes, the elementary layer for the first aspect, and the elementary layer for the second aspect (V, L_1, L_2).

$V = \{1,2,3,4\}$ $L_1 = \{A,B\}$ $L_2 = \{X,Y\}$ $L = \{(L_1, L_2)\}$; V – total set of nodes

L_1 – set of elementary layers for aspect 1 L_2 - set of elementary layers for aspect 2

Although the possibility of introducing as many numbers of aspects as desired, the nodes, according to the authors, must be aligned regarding attributes and presented characteristics. In the case of the Infrarium, this limitation refers to the complex nature of interdependencies between game elements, where each aspect corresponds to the type of relations and connections, which moves us back to the first question.

While the set of actions and status of the resource is quite straightforward and could be implemented as a node attribute, the characteristic of the player is much more complex and could be represented by the multilayer network itself. For the high level of conceptualization, where drastic simplification could be done without significant disturbance to the general vision, for the desired functional conceptual model, the player is crucial to be defined in a much more detailed way.

As briefly presented at the beginning of this section, all the entities that define a puzzle interact with each other. Also, the players could interact with each other, changing the status of different players' characteristics, which is not implementable as in the high abstract definition of a puzzle, players are not distinguished.

Consequently, a new concept is needed to capture the complexity of identified interrelations while ensuring the model's coherence and descriptiveness. One of the tools that seem to be suitable to fulfill these requirements is the Swiss Cheese Model (Reason J. , 2000), which, when adapted according to the intra- and inter-layer edges, partially addresses the faced challenge.

4.2 Swiss Cheese Model

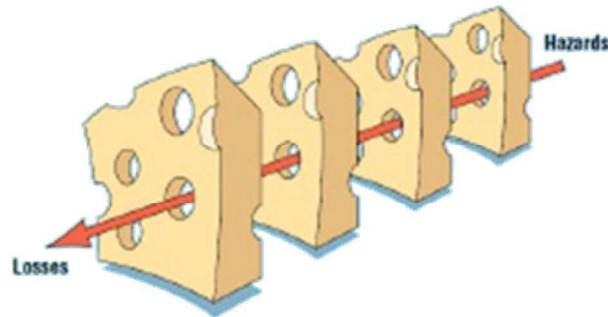


Figure 4-3: Adapted OAM to the Swiss Cheese Model
(Reason J., 2000)

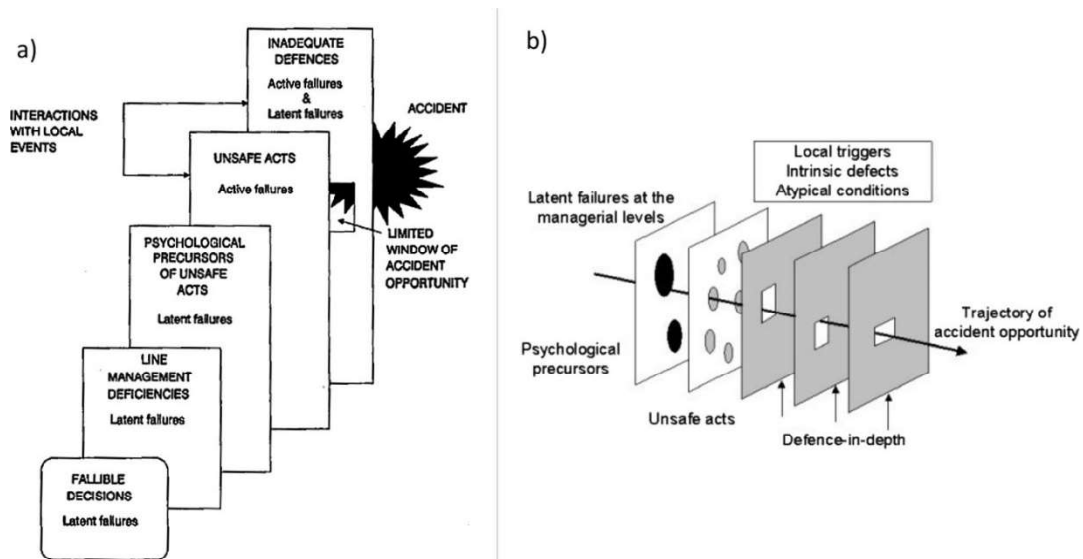


Figure 4-2: First OAM (Reason J., 1990)

In 1990, Reason & Wreathall published their work about the concept of conditions that have to occur on a path to an accident (Larouzee i Le Coze, 2020). The original Organisational Accident Model presented in Figure 4-2 (a) was designed based on the analysis of human factors and the importance of the psychological factors in errors that happen on the organizational level, including human source management or occasional predispositions. Further, the model was adjusted to the concept of barriers that need to be passed through holes to make an accident occur, and the trajectory of accident opportunity became visible, as presented in Figure 4-2 (b).

The year after, Reason adjusted one more time the OAM and generalized it to the point the new SCM is well known and used in different fields of research where human factors play a significant role in a system (Larouzee i Le Coze, 2020).

As presented above, Swiss Cheese offers the path to make an event happen, created by the holes in each Swiss Cheese layer positioned in one line. The holes represent the critical factors that need to occur to cause an event, and it can happen only if the set of such crucial factors aligns.

4.2.1 Infrarium vs. SCM

Implementation in the Infrarium case is an almost direct implementation of the above-defined SCM. Similarly to a multilayer network, each layer adequately represents one component's one-dimensional network of states. The holes represent those states in which that component could be. Processes behind the status change follow the rules determined for each layer separately. As presented in Figure 4-4, the layers, rules, and holes must be defined to represent the Infrarium game in such an adaptation of the Swiss Cheese model.

Based on the game analysis presented in Chapter 3, the three components with their layers could be distinguished: players, hardware, and resources. To move forward in gameplay, each component needs to be in the required state to make the action possible that is represented in a model as an intersection between layers.

The player layer is a graphical representation of all possible states the player could be in. The first requirement is for the players to be in a state that allows them to act. This chapter provides a deeper evaluation of that statement with the rules defined further in this chapter.

The resource layer is a graphical representation of all possible states the resource could be in. It is understood as all the information the game environment offers the players. Therefore, the second requirement is for the resource layer to provide enough information to make players' actions possible.

The hardware layer is a graphical representation of all possible states the game's hardware could be. The hardware here is understood as a part of the game with which the player interacts. Though it is called hardware, that term also includes software and all the game logic states presented for the player in the form of hardware. The third requirement is for the playable features to be in a working condition that allows for the action between the game components and the software behind it that drives the data from the hardware through the logic state of the game and thus follows the information back to the players.

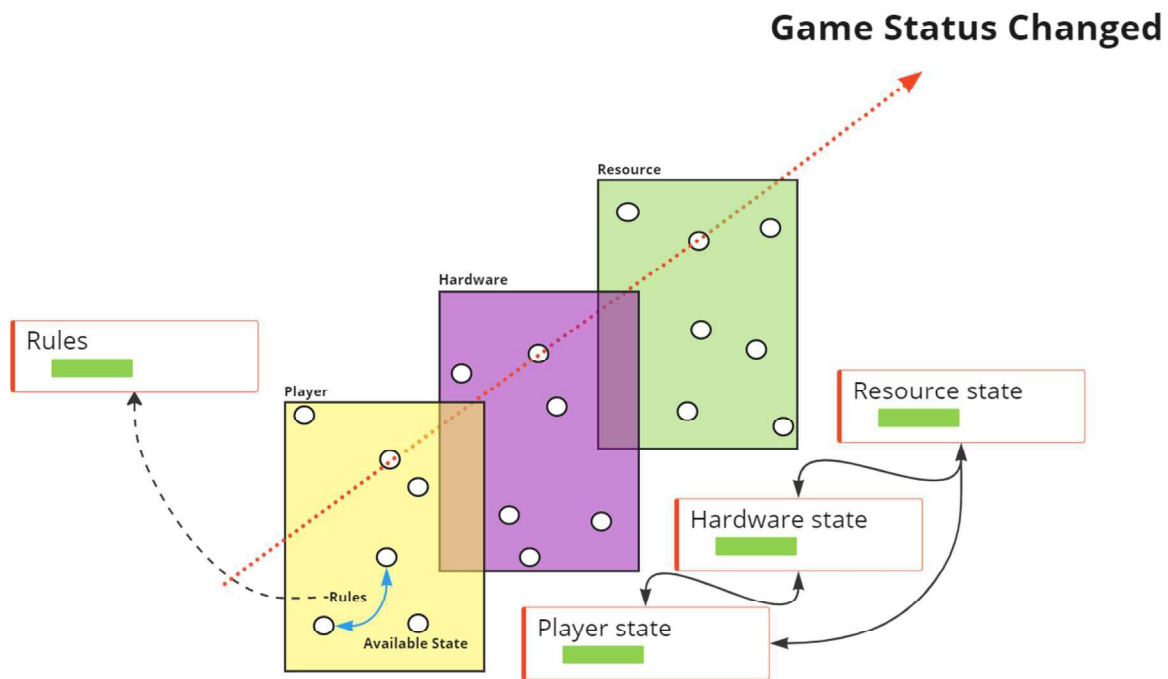


Figure 4-4: Adaptation of the Swiss Cheese Model to the Infrarium environment

Having identified the layers, each component's state's attributes need to be specified. As presented above, all three components have different characteristics. Thus, those states need to be defined separately for each layer.

From the player's perspective, each resource can have three generalized states during the gameplay: hidden, available, and possessed. For example, the information players could possess could be hidden at a certain point in the gameplay. Then, it could evaluate in time to be directly available or not.

Hardware, though, is much more complex as it consists of different elements with entirely different characteristics, like playable tools (e.g., cables), functional features (e.g., backbones), and informative decorations (e.g., screens). Moreover, behind the term 'hardware,' as explained before, the logic state of the game, software implementation, data storage, and communication between them are hidden. Thus, each element's standard status definition is tough to find. Playable tools must be accessible to the player and compatible with adequate functional features. Functional features must be 'active' and compatible with adequate playable tools. However, the "active" term is a broader description for being recognized by the game logic, assigned to the correct data sets, responsive to received information, and much more. To understand better how complex it is, let's consider the example of the backbone of each source of energy type. First, it needs to be recognized by the game itself as a backbone. That implies the grid infrastructure that allows power to flow between the source and the grid control panel to be further distributed

among companies in the port. Then, the data about the energy type source and the pipeline capacity needs to be assigned correctly and updated during the gameplay according to the dataset for each moment of the game. After all, each backbone has its ports allowing connecting by the cables (playable tool) to the grid control panel. Each port needs to 'work': recognize the connection to the cables and the amount of electricity that flows through each line. Ultimately, the spaghetti of relations between different elements can hardly be followed. Based on the theory presented in Chapter 4.2, the Swiss Cheese Model is not the most suitable way to address this challenge.

Then why not create more easily groupable layers with more homogenous characteristics? That would fit more appropriately based on the previous definition. Nonetheless, the relationships between elements remain the same, and with more layers, more relations and dependencies between layers are created, which is not easily fixed in this model. Even assuming that part of those relations is an effect of a process depicted as a black box, for now, the rising number of relations between heterogenic layers becomes more and more problematic as the SCM is not suitable to visualize any of those relations.

The next step is to define the status of players. A scenario-based diagram, presented in Figure 4 - 5, was created to visualize and thus help to identify adequate attributes that could characterize the player's state and the player's path within each timestep of the gameplay.

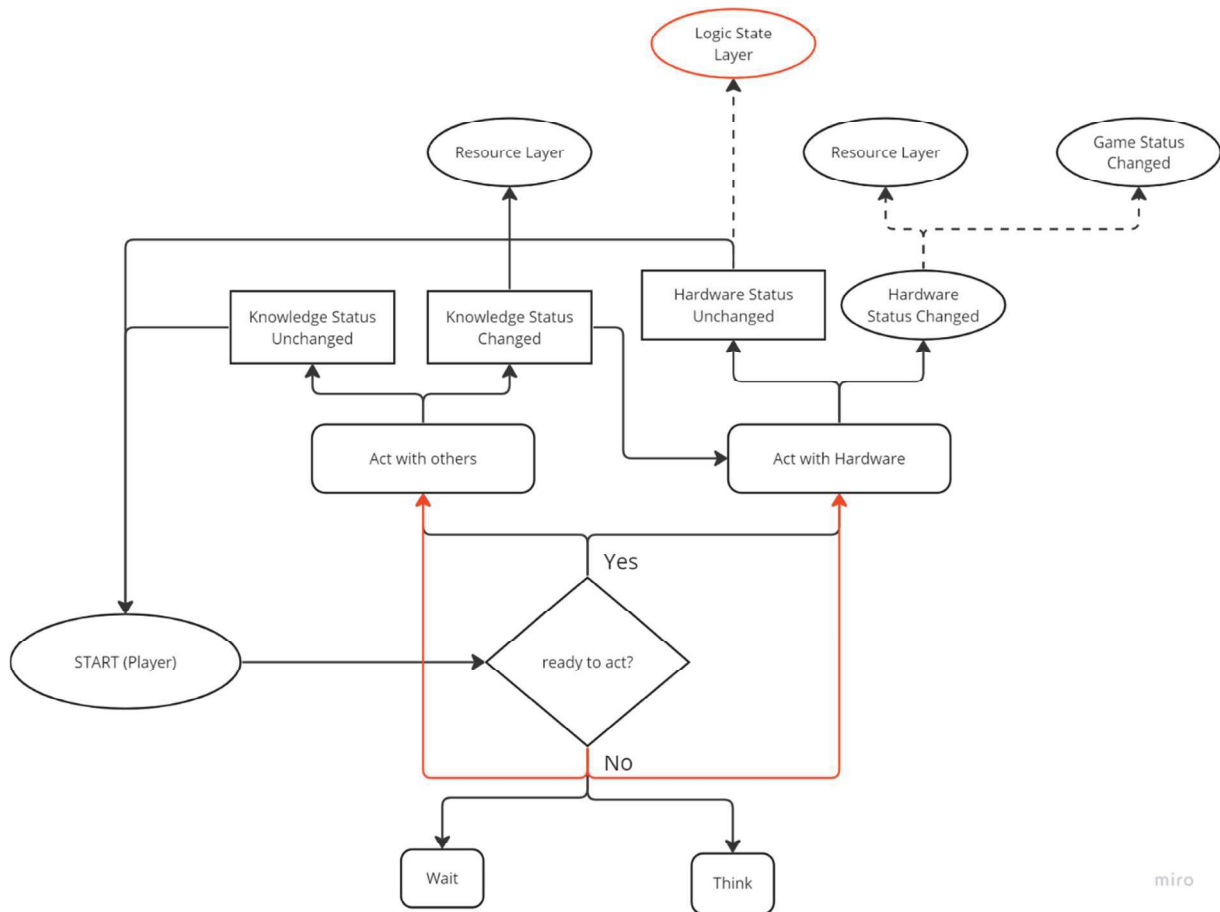


Figure 4-5: Simplified diagram of the player's behaviour during gameplay

The diagram shows the simplified path for the player to decide what to do during gameplay. Although several limitations affect whether the player is ready to act, like emotional state, knowledge, and independence, the primary status that can be distinguished is the player's readiness to play, characterized by the boolean values, true or false. The process behind it is assumed to be the 'black box' for the scope of this research. However, factors influencing the processes behind those black boxes, like the emotion state of the player, could be directly connected with the independence and importance of the player's role during gameplay, the knowledge that the player already possesses, and the education process during the gameplay.

The next step is to define the rules to be followed in each layer to change the status of the component. Again, due to the different characteristics of the states, those rules need to be established separately for each layer to fit the status change process best.

However, from the previous analysis, different relations between the layers are noticed. Players act with game infrastructure, and by that, their action drives the status change within the hardware layer. Their actions could also change the status of hidden resources, which is also connected with the evolution of the hardware. The question appears as whether the players' layer is independent and drives the change of the other layers, but the answer is also not so simple.

Indeed, as the example above shows, players' action causes the change, though their readiness to act also depends on the resource and hardware states. They need to have the resources and infrastructure available to act. This approach again leads the research to complex, tangled 'spaghetti' relations.

Also, requirements for the status to change are not that easy to represent in the SCM. Again, different needs can be distinguished and end up with the relations between the layers' requirements, like in the example above. One of the requirements for the resource to change status from hidden to available is the hardware change. In contrast, the requirement for the hardware to change status from non-active to active is the player status to be ready to act, which depends, among others, on the knowledge influenced by the resource state.

Finally, the Swiss Cheese turned out to be, like the multilayer network of puzzles graph, not suitable for visualizing and modeling interrelations on the desired level of details. Therefore, the need for a more traceable relationship model that explains the game's complexity is even more evident. Also, as the trial to adjust Reason's model showed, clarification of the notation is required. Therefore, the search for other possible models and language was established and presented further in the thesis.

Nonetheless, all the relations identified during the given phase of the research are additionally used and implemented in the newly chosen approach presented in Chapter 5.

4.3 Unified Modelling Language

As motivated in the previous section, another notation and language is needed to capture the complexity of identified interrelations while ensuring the model coherence and descriptiveness. One of the tools that seem to meet the above-mentioned requirements is Unified Modelling Language, which better catches the core of the complexity of the decision-making process under deep uncertainty (Bielli, Boulmakoul, & Rida, 2006; Vieira Park & Castillo Brieva, 2010).

A significant advantage of UML is a standardized way to model different aspects of complex systems by using two main categories of diagrams: structural and behavioral ones. Both of them support design and modeling on a higher level of conceptualization, both hardware and software systems on different levels of detail, and focus both on the functional and non-functional aspects of the system or process (Sparx Systems, 2023).

4.3.1 SysML

Although many of the primary studies in serious games rely on UML (Miguel, et al., 2022), Systems Modelling Language, which is a designated part of the UML adjusted to more system perspective, seems a better option because of its characteristics and purpose. SysML is mostly used for more abstract relations, objects, and blocks, and thus, its notation, though based on UML, is slightly changed. SysML introduces new elements, objects and blocks that are much more general and flexible than the UML classes, which allows for modeling both software and physical systems that continuously interpenetrate each other (Sparx Systems, 2023). Even though, according to the outcome of the literature review conducted, SysML is not used yet in serious game projects, existing literature on UML-based serious game projects argues that some extension to the UML is needed as it does not capture requirements that investigated serious games have (Miguel, et al., 2022).

Therefore, the SysML notation is used for further design and development of the Infrarium model. To ensure clarity of the report, from that moment on, the SysML notation is used to explain, describe, and motivate the application of available features; thus, the usage of a SysML glossary (Appendix D) is recommended.

Similarly to the UML, SysML differentiates two types of diagrams: structural and behavioral ones. One of the most fundamental structures while creating the SysML model are Block Definition and Internal Block Definition Diagrams. BDD captures the system components and their interrelationships. The blocks might include both hardware and software elements, and connectors could represent different types of relations like information flow, dependencies, or communication paths. Internal BDD defines further the structure of the block used on a higher-level diagram. Such a division of structure and way of visualization provide the desired level of details that can be modeled while ensuring the traceability of relations.

State Machine Diagrams and Activity Diagrams are considered both representations of the behavioral type of diagrams but with a different focus. SMD captures the behavior of the system element as a set of its states and transitions between them, while AD shows the control flow through a series of actions to be performed in order to complete the corresponding activity. Both diagrams are crucial to represent detailed relationships between BDD blocks and paths that players can follow that are not included in the structure type of diagrams.

SMD represents not only software states but also physical states. The transitions represent the events or conditions that cause the system component to move from one physical state to another. They illustrate how an element can move between states, classifying its behavior according to

transition triggers and constraining guards. Moreover, SysML introduces additional constructs for SMDs, such as state variables and signals, which, again, can add more detail and context to the diagram, particularly with a combination of other diagrams.

Activity Diagrams might be combined with SMDs to show how the system or its sub-components respond to different events. The activities and actions may be linked to system components, such as blocks or parts, to show how the system architecture supports the modeled behavior. ADs could also present additional information, such as the inputs and outputs of the activities or the conditions under which specific actions are performed. Additionally, activity diagrams can include other constructs, such as state machines and decision tables, which can be used to represent more complex behavior (Sparx Systems, 2023).

The next chapter introduces the SysML approach, which is combined with other findings from previous analyses of both the Multilayer Network of Puzzles and the Swiss Cheese Infrarium Adaptation model to address thesis objectives and MRQ.

5. Conceptual Model

To untangle the 'spaghetti' of the complex behavior of the system, there is a need for a language and adaptable model that addresses the challenge of following the logic and complex structure of the Infrarium.

Several concepts were combined to answer this need and create a language that provides traceable logic flow.

The model was designed and developed with Enterprise Architect v16.1 and can be found on the open-sourced GitLab Infrarium project available at <https://gitlab.tudelft.nl/inikolic/infrarium>.

5.1 Infrarium in SysML

SysML, with its diagrams, is an example of the language that addresses the difficulty of capturing the complexity of relations and the behavior of Infrarium. Blocks, Objects, and Relations are a basic notation for the conceptual model for which the choice of the available diagrams is crucial to grasp the complexity of Infrarium sufficiently. Therefore, the SysML-based model can be perceived as a vital step to achieve that and, if successfully implemented in the existing Python environment of the game, can provide the tool to steer the game flow by indicating all possible state permutations and showing corresponding changes of the states in different game components. However, due to the limitation of time and scope of the thesis, implementation to the Python environment is not included, though highly recommended.

5.1.1 Block Definition Diagram

In SysML, the Block Definition Diagram focuses on blocks, showing their attributes, operations, and relationships between them. The system's physical or functional decomposition into its constituent parts is possible to present as well. BDDs are used to model a system's physical or functional structure and are typically used in systems engineering to define the components of a complex system (Sparx Systems, 2023).

SysML also supports modeling physical systems by introducing Parts and Ports. Parts are used to model the physical or logical components of a Block, while Ports are used to model the inputs and

outputs of a Block. Ports can also be used to model connections between Blocks, which can be used to show how data and signals flow through the system (Sparx Systems, 2023).

To summarize, BBDs are the more general type of diagrams that can show a broader range of system structures, including those that may not be related to Blocks or components. For example, it can be used to model complex hierarchies of Parts and sub-Parts and their relationships.

Block Definition Diagram is a starting point while creating the Infrarium model using SysML language. To provide a more structured and clear presentation of the conceptual model, analysis is done from the broadest perspective, starting with elements in the Main Block Definition Diagram, towards the more detailed description of parts and actors and their properties.

5.2.1.1 Player

Firstly, the most homogeneous elements combined in the most heterogeneous groups were defined based on the analysis done for the Swiss Cheese Model. As shown in section 5.1, a player can be the primary element in the Infrarium structure that will be the core of the Main BDD. Compared to Reason's model, SysML allows for a more accurate description through *generalization*. Therefore, three roles can be distinguished and modeled separately: *grid operator*, *port manager*, and *Top Oil* company. They are represented in SysML language as three separate blocks that have the same attributes and owned behavior as a generalized actor *player*. Even though three separable roles coexist in the gameplay, all the players have common attributes: *Readiness-To-Play*, *Readiness-To-Move*, *Availability-For-Collaboration* with other players, and *owned behaviors*: *Collaborate*, *Play*, *Wait*, and *Make Decision*. Such assigned characteristics allow for traceable connections between the Infrarium Structure BDD and activity diagrams directly connected to each game element's owned behaviors and states. The last two are discussed accordingly in subchapters 5.2.2 and 5.2.3.

Player's attributes and owned behaviors

The player's attributes reflect the player's state and thus establish the requirements for specific activities to occur. Therefore, all indicated attributes are set as boolean variables whose initial values are FALSE and can be changed while changing the player's state under certain conditions. As activity and state machine diagrams are discussed further in the research, only one example is briefly presented to clarify the relationship between attribute, owned behavior, activity, requirements, and state. When the player enters the game and is ready to take up an action, its attribute *Readiness-To-Move* changes value to TRUE. It's a critical requirement for further possible activities owned by the player as its behaviors: *collaborate* with other players or *play* with the hardware. A different type of player's behavior is a State Machine *Player States*. Although it is not directly connected with a particular activity, it also captures the behavior of the player by

presenting the transition between states that are triggered by executing a specific activity, e.g., the player can be in a state of *collaborating* when performing *collaborate* activity under the requirements for collaborating players' attribute *Availability-For-Collaboration* set to true.

To summarize, below all the player's attributes and owned behaviors are presented:

- *Readiness-To-Move* – indicates the player's readiness to interact with the game elements, including other players. Critical requirements for *make decision* activity and status transition from *waiting*.
- *Readiness-To-Play* – indicates the player's readiness to interact with the hardware playable game elements.
- *Availability-For-Collaboration* – indicates whether the player is ready for collaboration and/or available for collaboration with other players. Critical requirements for the *collaborate* activity to occur and status transition to *collaborating*.
- *Make Decision* – one of the player's owned behaviors; an activity of decision-making leads to other possible activities that the player can do: *collaborate*, *play*, and *wait*.
- *Collaborate* – one of the player's owned behaviors; an activity of collaborating as a result of which the player's status changes to *collaborating*.
- *Play* - one of the player's owned behaviors; an activity of playing with the hardware that triggers the hardware elements' statuses to change.
- *Wait* – one of the player's owned behaviors; the player waits when not ready to move during a certain timestep of the game flow.

The term "move" represents any action involving interaction with the game elements. Although "waiting" could also be considered a "play action," from the perspective of the player's environment, the player does not do anything and does not interact with the environment. That is why waiting as a possible separate action is differentiated, even though behind that term, there are also other activities that players can do, like thinking, processing data, or observing. However, for this research and the chosen level of abstraction, it has been left out of the scope of this master thesis. Nonetheless, it is essential for further research to focus more on players' experience during and after the game flow to better understand how a change in a game flow could shape the players' game experience and how.

5.2.1.2. Hardware

The second group identified in the Swiss Cheese Model as a separate layer was the hardware implemented in the Infrarium Structure BDD as three separate blocks in a way that one corresponds to each player's hardware environment: *Port manager*, *Grid Operator*, and *Top Oil*

stations. Although they are modeled as independent blocks, their parts are connected by different ports, as visible in Figure 5-1. Similarly, the connection between players and their stations is made. This is a significant advantage of the SysML model compared to other investigated methods. Here, the difference in the type of relations can be modeled as different types of connectors and specific ports. Thus, the connecting points and relationships are clearly defined and visible in the model, similar to the definition of some game hardware elements. For example, cables that connect backbones with the grid operator control panel are partially defined by their ending and starting points. Using the SysML notation, it is possible to represent that in the same form: the origin and ending ports of different blocks, as visible in Figure 5-1. That could be a significant benefit for the game researcher to understand the game flow better while also identifying crucial elements for ensuring an undisturbed flow of game features like information or knowledge.

The Port Manager Station consists of three main parts: *Information Screen*, *Port Control Panel*, and *Windmill Turbine*. Each part block can be decomposed using a separate block definition diagram. For example, in the main *Infrarium Structure* diagram, plexiglass plates representing companies allocated among the port are not separated from the *Port Control Panel*. However, by adding an internal block definition diagram, those plates can be separated according to their assigned functions: companies, energy production facilities, and industries. Each plate could also have its own attributes, requirements, and constraints like position on the map, CO2 emission, and energy demand. Decomposition made in that way could go further; however, for the purpose of the thesis, what is happening under the *Port Control Panel* block is assumed as a "black box," and only the state of that block is shown in Appendix B.4 to show internal hardware components on the similar level of details. Here again, further vertical exploration is needed to reach the full potential of the SysML model.

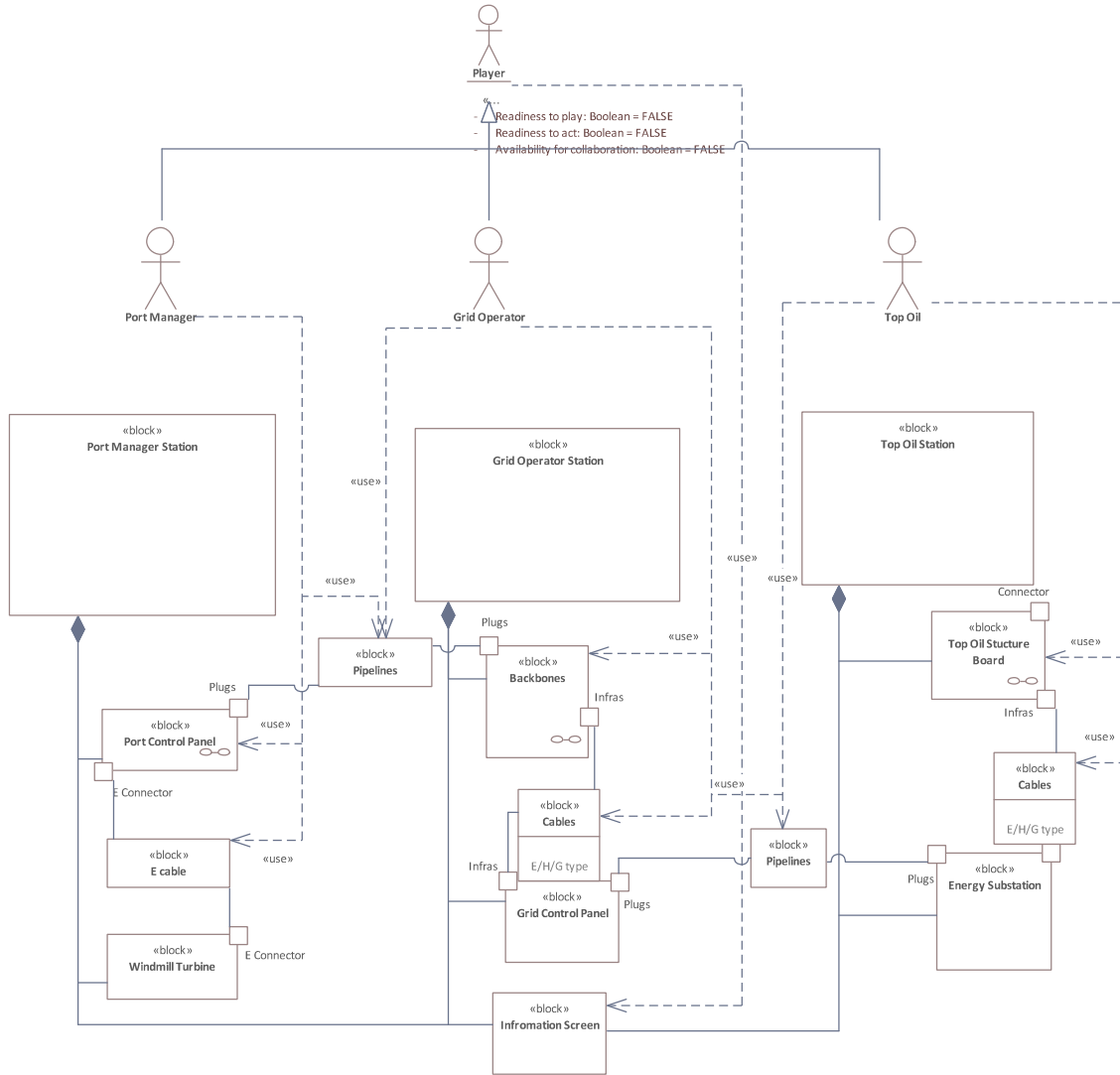


Figure 5-1: Main Block Definition Diagram of the Infrarium Model

Although the research is conducted more horizontally, in the main Infrarium Structure BDD, different types and levels of relations are already implemented. There are limited hardware elements that players can play with. In the case of the *Port Manager Station*, those are:

- *pipelines* connecting the *Port Control Panel* with the *Grid Operator Station*;
- plexiglass plates determining the CO₂ emission, revenue, and demand for energy from each source;
- *cable* connecting the windfarm with the *Port Control Panel*

As mentioned above, the plexiglass plates are assumed to be part of the *Port Control Panel* block, and the other two elements are presented in separate blocks that are not associated with any other blocks in the Infrarium Structure. The underlying motivation for this decision is as accurate depiction of the logic state of the game as possible. Both *pipelines* and *cables* are defined by the corresponding connecting points represented as ports. Two terms are used to distinguish the

type of connecting points: *plugs* for high-capacity *pipelines* and *infras* for local *cables*. Following a similar idea as in the case of plexiglass plates, within cables, the distinction is possible according to cable maximum capacity (low & high) and source of energy transferred (electricity, gas, hydrogen).

As illustrated in the diagram in Figure 5-1, the relations between ports are not direct, but by using specific tools, players create an information flow between two hardware parts. The dependency arrow of usage represents that kind of connection. The player uses cables and pipelines to connect two physical elements of the game. Meanwhile, the same player can use one of the physical game elements, like plexiglass plates in the *Port Control Panel*.

Similarly, the *Grid Operator* and *Top Oil Stations* are modeled too. The first consists of *Backbones*, a *Grid Control Panel*, and an *Information Screen*. Following the chosen level of abstraction, all three types of backbones are included within one block. One of the backbones presented can be switched from gas to hydrogen during gameplay, modeled as a direct <<use>> connection.

Top Oil Station consists of *Top Oil Structure Boards*, *Energy Substations*, and *Information Screen*. As presented in Chapter 3, there are different types of company assets depending on the energy source used, likewise the *Energy Substations*, and the function performed. As all the boards have the same connecting points and are mounted similarly to the game hardware, all the boards are presented by one block with two ports. The *Port Connector* represents the connection between the board, game container, and power supply infrastructure.

What merits attention is the *Information Screen* block. Unlike the other parts of the *Infrarium Structure*, it is present in all three station blocks. Although physically, each player has access to its information screen, they all contain the same information about the game status in CO2 emission level and generated Revenue. Thus, they are presented as a one-box used by the generalized *player* actor.

The last elements visible in the diagram are the owned behaviors of each station block. According to the definition of owned behavior, the state machine is one of the forms of presenting the behavioral aspects of the block. Activity diagrams are omitted as those blocks are models for physical players' environment elements, and state machine notation was assessed as more accurate in that case.

5.1.2 Activity Diagrams

Activity diagrams are used to model the behavior of complex systems. They might be combined with state machine diagrams of different blocks to show how the system or its sub-components

respond to different events. SysML provides additional constructs for ADs extensions to support modeling system-level concepts, such as requirements and constraints. The concept of the SysML Activity Diagram is similar to the scenario-based diagram presented in section 4.2.1 in Figure 4- 5, though it could be more effortlessly combined with other diagrams and thus create a more accurate and comprehensive conceptual model. Nonetheless, due to the similarity of both tools, the model description below is presented in the form of a scenario-based perspective of the *player*.

Firstly, the player entering a game session must decide what to do. That is why the first activity diagram, which contains other player's owned behaviors, depicts the *Make Decision* activity presented in Figure 5-2 below.

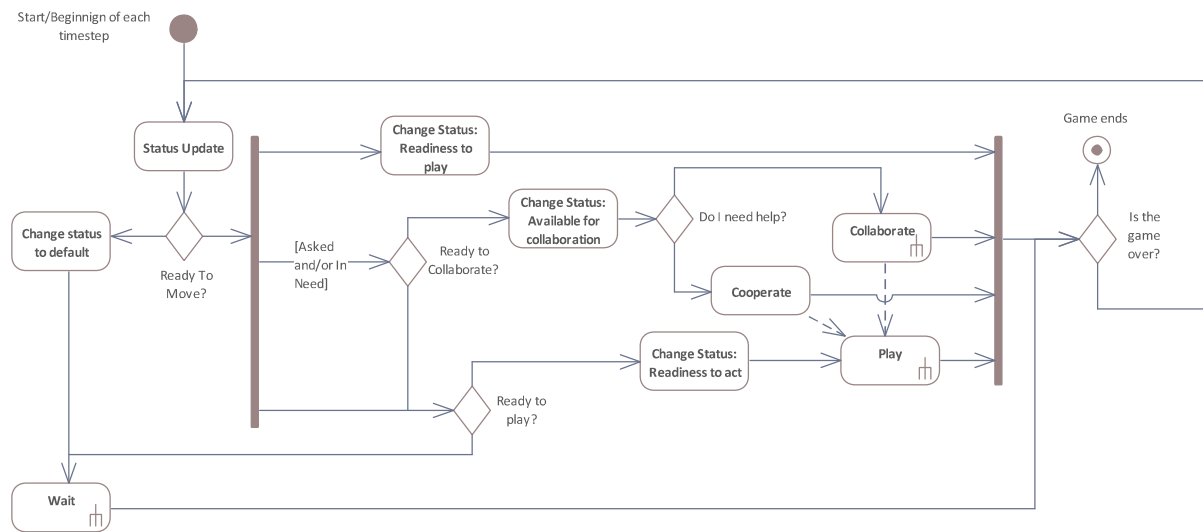


Figure 5-2: Make Decision Activity Diagram

In section 5.1.1, the main difference between activities and attributes was presented. In this section, the player's attributes are used as a determining factor when deciding about the next steps. The first decision point checks for the player's *readiness to move*. Even though the initial value is FALSE, multiple factors can influence the change of it, like possessed knowledge, level of dependency, the role assigned, emotional state, and many others. It is iteratively changed after each timestep, e.g., during a game session, a player's status ready to move might change under a blast of extreme emotions, and the need to *wait* and "miss a turn" might appear. Due to the scope of the thesis, the process behind that change is assumed to be a "black box" that could be elaborated further as separate research on the decision-making process.

On the other hand, while modeling *wait* activity, the perspective of the player's hardware environment and other players is taken. Even though the player, while waiting, is perceived as not active, it might perform some actions like thinking or processing data. However, the hardware environment is unaware of them as they do not contribute to their state change. Therefore, in the presented model, the *wait* activity represents all the actions possible for the player done without

any interaction with the game environment. Even though this behavior is significant and needs to be analyzed further while addressing the issue of shaping game experience, it is not included in this research. However, it is highly recommended to improve model accuracy in the future.

The following two decision points are dependent on each other. If the player needs collaboration or has been asked for it, the status of both interesting parties is checked for being ready to collaborate and further available for collaboration. Both are similar, though they might differ depending on the situation, e.g., the player who asked for help might be ready to collaborate but not available due to being in cooperation with another player. The next step is to choose one of the paths depending on whether the player has been asked for collaboration or is in need of cooperation. In the first case, the following action *cooperate* also belongs to the alternative collaboration activity, but the owned collaboration behavior is not called as depicted in Figure 5- 2 and Figure 5-3.

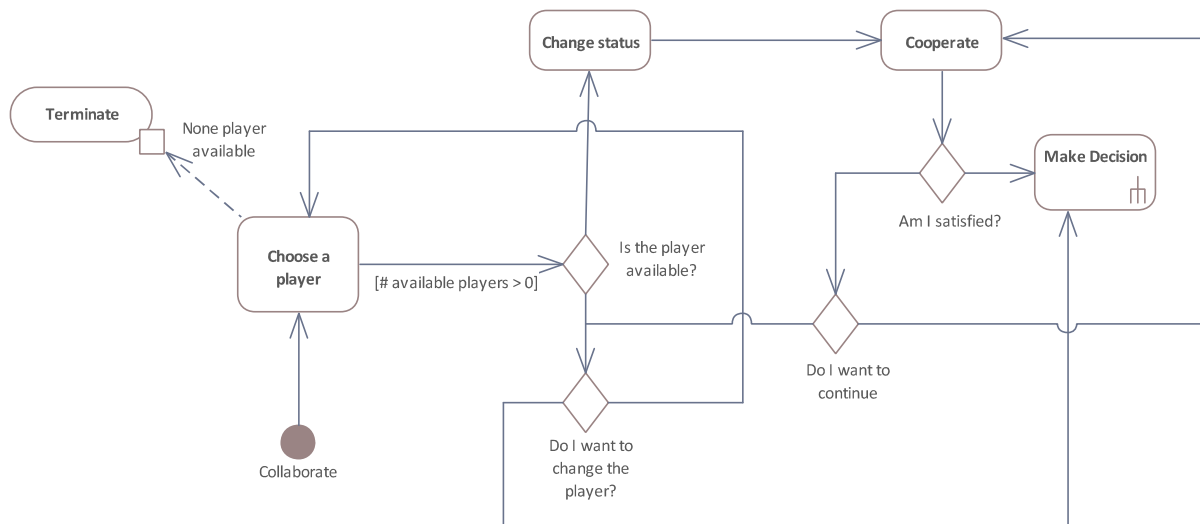


Figure 5-3: Collaborate Activity Diagram

The previous analysis shows that two players can interact with each other in two ways: conversation or *playing with the hardware* or both simultaneously. *Cooperate* is introduced to capture all the possibilities and clarify dependencies. Additionally, the Make Decision Activity Diagram adds two dependency relations between the *play*, *collaborate*, and *cooperate* actions. Moreover, the interaction continues until the player *in need* is satisfied. Similarly to readiness to move, the importance of external factors is immense to the point that it is considered another "black box" issue left for further research.

The *Collaborate* activity ends by calling the *Making Decision* activity so that, with each timestep, the player starts from the same point of the decision-making process about the next step. It also occurs if the called *collaborate* behavior cannot proceed due to a lack of available players. Then, an exception *terminate* is initiated, and the player starts again.

The last possible action, calls the owned behavior *play*, is presented in Figure 5-4. As the hardware environment of the player limits this activity, the diagram includes the hardware blocks from the *Infrarium Structure* Block Definition Diagram in the form of a dependency relation that limits the corresponding activities. Moreover, to support further development of the model, the realization of the *play* activity is designed to be achieved by three separate activities with common action captured already in the *Infrarium Structure* BDD. The <<flow>> relationship represents the flow of information as an outcome of each activity, which directly connects playing activities to the transition realization between states of interrelated hardware parts.

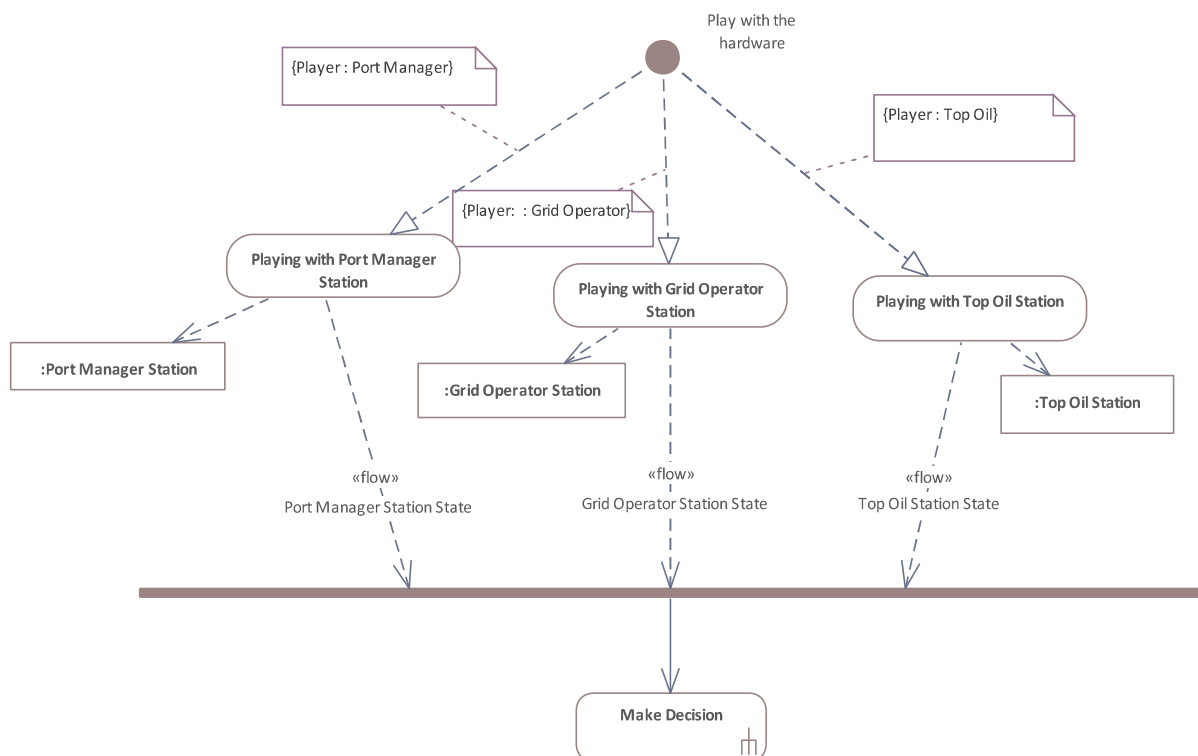


Figure 5-4: Play Activity Diagram

5.1.3 State Machine Diagrams

SysML State Machine diagrams depict both software and physical states. The transitions represent the events or conditions that cause the system component to move from one state to another. Moreover, because SysML introduces additional constructs for SMDs, activities, and actions may be linked to system components in the state machine diagrams to show how the system architecture supports the modeled behavior.

The previously presented *Play* Activity Diagram already uses these constructs. Top Oil Station State Machine Diagram presented in Figure 5-5 depicts the transition between states realized by activities already related to them in the previous chapter.

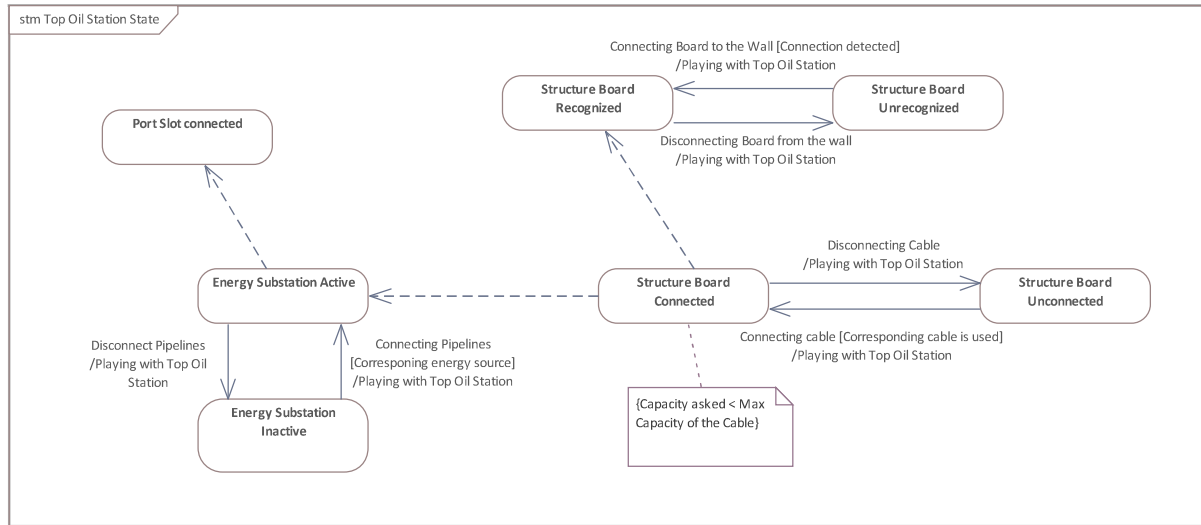


Figure 5-5: Top Oil State Machine Diagram

5.2 Final Assembly

None of the diagrams can represent the complexity of the Infrarium alone. Only through the perspective of the Swiss cheese model relevant diagrams set can be considered as an adequate visualization of the system. Although the resource layer from Reason's model adaptation is not explicitly implemented in the SysML environment, the connectors used in the model carry some resources behind them, so a de facto resource layer is hidden behind those connectors. This example shows the importance of the context while working with the SysML model. Only then the answer to the indicated research question can be formulated and further developed and implemented in the Python environment of the game. Due to time limitations and the scope of the Master Thesis, this implementation will not be investigated or further elaborated on in this research.

6. Discussion

The final chapter is about a short run-down of the thesis followed by a discussion related to the research question and reflection on the challenges and issues faced while approaching and modeling the final conceptual SysML representation of the Infrarium game. Finally, suggestions for future work regarding further research and development in the field of model-driven game design using the SysML language are formulated.

6.1 CoSEM relevance

In regard to the CoSEM field, the theory tells that Simulation and Serious Gaming are commonly used as tools for enhancing participative decision-making processes (Medema, Furber, Adamowski, Zhou, & Mayer, 2016) or modeling methods for evolving infrastructure and society (van Bilsen, Bekebrede, & Mayer, 2010). The combination of both is the main concept of Infrarium, which is a new perspective on designing Serious Games. This allows for answering challenges of one tool by using the advantages of another and thus gain more insightful outcomes out of more complex environments that are useful for approaching large socio-technical problems as they allow groups of people to come together, explore, and observe the system from multiple perspectives and thus enhancing collaboration and collective decision-making process. This new approach to the commonly known and used tool has many positive outcomes and enormous potential.

6.2 Discussion on the Conceptual Model

As previously mentioned, the presented way to approach the model-driven game design concept has its advantages, challenges, and limitations. This chapter presents issues faced while creating the SysML Infrarium conceptual model that needs to be considered while using, developing, or creating models based on SysML. The assumptions made while conceptualizing are discussed and followed by the model limitation they determined.

Compared to other approaches presented in this research, the UML-based model successfully catches the complexity of the modeled systems and could be implemented in Java or Python environment with satisfactory results of simulation run (Bielli, Boulmakoul, & Rida, 2006; Mehrpouyan, Jensen, Hoyle, Tumer, & Kurtoglu, 2012; Vieira Park & Castillo Brieva, 2010). Although Miguel et al. (2022) in their literature mapping paper present the trend to use UML with the support of another tool, in this research, we showed that the SysML model supported by two other concepts can sufficiently represent the complexity of the Infrarium game on the functional level, though the importance of the broader context while working with SysML is vital and cannot be missed while working with UML.

This broader context in modeling could be determined by the model's purpose. The model is only good enough if it fits its purpose. In the case of the Infrarium, the conceptual model is supposed to support the intervention design process to shape the gameflow. To do so, two requirements were set, coherence and descriptiveness, which fulfillment can be used as a criterion for model check for fitting the above-mentioned purpose.

The presented SysML Infrarium model allows for tracing all possible to occur game states determined by the state transition of every game element. The model diagrams visualize paths that lead to the game status change. Due to a clear structure that allows for identifying how different game elements influence each other, it provides insights on when, where, and what type of intervention needs to be made to obtain the desired outcome.

Nonetheless, to call the current conceptual model usable and testable, more in-depth research should be conducted to specify each of the introduced black boxes. The presented resilient structure could be easily modified in a deep level of detail while not changing the higher structure of the relation between blocks. That makes it ready to be forwarded to other experts that could develop each of the boxes further regarding, e.g., decision-making mechanisms. This can be performed using the same notation even though working in different fields of expertise, as SysML notation allows for combining pure technical elements with more complex issues involving human factors. This creates a space where experts can communicate and gain insights into different connections between different fields combined in complex socio-technical systems, which is alone a huge advantage of the presented approach in the field of model-driven game design.

Moreover, the SysML model allows for evaluation simultaneously with the development of the design. Thanks to the different relations types and their characteristics, it is possible to first indicate a comprehensive relation between elements, which could be further specified as, e.g., information flow. In the production phase, it could be further specified how this flow will be

executed, what input and output requirements should be, and much more. Therefore, all changes made in the system, requirements, relocations, blocks, and elements are traceable, thus making the design of the game more independent of the differentiation of designers, producers, testers, and other actors involved in the game design and development process. Such characteristics also make the model highly resilient to any change made to it at the higher levels of abstraction and thus might be considered an effective tool based on the new approach to model-driven game design.

Although the SysML-based models allow for modeling as detailed and complex systems as desired, the vertical level of details is not included. As presented in the main BDD, the points of connection between different blocks, called in SysML notation as ports, are crucial for the model. Through these points, the relationships between different game elements can be executed. Players cannot directly interact with other stations. The first direct contact is done by the player's own station, and further, the information flow within the software, the other station hardware, and the logic state are changed. That is why, to not lose the focus on the functional level of the conceptual model, details like influential factors for the players to change their status, players' willingness to collaborate, or processes that drive identified actions are not included. This decision might affect the model's accuracy, which cannot be checked until the model is developed into a testable version.

The first assumption resulting from the above-explained decision concerns the status of the player. Within the Make Decision Activity, the player's status is defined by its attributes and resets at the beginning of each time step. Although readiness to act is dependent on many other factors, like emotional state, gained knowledge, or psychological state, they are not included. Furthermore, not all the attributes of the player are specified. The presented model of the player is characterized by only three attributes (readiness to play, readiness to act, and availability for collaboration). Considering how complex player nature is, it is certainly not enough to model more sophisticated behaviors and processes like decision-making. Except for the model accuracy, this might cause doubts about the future strategy of development: could the experts work fully independently? For that moment, the only problematic component found is the player as a fundamental element of the model.

Similar assumptions are made on the game infrastructure element. From the perspective of the game designer, Infrarium can be perceived as an environment for the players to use available resources and interact with each other and the game infrastructure. Following that narrative, it can be stated that each component has its function and role in gameplay. However, due to time limitations and the limited scope of the analysis to the player's perspective only. All the details

that grab the player's attention, such as structure, material, and color of the element, are not modeled.

Another significant assumption is that the waiting activity is assumed to be a 'black box,' to be specified further. Similarly, the other activities of playing with the hardware. As the hardware elements are not specified, it is still unknown what exactly could be done within each.

Nevertheless, the purpose of that research is not to go into details. Although the presented Infrarium model contains a lot of 'black boxes,' it is sufficiently developed horizontally to enable more vertical analysis. Each of the mentioned black boxes could be further defined without disturbing already modeled higher-level relations. This is possible due to the already mentioned clear structure, traceability of dependencies, and relations provided by the presented SysML Infrarium model.

7. Conclusion

The final chapter is about a short run-down of the thesis followed by an answer to the main research question. Afterward, suggestions for future work regarding further research and development in the field of model-driven game design using the SysML language are formulated.

7.1 Answering the Main Research Question

The primary aim of the thesis was, using the given Network of Puzzle concept, to:

- Build a coherent, descriptive conceptual model of the Infrarium Game on the chosen level of functionality
- Adapt the conceptual model in a way that helps design an intervention method for the game flow

All of that contributes to the given research question:

How could the Network of Puzzles concept be used for developing the model-driven conceptual representation of the Infrarium Game and further a design tool for shaping the game flow?

In the primary vision of the Network of Puzzles, described in Chapters 1 and 4, the game itself is perceived as a space of all possible different states of the game elements. The deeper the Infrarium was analyzed physically, the more it deviated from the concept of a multilayer network consisting of predefined edges and nodes where one dimension represents the same type of entities or relation. Analysis conducted in Chapter 2 showed that the more profound the game's embedded logic state, the more elaborated definition of a node and an edge was required. The layers that evolved within that process led to the Swiss Cheese concept.

Nevertheless, both perspectives could not capture the expected level of complexity themselves. Thus, a different approach was taken to find a new modeling language that would capture the complex nature of the game. The final SysML conceptual model depicts the change of states at different levels of relationships and introduces various elements that cooperate with each other, as depicted in Figure 6-1. At the same time, it limits the path that each game element could take by imposing constraints and types of connections.

Although the Network of Puzzle concept was not directly adapted for the Infrarium, it drives the further process towards a more general multilayer perspective with interdependencies within and between layers in which only a limited number of connections can occur during a gameflow, creating a path towards the end of the game. Therefore, the presented SysML model addresses the first goal of the thesis at the functional level.

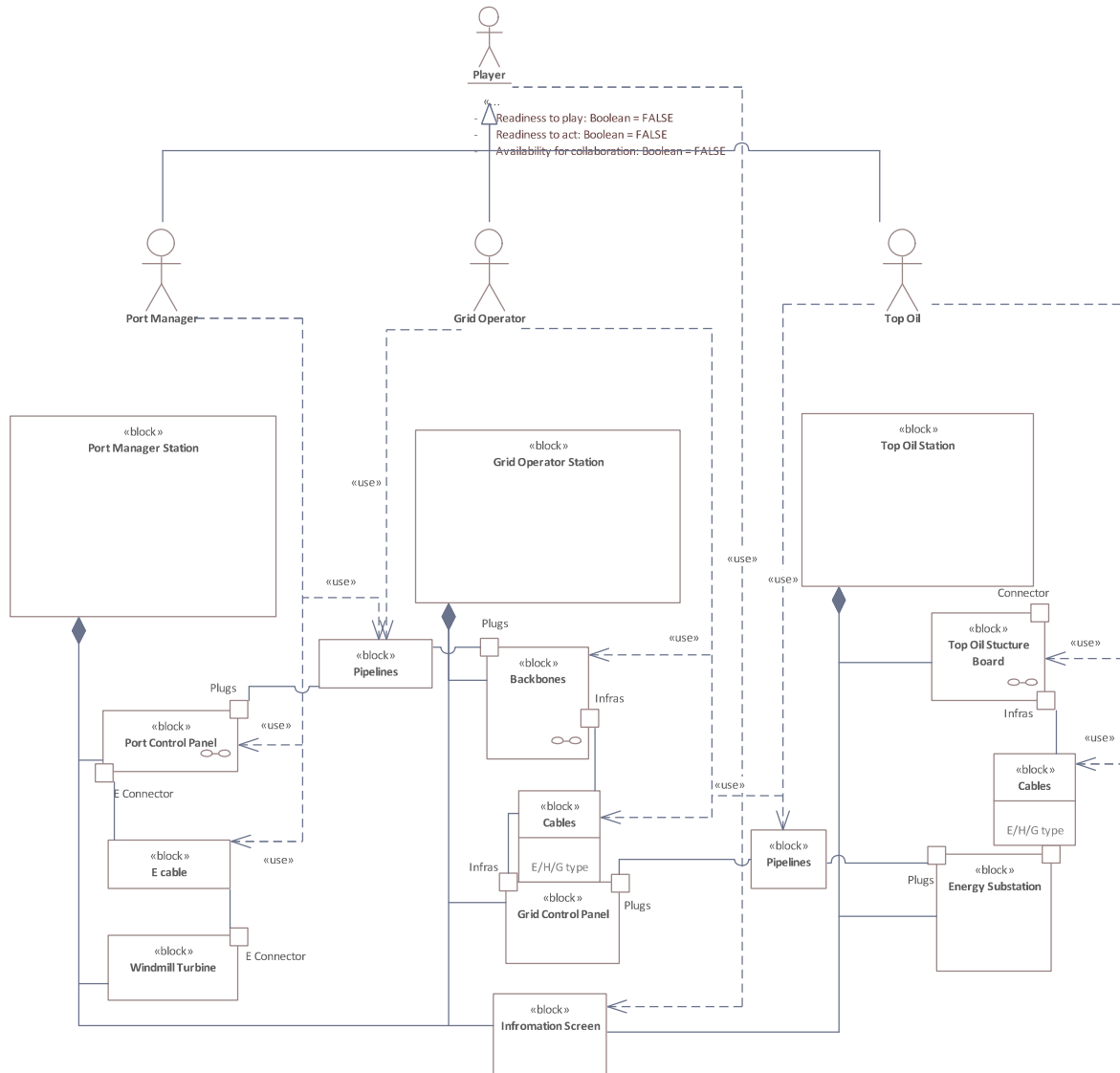


Figure 7-1: Main Block Definition Diagram of the Infrarium Model

The UML approach taken also serves the second aim of the thesis. The model shows all relations paths, which helps to understand where and what type of change must occur to obtain the desired outcome. It can be used as a tool to gain insights on which factor drives specific movement, where in the game flow the intervention is needed, what type of intervention is needed, and how it needs to be implemented. However, as presented in Chapter 5, the SysML model is not yet a testable version for experimental usage. Thus, several recommendations and future steps have been formulated and discussed in the following section.

Finally, the main RQ has been addressed. Conducted research explains and analyses the Infrarium environment based on the Network of Puzzles concept and, through the process, motivates its usage as an inspiration and base for the subsequent steps in the readership. As mentioned above, the complex nature of the Infrarium requires a more flexible and adaptable tool than the pre-assumed network with predefined node characteristics as a puzzle. Connections between puzzles defined as edges require the usage of multidimensional graphs where each dimension represents one connection type that creates an enormous and hardly traceable spaghetti cloud. Therefore, the idea of a multilayered perspective combined with a more flexible environment provided by SysML modeling language proved to be easily followed and flexible enough so that the level of detail depends on the modeler's desire. A clear structure not only provides a better understanding of the game mechanics but also combines, using a unified language, two fields: the hardware environment and the more abstract logic state of the game, so crucial to further design any intervention directed toward a change in the experience of the players. In simulation and gaming, such a model-driven game design approach might broaden the range of serious game usage, e.g., as a complex system research tool. Thus, SysML models could be the solution for model-driven serious game design that will enhance participative decision-making processes or a more traceable method for modeling evolving infrastructure and society in the environment embedded in a socio-technical system.

Moreover, the conceptual model's modularity allows for further development without disrupting the higher-level interrelations. For example, the player module is implemented at a high functional level, and thus, developing it further could be done separately from relations with other game elements. The coherence and cohesion are preserved.

For the Infrarium itself, such representation allows for further development of the game on different levels, making it more adjustable as a tool for further research and an education environment about the complex problem of achieving emission neutrality in a socio-technical system like the Infrarium port. Lessons learned in Infrarium might increase awareness of how challenging and complex the process of obtaining emission neutrality is.

To conclude, the conducted research presents a new approach for designing and evaluating serious games in the example of Infrarium game. This broader approach focuses on the interrelations between elements rather than the vertical analysis of each element. At the same time, the presented model allows for such vertical elaboration while not jeopardizing the existing functional level of the model. In the thesis, the motivation behind using SysML notation is presented through the Infrarium analysis that drives the conceptual model of the game. Due to the clarity and traceability of connections, such the model is a perfect base for future development of the tool for shaping the game flow and further the player experience. Thanks to unified

language, it might be used for designing any serious game with simulation elements, and its core is the spaghetti of interrelations between elements in different environments.

7.2 Recommendations and Further Steps

From the discussion presented in section 6.2 and presented results of the research, we would like to recommend some strategies and first steps worth considering in future development and research.

First of all, before any change is done to the model, we suggest first aligning and uploading data from .ods files available at <https://gitlab.tudelft.nl/inikolic/infrarium>. Current files are not fully aligned regarding the definition and naming of different game infrastructure elements. An example of this is the way different TO company assets (.ods) and structure boards (SysML) are defined together with the cables connecting the asset to the grid. See the Appendix A.1 for details. It might save a lot of time in the future while implementing Python version of the model to the existing simulation.

Most UML-dedicated programs like Enterprise Architect, used during the research, or Visual Paradigm, support Python code generation. However, how it could be integrated with the existing environment is not yet developed. The recommendation here is to first revise and design if needed, more relationships between hardware and software elements in the SysML diagrams environment to make the implementation to the Python environment of the simulation as smooth as possible.

Additionally, as discussed, the model of the player itself needs to be developed further. The previous analysis shows that the player element is complex enough to undertake separate research only to develop it further. However, it is necessary to create a complete Infrarium model that will allow and priorly investigate how different game flows will change and, thus, how and to what extent it could influence the players' game experience. The adapted SysML model combined with the still unused great potential of UML could be a foundation for a much more effective tool while addressing model-driven game design.

For developing the presented model only to the testable version, our recommendation is to revise the current models of decision-making processes, gaining knowledge, or any other useful, according to the future modeler, processes. In SysML, it is possible to implement several models depending on which activity or use case is called. However, it is worth noting that the time spent on translating existing models into SysML diagrams cannot be underestimated. Thus, the level of detail needs to be optimized with the amount of work required. It might happen that introducing

another attribute of the player is more efficient than adapting the existing model to the SysML environment, yet still satisfying.

However, given the much broader usage of the UML language and discussed possible contribution towards model-driven game design, it is highly recommended to conduct further research on the model of the players and further evaluation of the presented concepts.

Another point reflects on the time limit challenge faced. In the conducted research, only SysML diagrams used for designing the conceptual model of the Infrarium are elaborated. However, it is worth further research to mention that UML possibilities are much broader than the given examples of the diagrams. For a detailed analysis of the full potential of SysML, it is suggested to study the language deeply and increase model accuracy by adding other diagrams, if applicable.

SysML notation clearly presents what is used, by whom, for what, and how. Moreover, depending on the desirable level of abstraction, the model can represent the basic mechanism for interaction between two physical assets and the knowledge flow that occurs during the gameplay. Ultimately, it would be possible to create a space of all possible permutations of states within which the basic mechanisms driving interaction between any two physical assets and the knowledge flow that occurs during the gameplay is known. The potential of UML notation, in general, is definitely much greater than what has been used in conducted research. Presented future work recommendations could be the next step toward building a comprehensive intervention tool for the game designer.

However, the same advantage of SysML potential must be considered a significant threat to modelers and designers. The level of the desired details could be accurately described by the common phrase 'the sky is the only limit.' In SysML, every block, actor, or element could be investigated freely and modeled in an arbitrary detail, which means setting up boundaries is exceedingly difficult. Thus, the SysML models need to be considered in the context of the identified problem and the purpose of the model.

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Appendices

A. Infrarium Game Documentation

This appendix presents the pictures taken while studying the Infrarium game. The physical container is divided into three stations for each of the players: Port Manager, Grid Operator, and Top Oil Company. This division is also used while analyzing and presenting the Infrarium in Chapter 3 as well as in this Appendix. Pictures were taken in February 2023 and might differ from the current game appearance. The description is consistent with the actual game mechanics and infrastructure from the time period in which the research was conducted (11.2022-.2023).

A.1 Game Mechanics and Logic State

Within each station, some game elements are marked with a *TOOL* sign. It means that the marked element presented in the picture can be modified with the player, and we used the term “playable tools” while referring to this part of the game infrastructure.



Figure A-1: Port Manager Station Documentation

The port manager station consists mainly of the control panel, plexiglass plates, and the panel's connection points with other game elements. In Figure A-1, we can see that the control panel is divided into 24 slots. As explained in Chapter 3, Plexiglass plates represent companies that can rent the slot or could be used by the port itself. Details about each company and the company types are presented in section A.2.

The player can use the control panel that depicts the map of the port by placing on each slot a plexiglass plate that represents the specific company. From the information flow perspective, this map is also a central communication point with the rest of the game infrastructure. When the plate is attached to the slot, the information about the company placed on the map is sent to the logic state of the game, defined as presented in Chapters 3 and 4. The requirement for activating the company is a fulfilled energy demand. If the grid cannot provide the required amount of energy, the company stays inactive: it does not generate costs, CO₂ pollution, and revenue. The information about the current revenue and CO₂ emission is displayed on the screens available for the players.

On the panel, there are already placed some companies that are fully operational at the beginning of the game. The choice of the company and assigned slot depends on the gameplay. However, there is one company always there: Top Oil which represents one of the player's role. When removed from the map, the TO company station becomes inactive.



Figure A-2:Grid Operation Station Documentation

The map of the port also sends the request for the individual demand for each sector [sectors are defined as shown in the GO distribution panel] and the overall energy demand of each type and to the logic state of the game. Then, several requirements are checked. The sector on the GO distribution panel needs to be connected to the corresponding backbone and the correct type of inputs (visible in Figure A-2). The individual demand for each energy source requested from the sector needs to be lower than the maximum capacity of the corresponding cables connecting cables. The backbone needs to be connected to the main grid, and its capacity must be higher than the overall demand requested. Only then, the demand is satisfied, and the companies placed on the corresponding sector slots become active. All the details regarding the capacity of each game infrastructure element are available only for the GO player and are presented in section A.2

For the Top Oil Company, the demand for energy changes over time and depends on the action taken by the TO player, though the information flow regarding the energy demand request remains the same. The demand of the TO company is requested only if:

- the TO substations (visible in Figure A-3: three bottom right pictures) are connected with the GO distribution panel with the corresponding energy source type pipeline (substations are active), and
- recognized by the game logic (connected with the container) company asset (structure board) is connected with the corresponding type of energy source substation with the correct cable (structure board is active).

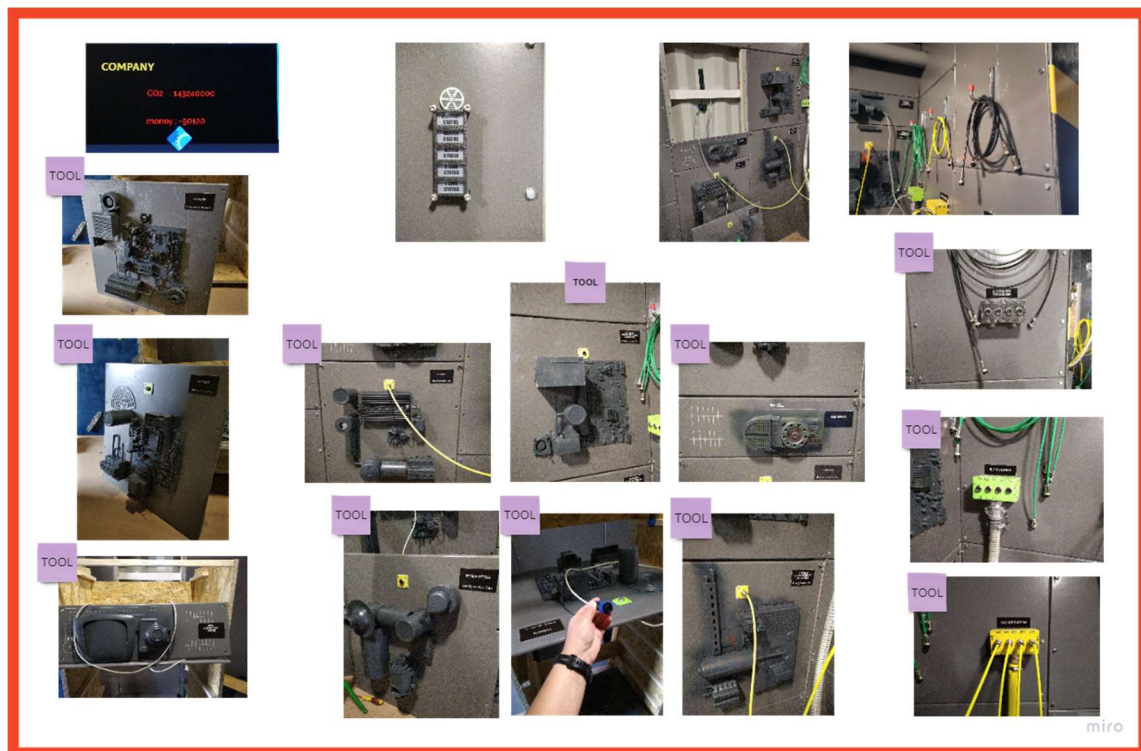


Figure A-3: Top Oil Company Documentation

The exception is the office asset, as it does not need the connection with the substation but requires all the company assets to be active.

The TO player can monitor which structure board is active (connected to the container AND connected to the active energy substation) on a display mounted on the left side of the structure wall. The green light sign depicts that the corresponding asset state is active. The red light, on the contrary, depicts that the asset remains inactive.

Coming back to the GO and the PM, both players, to start the game, need to connect offshore windfarm electricity to the grid. To do so, first, the PM must connect the windfarm (see picture placed in the top left corner of Figure A-1) to one of the electricity plug on the map. Then, the PM needs to place the offshore windfarm plate on the slot next to the electricity plug to which the windfarm corresponding backbone. Afterwards, the map of the port needs to be connected with the corresponding electricity backbone with the corresponding pipeline. First, the PM connects the pipeline to the panel and then forwards the pipeline to the GO player so the electricity produced by the windfarm can be connected to the main grid and available for usage.

Similarly, hydrogen could be connected to the grid. However, an extra step is needed from the GO site. One of the gas backbones needs to be switched to a hydrogen one. After that step, the gas from that backbone is no longer available. Only after connecting hydrogen to the main grid, the GO sectors could be supplied with the hydrogen and after connecting the GO distribution panel to the TO hydrogen substation, it becomes active.

A.2 Available Information for the Players

General Information



General information about the Infrarium, the story behind and the narrative is presented during the briefing before the start of the gameplay. The summary of that information is printed and distributed together with individual guidelines prepared for each player, and its distribution depends on the role the player has been assigned at the beginning of the game. The provided material contains condensed information about the game itself, its purpose, and its main objective. Players are also welcomed to the port and briefly introduced to the energy transition challenges they will face during the gameplay.

Port Manager: Companies Cards

The Port Manager has access to all the details about the available companies, as presented below. Cards are printed out and available only at the PM station. Companies are assigned to each of 5 categories

- **The container facility:** increase container capacity in the port and thus provide extra income and funds to the port but can operate only with electricity and have a high investment cost
- **The chemical industry:** companies with growing potential and lots of possibilities, able to switch between at least two different energy sources but with a high investment cost
- **The distribution companies:**
- **The energy suppliers:** have relatively low investment costs but are crucial for the process of energy transition, supplying the port with different energy sources

All the details regarding specific values or company specifications and requirements are placed on presented card below.

FLEXCONTAINERS	
BASIC INFO	
Registered Business Name: Flexcontainers BV	
Physical location: B1	Phone number: 810 7589462
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 20 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: Shipping consumer goods.
CO2 production: kg	
NOTES	
Flexcontainers is a shipping company which ships 14% of all containers that arrive in the port. Although the company building itself doesn't use gas, their vehicles do use gas and produce CO2.	
(OPERATING) COSTS	
Investment cost: 17 million euros	Cost for PM: 5
Operation cost: 21 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Port-manager profit: 3 million euros per year	

DORP INC	
BASIC INFO	
Registered Business Name: Dorp incorporated	
Physical location: B2	Phone number: 810 4895961
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 15 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: Shipping of industry goods
CO2 production: kg	
NOTES	
Dorp inc is a shipping company that ships containers with industry goods such as machinery and raw materials. Their vehicles are powerful and use a lot of gas although Dorp inc is looking for a way to become more sustainable.	
(OPERATING) COSTS	
Investment cost: 17 million euros	Cost for PM: 5
Operation cost: 16 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 2 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Port-manager profit: 3 million euros per year	

EUROCO	
BASIC INFO	
Registered Business Name: EuropaCooperation	
Physical location: C1	Phone number: 810 5984257
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 20 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: International shipping company
CO2 production: kg	
NOTES	
<p>Euroco ships consumer goods from the port further inland and to neighboring countries such as Germany and Poland. They ship about 8% of the containers that reach the port. They are reliant on the gas production in the port for their vehicles. Euroco tries to compensate their vehicle's CO2 by planting trees in Germany and the east of the Netherlands.</p>	
(OPERATING) COSTS	
Investment cost: 19 million euros	Cost for PM: 3
Operation cost: 13 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Port-manager profit: 3 million euros per year	

EASYTERMINAL	
BASIC INFO	
Registered Business Name: EasyTerminal	
Physical location: C2	Phone number: 810 4587457
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 25 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: Shipping consumer goods
CO2 production: kg	
NOTES	
<p>Easyterminal is a smaller container terminal. They are very eager to move to more sustainable methods of shipping. They mostly work for sustainable companies. They want to experiment with hydrogen energy sources. They have recently purchased automated electrical vehicles to start incorporate in their fleet.</p>	
(OPERATING) COSTS	
Investment cost: 13 million euros	Cost for PM: 2
Operation cost: 8 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 3 million euros per year	

DEEPCO	
BASIC INFO	
Registered Business Name: DeepCo and sons	
Physical location: H4	Phone number: 810 5412546
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 15 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: Shipping of various goods
CO2 production: kg	
NOTES	
<p>DeepCo is a medium shipping company that handles about 10% of the containers that come into port. It is a traditional company that has grown in size over the last few years.</p>	
(OPERATING) COSTS	
Investment cost: 8 million euros	Cost for PM: 3
Operation cost: 16 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Port-manager profit: 3 million euros per year	

PETROCO	
BASIC INFO	
Registered Business Name: Petroleum Cooperation	
Physical location: C3	Phone number: 810 6578459
Business type: Oil Refinery	Category: Refinery
Energy consumption:	Energy production:
Gas: <input checked="" type="checkbox"/> 600 MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 15 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Petrol production	Service:
CO2 production: 129600 kg	
NOTES	
<p>Petroco is a company that produces a lot of oil and petrol for the Dutch and European gasoline market. They receive their oil with a ship. It's an old company that is not too keen on making changes.</p>	
(OPERATING) COSTS	
Investment cost: 10 million euros	Cost for PM:
Operation cost: 28 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 2 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2 million euros per year	

TOP OIL	
BASIC INFO	
Registered Business Name: Top Oil	
Physical location: D2	Phone number: 810 5794612
Business type: Oil Refinery	Category: Refinery
Energy consumption:	Energy production:
Gas: 665 MW	Gas: MW
Electricity: 15 MW	Electricity: MW
H2: MW	H2: MW
Production: Petrol and oil production	
CO2 production: 143640	kg
NOTES	
<p>Top Oil is the biggest oil refinery in this port and even in Europe. They rely heavily on big amounts of gas and need to change all of their assets and perhaps their whole product if they want to become more sustainable.</p>	
(OPERATING) COSTS	
Investment cost: 15	million euros Cost for PM: 2
Operation cost: 35	million euros per year On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 2	million euros per year On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2	million euros per year

CHLORYON	
BASIC INFO	
Registered Business Name: Chloryon	
Physical location: D4	Phone number: 810 256487
Business type: Chemical Company	Category: Chemical
Energy consumption:	Energy production:
Gas: 200 MW	Gas: MW
Electricity: 200 MW	Electricity: MW
H2: MW	H2: MW
Production: Chlorine products	
CO2 production: 43200	kg
NOTES	
<p>Chloryon produces several chlorine products for pools, cleaning and the like. Part of their waste is toxic and needs to be transported to a safe facility. The factory has several processes that need to be active day and night. This requires quite some energy and makes it difficult to switch to an alternative energy source.</p>	
(OPERATING) COSTS	
Investment cost: 15	million euros Cost for PM: 2
Operation cost: 32	million euros per year On PM (check if yes): <input type="checkbox"/>
Infrastructure cost:	million euros per year On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2	million euros per year

CHEMICO	
BASIC INFO	
Registered Business Name: Chemicolors Rotterdam	
Physical location: E3	Phone number: 810 5748445
Business type: Chemical Company	Category: Chemical
Energy consumption:	Energy production:
Gas: 300 MW	Gas: MW
Electricity: 20 MW	Electricity: MW
H2: MW	H2: MW
Production: Paint production	
CO2 production: 64800	kg
NOTES	
<p>Chemico creates various types and colors of paints using different methods. They are currently relying on their gas generators for the chemical part of their process. If another energy source proves to be reliable enough, they are willing to transfer.</p>	
(OPERATING) COSTS	
Investment cost: 15	million euros Cost for PM: 2
Operation cost: 17	million euros per year On PM (check if yes): <input type="checkbox"/>
Infrastructure cost:	million euros per year On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2	million euros per year

CEMENTCo	
BASIC INFO	
Registered Business Name: Cement and Cooperating Groups	
Physical location:	Phone number: 810 2244787
Business type: Chemical Company	Category: Chemical
Energy consumption:	Energy production:
Gas: 600 MW	Gas: MW
Electricity: 10 MW	Electricity: MW
H2: MW	H2: MW
Production: Chemicals for consumer and food use	
CO2 production: 129600	kg
NOTES	
<p>CementCo creates chemicals that are used in various consumer products such as clothing as well as aroma's. They therefore have a high security standard and are slow to implement changes. They all need to be tested and tested again before they can be implemented.</p>	
(OPERATING) COSTS	
Investment cost: 15	million euros Cost for PM: 2
Operation cost: 27	million euros per year On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1	million euros per year On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2	million euros per year

WOBAK	
BASIC INFO	
Registered Business Name: Wobak	
Physical location: G4	Phone number: 810 7978778
Business type: Chemical Shipping Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input checked="" type="checkbox"/> 600 MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 10 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Shipping and storing of several chemicals	
CO2 production: 86400 kg	Service:
NOTES	
<p>Wobak is a big shipping company who ships most of the chemicals in used or produced in the port. They have plans to make a massive shift towards hydrogen as their main energy source. They hope to fulfill this shift in the near future.</p>	
(OPERATING) COSTS	
Investment cost: 19 million euros	Cost for PM: 3
Operation cost: 26 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 3 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2 million euros per year	

DISTRILOTS	
BASIC INFO	
Registered Business Name: Distriots transport company	
Physical location: E4	Phone number: 810 2124487
Business type: Distribution company	Category: Distribution
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 40 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	
CO2 production: kg	Service: Distribution of consumer goods
NOTES	
<p>Distriots is a sustainable company responsible for shipping various consumer goods throughout Europe. They do this mainly by train.</p>	
(OPERATING) COSTS	
Investment cost: 10 million euros	Cost for PM: 1
Operation cost: 16 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 2 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 1 million euros per year	

ABC CARGO	
BASIC INFO	
Registered Business Name: Albert Bertus Carri Cargo company	
Physical location: G3	Phone number: 810 1234567
Business type: Distribution company	Category: Distribution
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 30 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	
CO2 production: kg	Service: Shipment of semi-finished products
NOTES	
<p>The ABC cargo company is an old company founded by three brothers. Their company is one of the largest distribution companies in the port. They ship various goods and big shipments by train and with their trucks. They mostly ship semi-finished products to their final production facility.</p>	
(OPERATING) COSTS	
Investment cost: 12 million euros	Cost for PM: 2
Operation cost: 23 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 2 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 1 million euros per year	

LOGIGROEP	
BASIC INFO	
Registered Business Name: Logigroep	
Physical location: H3	Phone number: 810 4584557
Business type: Distribution company	Category: Distribution
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 50 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	
CO2 production: kg	Service: Shipment of consumer groups with trucks
NOTES	
<p>Logigroep is a smaller distribution company in the port. They mostly ship products to stores using trucks. Recently they have switched to electrical vehicles which increased their electricity usage.</p>	
(OPERATING) COSTS	
Investment cost: 8 million euros	Cost for PM: 1
Operation cost: 9 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 1 million euros per year	

GAS TERMINAL 1	
BASIC INFO	
Registered Business Name: Gas import terminal 1	
Physical location:	Phone number: 810 9775463
Business type: Gas import	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input checked="" type="checkbox"/> 1400 MW
Electricity: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Gas energy	Service:
CO2 production: 302400	kg
NOTES	
<p>This gas import terminal distributes gas to the port network and the Netherlands. It imports gas from various sources. To process and distribute the gas, the terminal produces a lot of CO2 which is distributed directly into the port.</p>	
(OPERATING) COSTS	
Investment cost: 10	million euros
Operation cost: 2	million euros per year
Infrastructure cost:	million euros per year
Port-manager profit: 1	million euros per year

GAS TERMINAL 2	
BASIC INFO	
Registered Business Name: Gas import terminal 2	
Physical location:	Phone number: 810 1148769
Business type: Gas import	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input checked="" type="checkbox"/> 1400 MW
Electricity: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Gas energy	Service:
CO2 production: 302400	kg
NOTES	
<p>This gas import terminal distributes gas to the port network and the Netherlands. It imports gas from various sources. To process and distribute the gas, the terminal produces a lot of CO2 which is distributed directly into the port.</p>	
(OPERATING) COSTS	
Investment cost: 10	million euros
Operation cost: 2	million euros per year
Infrastructure cost:	million euros per year
Port-manager profit: 1	million euros per year

POWER PLANT	
BASIC INFO	
Registered Business Name: Coal fired power generation plant	
Physical location:	Phone number: 810 5787566
Business type: Coal power generation	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input type="checkbox"/> MW	Electricity: <input checked="" type="checkbox"/> 500 MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service:
CO2 production: 108000	kg
NOTES	
<p>The coal fired power generation generates a lot of electrical energy for the port. They do this by burning trash and other items which generates a lot of CO2. With the introduction of the wind turbine the port might want to close the power plant in the near future.</p>	
(OPERATING) COSTS	
Investment cost: 12	million euros
Operation cost: 4	million euros per year
Infrastructure cost:	million euros per year
Port-manager profit: 1	million euros per year

OFFSHORE WIND FARM	
BASIC INFO	
Registered Business Name: Landing station offshore wind farm 1	
Physical location: No.	Phone number: 810 8799563
Business type: Wind generation	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input type="checkbox"/> MW	Electricity: <input checked="" type="checkbox"/> 200 MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Generates electrical energy	Service:
CO2 production:	kg
NOTES	
<p>The new wind energy will provide more electrical energy to the network without producing more CO2. This might promote companies in the port to transition towards electrical energy rather than gas.</p>	
(OPERATING) COSTS	
Investment cost: 2	million euros
Operation cost: 1	million euros per year
Infrastructure cost:	million euros per year
Port-manager profit: 1	million euros per year

NEW OFFSHORE WIND FARM	
BASIC INFO	
Registered Business Name: Landing station offshore wind farm 3	
Physical location: No.	Phone number: 810 3263783
Business type: Wind generation	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input type="checkbox"/> MW	Electricity: <input checked="" type="checkbox"/> 800 MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production: Generates electrical energy	Service:
CO2 production: kg	
NOTES	
<p>If the first wind farm proves reliable, the port might want to produce a second bigger farm which will allow the port to transition even further towards clean energy.</p>	
(OPERATING) COSTS	
Investment cost: 5 million euros	Cost for PM: 5
Operation cost: 2 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Infrastructure cost: million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 1 million euros per year	

H2 PRODUCTION	
BASIC INFO	
Registered Business Name: H2 production facility	
Physical location: No.	Phone number: 810 2244226
Business type: H2 energy production	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 200 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input checked="" type="checkbox"/> 250 MW
Production: Produced H2 for the port network	Service:
CO2 production: kg	
NOTES	
<p>The H2 production facility can use the wind power from the shore to create H2 for the network which can be used as an alternative energy source.</p>	
(OPERATING) COSTS	
Investment cost: 15 million euros	Cost for PM: 15
Operation cost: 8 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 2 million euros per year	

H2 IMPORT	
BASIC INFO	
Registered Business Name: H2 import terminal Rotterdam	
Physical location: No.	Phone number: 810 4458445
Business type: H2 energy import	Category: Energy
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input checked="" type="checkbox"/> 1000 MW
Production: Imports H2 energy for the port network	Service:
CO2 production: kg	
NOTES	
<p>Instead of producing our own H2, the port can import H2 from elsewhere to use as an alternative energy source in the port.</p>	
(OPERATING) COSTS	
Investment cost: 10 million euros	Cost for PM: 10
Operation cost: 6 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: 1 million euros per year	On PM (check if yes): <input checked="" type="checkbox"/>
Port-manager profit: 3 million euros per year	

NEW CONTAINER SMALL	
BASIC INFO	
Registered Business Name: Trip Transport and logistics	
Physical location: No.	Phone number: 810 4854796
Business type: Container Company	Category: Shipping
Energy consumption:	Energy production:
Gas: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW
Electricity: <input checked="" type="checkbox"/> 15 MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW	H2: <input type="checkbox"/> MW
Production:	Service: Shipping service
CO2 production: 3240 kg	
NOTES	
<p>The trip transport and logistics company is a small container company that might want to settle in the port.</p>	
(OPERATING) COSTS	
Investment cost: 17 million euros	Cost for PM: 5
Operation cost: 12 million euros per year	On PM (check if yes): <input type="checkbox"/>
Infrastructure cost: million euros per year	On PM (check if yes): <input type="checkbox"/>
Port-manager profit: 3 million euros per year	

NEW CONTAINER BIG			
BASIC INFO			
Registered Business Name: Labowski Labour Trucks			
Physical location: No.		Phone number: 810 8897225	
Business type: Container company		Category: Shipping	
Energy consumption:		Energy production:	
Gas: <input type="checkbox"/> MW	Electricity: <input checked="" type="checkbox"/> 25 MW	Gas: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW		H2: <input type="checkbox"/> MW	
Production:		Service: Shipping service	
CO2 production: 5400 kg			
NOTES			
Labowski is a big shipping organization that wants to introduce themselves in the port. They are an already established company with facilities in other places and want to expand themselves internationally.			
(OPERATING) COSTS			
Investment cost: 17 million euros		Cost for PM: 5	
Operation cost: 17 million euros per year		On PM (check if yes): <input type="checkbox"/>	
Infrastructure cost: million euros per year		On PM (check if yes): <input type="checkbox"/>	
Port-manager profit: 3 million euros per year			

NEW CHEMICAL GAS INDUSTRY			
BASIC INFO			
Registered Business Name: Harnews chemstreet			
Physical location: No.		Phone number: 810 6697664	
Business type: Chemical industry		Category: Chemical	
Energy consumption:		Energy production:	
Gas: <input checked="" type="checkbox"/> 500 MW	Electricity: <input checked="" type="checkbox"/> 10 MW	Gas: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW		H2: <input type="checkbox"/> MW	
Production: Chemicals for the medical industry		Service:	
CO2 production: 110160 kg			
NOTES			
Harnews industry is a new company that has found a new way to produce useful chemicals for medical operations and machinery. They plan to use gas based machinery.			
(OPERATING) COSTS			
Investment cost: 15 million euros		Cost for PM: 1	
Operation cost: 29 million euros per year		On PM (check if yes): <input type="checkbox"/>	
Infrastructure cost: million euros per year		On PM (check if yes): <input type="checkbox"/>	
Port-manager profit: 1 million euros per year			

NEW CHEMICAL H2 INDUSTRY			
BASIC INFO			
Registered Business Name: Cherico b.v.			
Physical location: No.		Phone number: 810 1156768	
Business type: Chemical industry		Category: Chemical	
Energy consumption:		Energy production:	
Gas: <input type="checkbox"/> MW	Electricity: <input checked="" type="checkbox"/> 10 MW	Gas: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input checked="" type="checkbox"/> 250 MW		H2: <input type="checkbox"/> MW	
Production: Plastic production		Service:	
CO2 production: 2160 kg			
NOTES			
Cherico is looking for a port where H2 energy sources are available. Their company produces recycled plastics and they want to do so with sustainable energy sources.			
(OPERATING) COSTS			
Investment cost: 15 million euros		Cost for PM: n	
Operation cost: 23 million euros per year		On PM (check if yes): <input type="checkbox"/>	
Infrastructure cost: million euros per year		On PM (check if yes): <input type="checkbox"/>	
Port-manager profit: 1 million euros per year			

NEW OFFSHORE WIND FARM			
BASIC INFO			
Registered Business Name: Offshore wind farm			
Physical location: At sea		Phone number: -	
Business type: Energy generation		Category: Energy	
Energy consumption:		Energy production:	
Gas: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW	Gas: <input type="checkbox"/> MW	Electricity: <input type="checkbox"/> MW
H2: <input type="checkbox"/> MW		H2: <input type="checkbox"/> MW	
Production: The wind farm generates the energy which is processed by the terminal.		Service:	
CO2 production: kg			
NOTES			
The new wind farm will generate clean energy that can be used in the port.			
(OPERATING) COSTS			
Investment cost: 12 million euros		Cost for PM: 12	
Operation cost: 2 million euros per year		On PM (check if yes): <input type="checkbox"/>	
Infrastructure cost: million euros per year		On PM (check if yes): <input type="checkbox"/>	
Port-manager profit: 0 million euros per year			

Grid Operator: Grid Infrastructure Specifications

Line name	physical representation	Ca- pacity Gas (MW)	Capacity Electrici- ty (MW)	Capacity H2 (MW)	Cost
Main electricity cable	PVC tube		600		
Main gas pipeline 1	PVC tube	20,000			
Main gas pipeline 2	PVC tube (same as Main H2 pipe- line)	4,000			
Gas pipeline local small	yellow cable, blue tag	500			
Gas pipeline local large	yellow cable, red tag	1,000			
Electricity cable local small	black cable, blue tag		100		
electricity cable local large	black cable, red tag		250		
Main H2 pipeline	PVC tube (same as Main gas pipe- line 2)			2,500	
H2 pipeline local	green cable			1,000	

Top Oil: Company Assets Specifications

Current Assets:	gas use (MW)	Electricity use (MW)	H2 use (MW)	CO2 (kg)	Investment costs (mil- lion Euros)
Base refinery	171	0	0	300,000	
Internal steam methane reformer	0	0	0	1,000,000	
Steam kettle	25	0	0	50,000	
Furnaces	200	0	0	350,000	
Steam methane reformer	300	0	0	550,000	
Office	10	0	0	20,000	
New Assets:					
Furnace (electric)	0	200	0	0	4,000
Steam kettle (electric)	0	25	0	0	2,500
Electrolyse hydrogen (electric)	0	300	0	0	2,000
Electrolyse hydrogen (electric) internal	0	400	0	0	1,500
Furnace (hydrogen)	0	0	200	0	1,000
Steam kettle (hydrogen)	0	0	25	0	2,000
Remove SMR buy H2	0	0	0	0	200
Carbon Capture Storage	0	0	0	-750,000	400
Sustainable office	0	0	0	0	already paid

1.1 Players' Guidelines

Presented guidelines are distributed among the players at the start of the gameplay. Each of the three challenges is first introduced and explained. Then, suggestions and tips on how to address each challenge are provided.

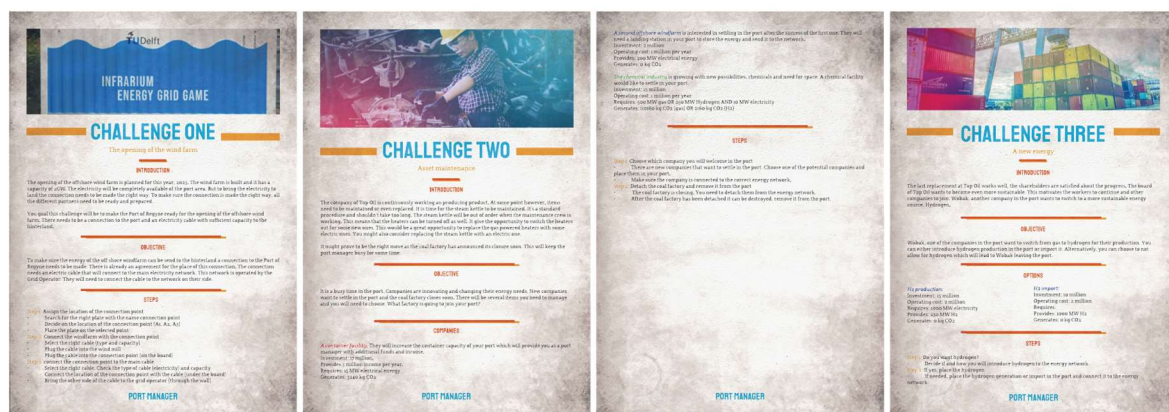
The first challenge concerns supplying the port with a sustainable source of electricity by adding offshore windfarm and connecting it to the main grid. For the TO company, it means switching to the new sustainable office.

Challenge two relates to the TO assets maintenance that creates an opportunity to switch from gas energy to electricity. However, due to the diversity of roles and responsibilities of the players for every station, this challenge is addressed by different objectives.


The third challenge is about switching to fully sustainable hydrogen. Similar to the second challenge. Here, the biggest challenge is not to overload the grid during the transition process while keeping the port still on the operational level.

Details are provided with the printed version of the guidelines at the start of the gameplay.

1.2 Port Manager Guideline & Challenges



1.3 Grid Operator Guideline & Challenges



CHALLENGE ONE

The opening of the wind farm

INTRODUCTION

The opening of the offshore wind farm is planned for this year, 2023. The wind farm is built and it has a capacity of 350W. The electricity will be completely available of the part area. But to bring the electricity to land the connection needs to be made the right way. To make sure the connection is made the right way, all the different partners need to be ready and prepared.

You and this challenge will be to make the Part of Regio ready for the opening of the offshore wind farm. There needs to be a connection to the part and an electricity cable with sufficient capacity to the hinterland.


OBJECTIVE

You know the connection to the Wind Farm is about to be made. You hear there is a connection point in the Part of Regio since you are the network operator of the part area, you are the one that needs to make sure the infrastructure is ready. This means you will need to connect the wind farm to the main electricity network and you will need to create a connection from the main network to the distribution station.

STEPS

- 1. Connect the production with the main network.
- 2. Select the right cable (Also check with Port Manager)
- 3. Connect the cable with the main network and connect with the right network.
- 4. Make a connection between the main cable and distribution station.
- 5. Select the right cable. Check the type of cable (electricity) and capacity.
- 6. Plug the cable into the distribution area.
- 7. Check if the lights go on and the capacity of the main cable.

GRID OPERATOR



CHALLENGE TWO

Asset maintenance

INTRODUCTION

The company of Top Oil is continuously working on producing product. At some point however, items need to be maintained or even replaced. It is time for the steam kettle to be maintained. It is a standard procedure and should take time long. The steam kettle will be out of order when the maintenance crew is working. This means that the heaters can be turned off as well. It gives the opportunity to switch the heaters out for some new ones. This could be a great opportunity to replace the gas powered heaters with some electric ones. You might also consider replacing the steam kettle with an electric one.

It might prove to be the right move as the coal factory has announced its closure soon. This will keep the port manager busy for some time.


OBJECTIVE

A lot is happening in the part and a lot is changing. Companies want to settle in the part, others leave and several are getting away from gas. What does this mean for you? The grid operator, you, need to make sure that the network can handle all these changes. Keep an eye on the capacity of the main pipeline as well as the network cables.

STEPS

- 1. Help the port and company while they make changes.
- 2. Help the company to replace their components and the Port manager with new companies according to the changes happening.
- 3. Check the network.
- 4. Make sure that all the pipes and the cables can handle the capacity put on them.

GRID OPERATOR



CHALLENGE THREE

A new energy

INTRODUCTION

The last replacement at Top Oil works well, the shareholders are satisfied about the progress. The board of Top Oil wants to become even more sustainable. This motivates the workers to continue and other companies to join. Wihab, another company in the part wants to switch to a more sustainable energy source, Hydrogen.

OBJECTIVE


One of the companies in the part wants to move towards hydrogen use. One of the main pipelines could work as a hydrogen network as well. You will need to disconnect the companies from the gas line in order to transition it to a hydrogen pipe. Additionally you might need to further facilitate Top Oil as they transition to more sustainable solutions. Keep your eye on the capacity of the pipelines so that the network is able to handle the request.

STEPS

- 1. Prepare to detach gas pipes.
- 2. Determine which companies are currently using the second gas pipe the middle pipe.
- 3. Ensure that these companies can get their energy from one of the other pipes or are fully transitioning towards hydrogen energy.
- 4. Connect the companies to the new energy if needed and disconnect them from the second gas pipe.
- 5. Transition from gas to hydrogen.
- 6. Turn the gas pipe into a hydrogen pipe.
- 7. Connect the company or companies to the hydrogen pipe.
- 8. Make sure that the network is not over capacity.

GRID OPERATOR

1.4 Top Oil Guideline & Challenges



CHALLENGE ONE

The opening of the wind farm

INTRODUCTION

The opening of the offshore wind farm is planned for this year, 2023. The wind farm is built and it has a capacity of 350W. The electricity will be completely available of the part area. But to bring the electricity to land the connection needs to be made the right way. To make sure the connection is made the right way, all the different partners need to be ready and prepared.

You and this challenge will be to make the Part of Regio ready for the opening of the offshore wind farm. There needs to be a connection to the part and an electricity cable with sufficient capacity to the hinterland.


OBJECTIVE

There is a lot going on in the part. You heard that the new wind farm will be connected to the part immediately in the area. It is time to make the right move as the coal factory has announced its closure soon. This will keep the port manager busy for some time.

STEPS

- 1. Prepare the infrastructure.
- 2. Disconnect the old cable from the infrastructure by removing the cables.
- 3. Connect the new cable to the infrastructure. By removing the old cable the infrastructure is ready to use.
- 4. Place the new cable in the area.
- 5. Connect the cable to the infrastructure.
- 6. Check the capacity of the infrastructure.
- 7. Connect the cable to the infrastructure.
- 8. Check the capacity of the infrastructure.

COMPANY



CHALLENGE TWO

Asset maintenance

INTRODUCTION

The company of Top Oil is continuously working on producing product. At some point however, items need to be maintained or even replaced. It is time for the steam kettle to be maintained. It is a standard procedure and should take time long. The steam kettle will be out of order when the maintenance crew is working. This means that the heaters can be turned off as well. It gives the opportunity to switch the heaters out for some new ones. This could be a great opportunity to replace the gas powered heaters with some electric ones. You might also consider replacing the steam kettle with an electric one.

It might prove to be the right move as the coal factory has announced its closure soon. This will keep the port manager busy for some time.

OBJECTIVE


It is time to do the maintenance on the steam kettle. This means that the steam kettle and the heaters need to be turned off so that the maintenance crew can do their work. This also gives you the opportunity to further transition away from gas (based on companies). The board is interested in the network, the infrastructure.

You can consider moving away from the gas company for electrical sources of resources. The board has announced its closure and the company Top Oil will not be able to produce fuel any more you are able to ensure good action as quickly as possible.

STEPS

- 1. Help the port and company while they make changes.
- 2. Help the company to replace their components and the Port manager with new companies according to the changes happening.
- 3. Check the network.
- 4. Make sure that all the pipes and the cables can handle the capacity put on them.

COMPANY



CHALLENGE THREE

A new energy

INTRODUCTION

The last replacement at Top Oil works well, the shareholders are satisfied about the progress. The board of Top Oil wants to become even more sustainable. This motivates the workers to continue and other companies to join. Wihab, another company in the part wants to switch to a more sustainable energy source, Hydrogen.

OBJECTIVE

Disconnect which assets you would like to replace and if you would like to transition that part to electrical energy or to land hydrogen.

STEPS

- 1. What do you want to change?
- 2. Determine which assets you would like to replace.
- 3. Prepare to make the change.
- 4. Disconnect the old infrastructure. It is possible to replace the asset and then.
- 5. Remove the asset from your factory.
- 6. Change the asset.
- 7. Connect the new asset and place it in your factory.
- 8. Connect the new asset to the network network.
- 9. Make sure that the network is not over capacity.

COMPANY

B. SysML Infrarium Model

SysML Infrarium Model is in detailed explained and described in Chapter 5. In this appendix, diagrams are shown to better visualize the whole model. Also diagrams that are only mentioned and not presented within Chapter 5 are also presented below.

B.1 Block Definition Diagram

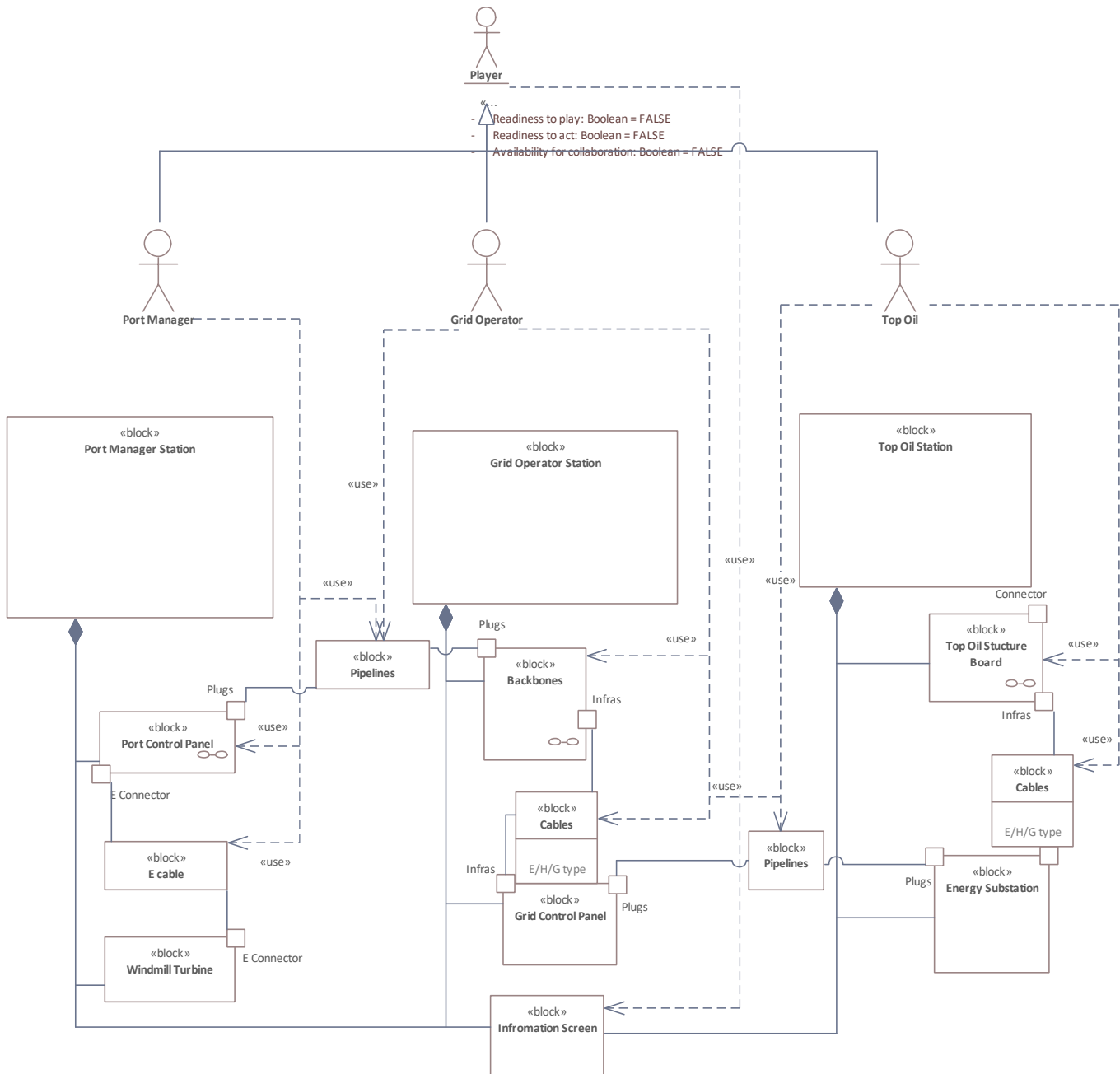


Figure B-4: Main Block Definition Diagram of the Infrarium Model

B.2 Activity Diagrams

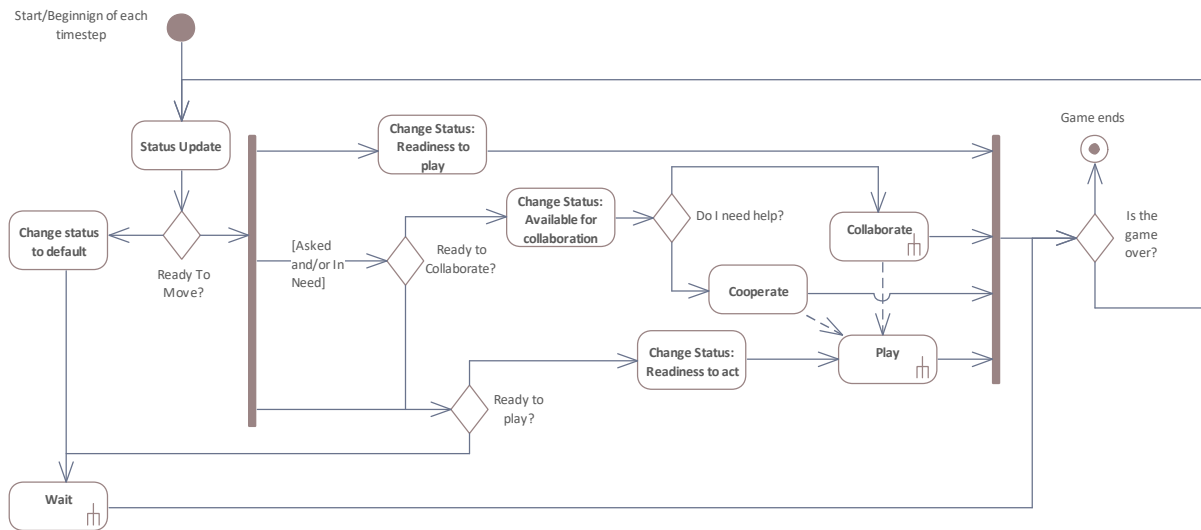


Figure B-5: Make Decision Activity Diagram

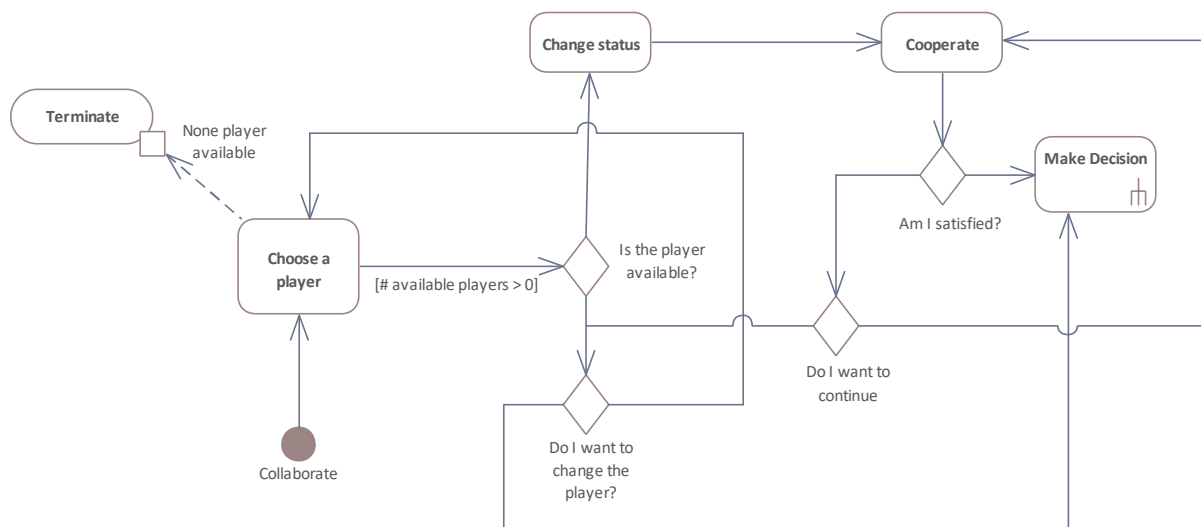


Figure B-6: Collaborate Activity Diagram

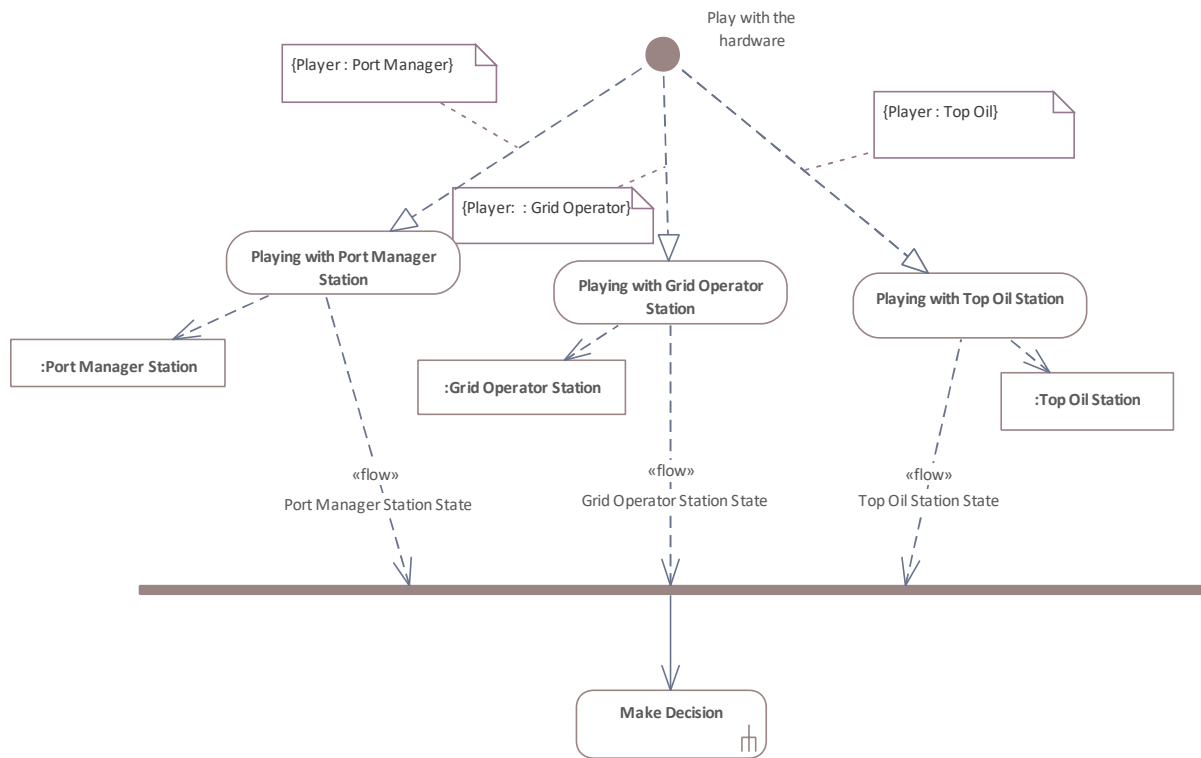


Figure B-7: Play Activity Diagram

B.3 State Machine Diagrams

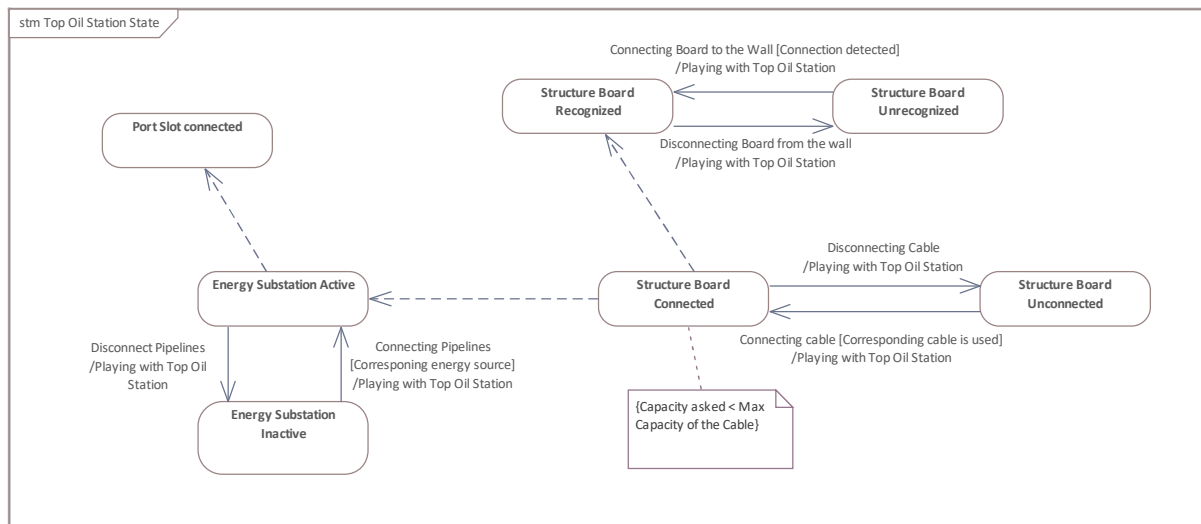


Figure B-5: Top Oil Station State Machine Diagram

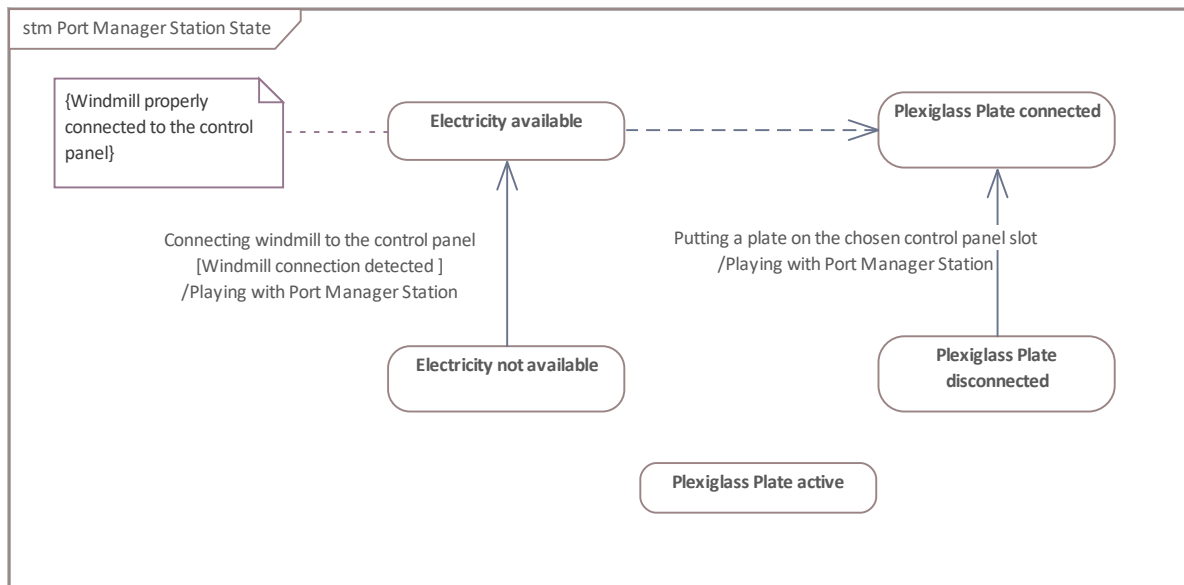


Figure B-6: Port Manager Station State Machine Diagram

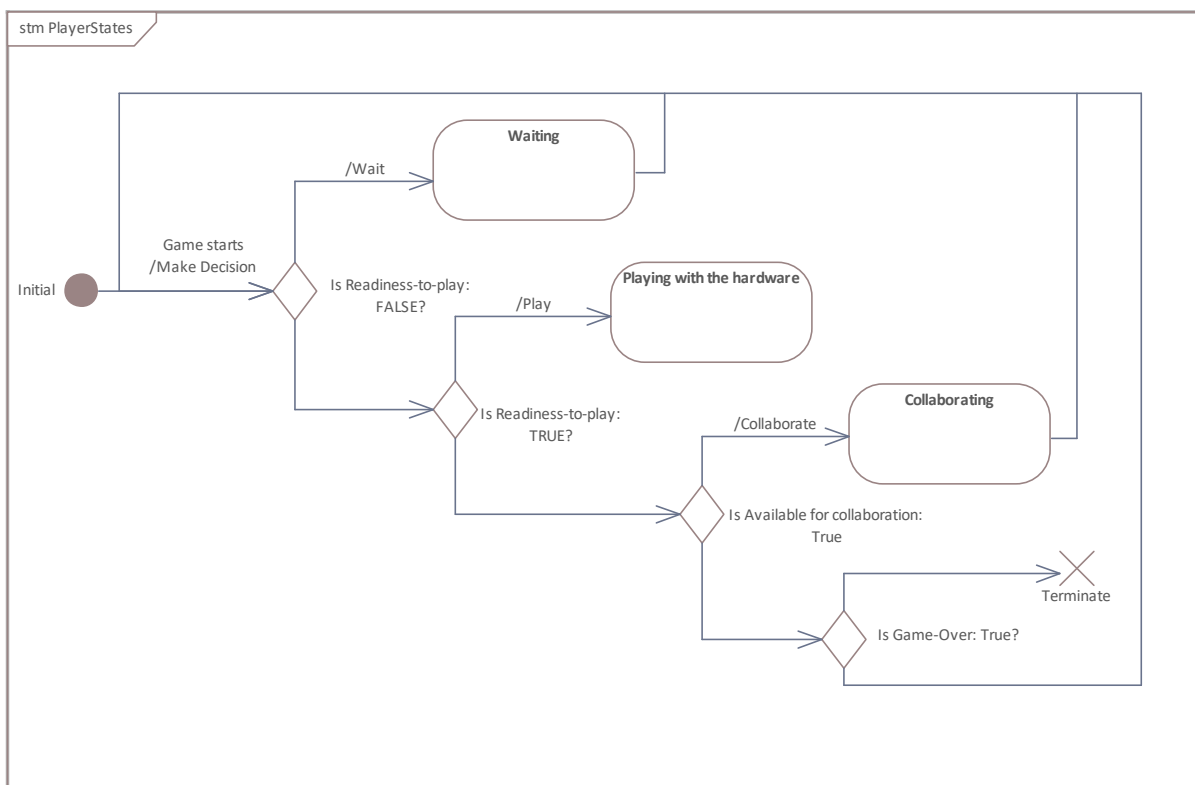


Figure B-7: Player State Machine Diagram

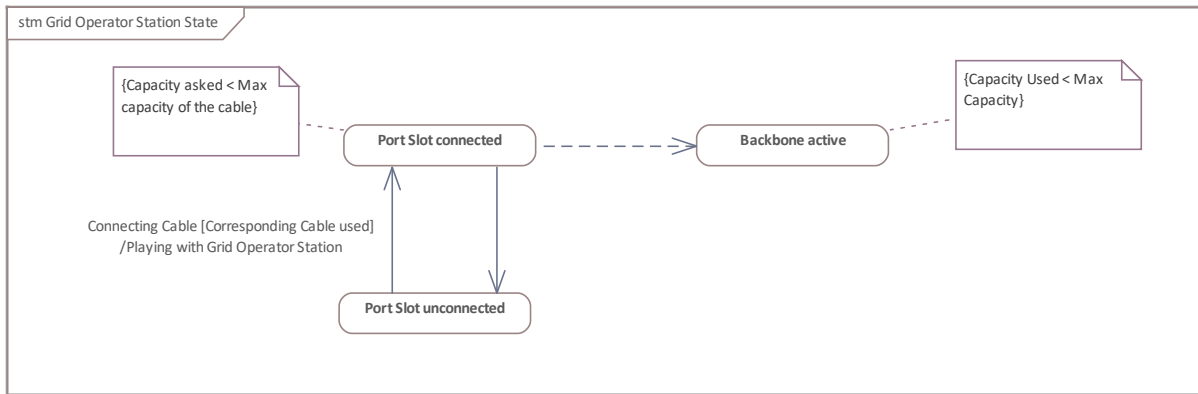


Figure B-8: Grid Operator Station State Machine Diagram

B.4 Other Diagrams

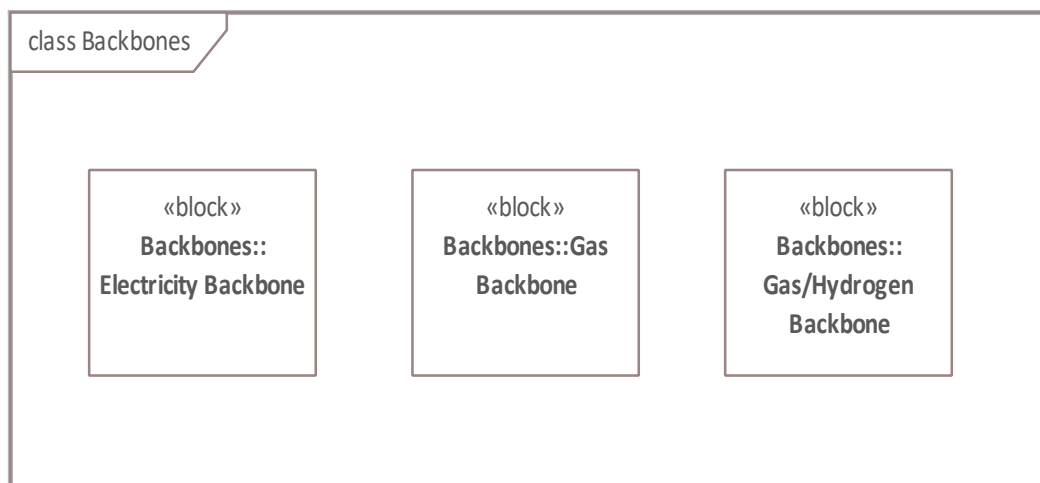


Figure B-9: Backbones Internal Block Definition Diagram

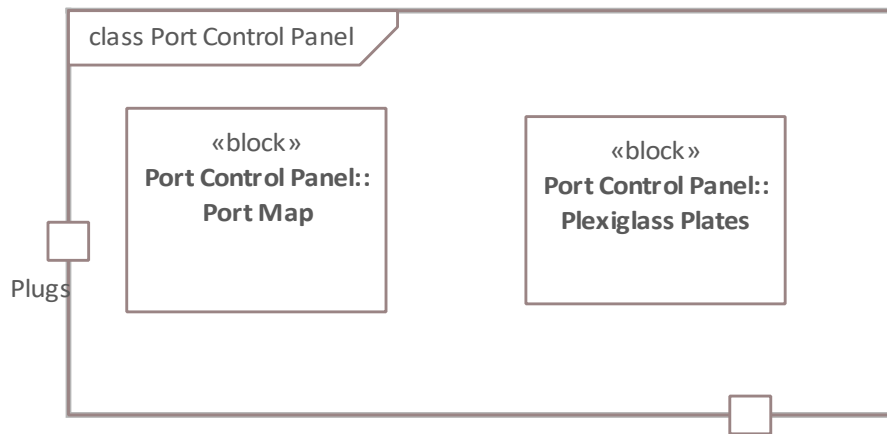


Figure B-10: Port Control Panel Internal Block Definition Diagram

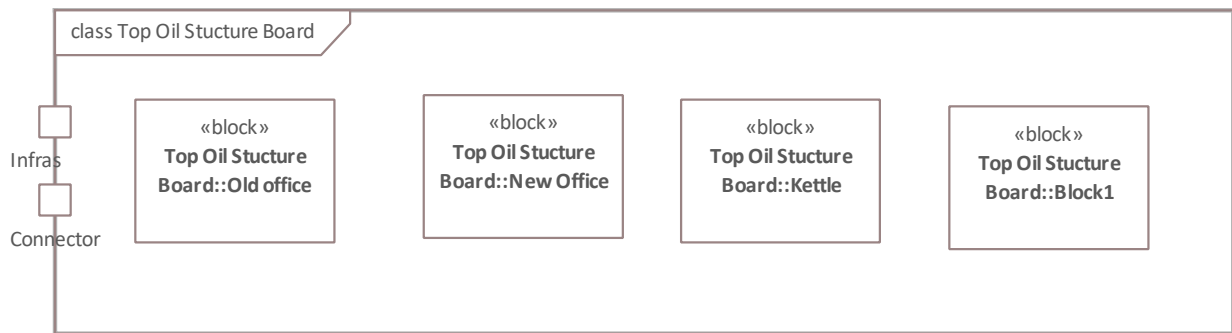


Figure B-11: Top Oil Structure Board Internal Block Definition Diagram

C. EA Infrarium SysML Model file

Enterprise Architect *ModelInfrarium.gea* uploaded on the Infrarium GitLab projet. All the data collected and used could be found along with the model could be found on:
<https://gitlab.tudelft.nl/inikolic/infrarium>

D. SysML Dictionary

The dictionary is done based on the glossary available at <https://sparxsystems.com>.

Block

Defines a composite system entity in SysML; represents a modular unit of a system or a model. It defines an element's structure, behavior, and properties in the system. A block is a reusable component that can be used to create instances and contain properties, operations, and other features. A block can have both structural and behavioral aspects. The structural aspects are captured through the block's properties, parts, and relationships with other blocks. The behavioral aspects are captured through the block's owned behaviors, which describe how the block behaves or interacts with other elements in the system.

Part

Represents a constituent element or component within a block. Parts define the internal structure of a block by specifying its components or sub-elements.

Port

Describes a structural interaction point of a SysML Block, which in turn connects interacting parts of a block.

Actor

Represents a user that interacts with one or more SysML systems.

Dependency

Establishes a traceable relationship describing how one element is dependent upon another.

Generalization

Describes an element as a specialized descendant of another element, containing additional properties and behavior.

Part Association

Describes the characteristics of a connection between a SysML Block and its internal parts, such as the multiplicity and type.

Activity

Defines a SysML Block of executable behavior as an Activity. An activity represents a higher-level behavior that encompasses a collection of actions and control flow between them. Activities can include multiple actions, decisions, loops, concurrency, and synchronization points.

Action

Declares a unit of execution in the Activity. It typically represents a specific operation or task that is performed by an element in the system.

Control Flow

Establishes a flow of logic between two Activity or Action nodes.

State

Declares a significant condition in the life of a SysML Block within its State Machine.

State Machine

Describes the life-cycle behavior of a SysML Block in terms of its states and transitions.

Transition

Establishes a life-cycle path between one State and another, based on its operational conditions.

Owned Behaviors

A set of behaviors or actions that are associated with a block within a system, captures the behavioral aspect of the block.

Collaboration

As a structural diagram element, A collaboration describes a structure of collaborating elements (roles), each performing a specialized function, which collectively accomplish some desired functionality. Its primary purpose is to explain how a system works and, therefore, it typically only incorporates those aspects of reality that are deemed relevant to the explanation.

Connector

Specifies a link that enables communication or relation execution between two or more instances.

a connector is used to represent a relationship or interaction between two or more blocks. It establishes a connection between blocks to define how information or signals flow between them. Connectors are used to model the structural and behavioral relationships between blocks in a system.

Here are some key points about connectors in SysML:

- **Relationship Representation:** A connector visually represents the relationship between blocks in a diagram. It typically appears as a line or arrow connecting ports or parts of blocks.
- **Information Flow:** Connectors define how information, signals, or data flows between blocks. They specify the flow of data or control from one block to another.
- **Port-to-Port Connection:** Connectors are commonly used to connect ports of blocks. Ports are the interfaces through which blocks communicate with each other.
- **Block-to-Block Connection:** Connectors can also connect blocks directly, without involving ports. This is often used when the connection represents a structural relationship or dependency between blocks.
- **Communication Path:** Connectors can represent different types of communication paths, such as data flow, control flow, power flow, or information exchange.
- **Connector Ends:** A connector has two or more ends that connect to ports or parts of blocks. Each end of the connector specifies the source or target of the connection.
- **Stereotypes and Attributes:** Connectors can be annotated with stereotypes or additional attributes to provide more information about the nature of the connection.

Connectors play a crucial role in modeling the interactions and relationships between blocks in SysML, helping to capture the flow of information and signals within a system. They enable the representation of the system's structure, behavior, and communication paths, aiding in the analysis, design, and simulation of complex systems.