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Fostering Sustainable Transportation Operations through Corridor Management: A Simulation Gaming Approach

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Abstract: Synchromodality is described as a network of well-synchronised and interconnected transportation modes. One of the most important advantages of synchromodality is the development of a sustainable transportation system. Given the numerous stakeholders and network interdependencies within freight transport corridors, achieving efficient coordination and management is complex. In this paper, we regard information exchange as one of the main enablers of collaboration between the infrastructure managers. We developed a digital single-player simulation game called "Modal Manager" comprising logistic service providers and infrastructure managers. Each player takes over the role of an infrastructure manager who must use information provision as a tool to control flows in a network where various planned and unplanned disruptions occur. We include the game in a session where participants are able to interact with the game and with each other. The first gameplay session with Dutch experts revealed that infrastructure managers perceive synchromodality as a way to cope with disruptions more efficiently. On the other hand, the concept of synchromodal corridor management is ambiguous and various legal and governance barriers exist that hinder its implementation.

Keywords: simulation gaming; synchromodal corridor management; infrastructure managers; information exchange

1. Introduction

Despite economic turbulence in the last decade, the growth rates of economies and trading sectors [1] continue to increase. Trade volumes are expected to continue growing, leading to increasing demands with regard to the performance of freight transport networks ([1–3]). The current estimations for Europe are predicting a 50% increase in passenger and freight transport within the next 20 years [4]. The performance of freight transport networks very much depends on how they are managed and operated [5]. New mobility services and solutions are being created to provide passengers with the ability to choose between different modalities, and their choices are well catered with respect to cost, flexibility, and sustainability [6]. However, when it comes to freight transport, not enough attention has been given to getting goods from the origin to the destination as quickly, easily, and sustainably as possible. At the moment, many European corridor managers feel that freight transport is not altogether efficient and safe, let alone sustainable [6]. The 'Mobility as a Service' (MaaS) concept is already applied in passenger transport and offers each traveller a personalised mobility solution that combines options from different modes and transport providers into one service, taking into account real-time disruptions and passenger needs [7].

Following the MaaS paradigm, synchromodality is a promising, yet still controversial concept towards improving the flexibility, sustainability, and cost-effectiveness of port–hinterland freight transport. It is defined as the vision of a network of well-organised and interconnected transport modes, which together cater for the aggregate transport demand and can dynamically adapt to the individual and instantaneous needs of transport users [8]. ALICE (Alliance for Logistics Innovation through Collaboration in Europe), a leading EU group on logistics, states that the efficiency of freight transport corridors and hubs can benefit from synchromodal transport solutions. Synchromodality can be defined as the service (Synchromodality as a Service—SaaS) which, through informed and flexible planning, booking, and management, allows mode and routing decisions to be made at the individual shipment level and as late as possible in the transport planning process, including within the trip itself [9].

Synchromodal corridors, which can be also named green transport corridors, are potential trans-shipment routes for long-distance freight traffic based on intermodal transport supported by advanced ICT solutions [3]. Key challenges identified in a summit of EU corridor managers were related to information sharing, establishing standards, and the ICT required to connect the stakeholders in a complex environment of policy barriers, different interests, priorities, and connectivity [6]. An additional challenge is that synchromodality still seems to be an academic concept of which the actors in the domain are not fully aware. In particular, the advantages of the concept in relation to flexibility of services, network robustness, and environmentally friendlier transportation solutions are not yet known [1]. Synchromodal corridor management in particular requires new forms of collaboration, like smart contracts, information sharing, and open databases, in order to use all assets in a flexible, sustainable, yet efficient way [1]. Although it appears to be a complicated solution, research and innovation investments in the topic are expected to bring primary and secondary benefits to consumers (service quality, flexibility, transparency), the environment (sustainability), and industry (cost reduction), as shown in Table 1.

Table 1. Expected impact of research innovation activities on corridors, hubs, and synchromodality (adjusted from [9]).

	Primary Impacts	**Secondary Impacts**
Consumers	+ Customer satisfaction. + Product availability. + Secure transport.	+ Load factors: weight and cube fill of vehicles. + Volume flexibility (Time to +/− capacity). + Route and mode flexibility.
Environment	− Energy consumption (kWh Logistics/GDP). + Renewable energy source share. − CO_2 Emissions (kg CO_2/tkm). + Modal Shift.	+ Asset utilisation. + Supply Chain Visibility. + Reliability of transport schedules. + Transport route optimisation (reducing distance). + Transport actors using automatic data exchange.
Industry	+ Return on assets. − Cargo lost to theft or damage. − Total supply chain costs.	+ Cargo and logistics units integrated in the automatic data exchange. + Supply Chain Adaptability and Flexibility. + Decoupling logistics intensity from GDP. − Waiting time in terminals. − Risk factor reduction. − End-to-end transportation time. − Lead times.

Legend: + increase in; − decrease in.

As we are already entering the big data era, the growing availability of information enhances the improvement of processes and services and benefits the development of new infrastructure based on ICT [10]. However, the data that are needed to ensure the development of a synchromodal transport system are controlled by different actors. Hence, information exchange between actors is one of the most important enablers of synchromodal transport [8].

Our study is a part of a research initiative known as the 'SynchroGaming' project sponsored by the The Netherlands Organisation for Scientific Research (NWO). One of the research objectives of this project is to understand the constraints and opportunities of synchromodal corridor management for freight transportation. In this study, we develop a simulation game to address the key challenges of applying information exchange to facilitate the development of synchromodal corridor management.

The remaining of the paper is structured as follows: In Section 2, we present the synchromodal concept, and related challenges and opportunities, and we elaborate on the information requirements necessary to ensure synchromodal management in freight corridors. In Section 3, the methodology is described, while in Section 4 we discuss the attitudes of stakeholders towards the concept observed during gameplay; with Section 5, we conclude this paper.

2. Background

In this section, we describe synchromodality, the synchromodal corridor management concept, and the information requirements necessary to achieve efficient management of the freight transport network.

2.1. Synchromodality

The transportation of goods from an origin to a destination frequently requires the combination of different modes. In multimodal transport, several modes of transport are combined to transport freight [11]. Intermodality is the technically optimised intermodal transport where intermodal transport units are used (such as containers, semitrailers, etc.) to facilitate the transfer of freight between modes without direct handling of the goods [11]. A more evolved and synchronised form of intermodal transport is synchromodality [12]. Synchromodality is defined as "[a] network of well-synchronised and interconnected transportation modes, which together cater for the aggregate transportation demand" [8]. Synchromodality—an advanced type of freight transportation—is regarded by the scientific community as the new stage of freight network development and is expected to deliver considerable advantages in terms of the cost and quality of offered services [8]. This innovative service is proposed as a solution to meet the challenge of smart, green, and integrated transport as promoted by the European Union in its Horizon 2020 Strategic Research Agenda [13].

Synchromodality is still an early concept and the expected benefits are not yet quantified and fully understood. The most quoted benefit of synchromodality in the literature is the increase in both economic and environmental sustainability [14]. A smarter, more synchromodal scheduling of services will benefit sustainable freight transport [15]. This accrues partly from an expected increase in modal shift but also from the real-time planning of the transportation mode services to adapt to variabilities in the demand.

The involvement of numerous stakeholders in freight transportation and the complex and subtle relationships formed between them show characteristics of a complex sociotechnical system—a system that involves a large number of physical–technical elements and networks of independent stakeholders ([16,17]). The actors engaged in freight transport have different needs and goals, and are often competitive with each other. However, they have to align their plans and share information to make suitable decisions in this complex and uncertain environment, which impedes the adoption of the synchromodal concept.

In the complex system of freight transport, the key stakeholders operate on four different levels. Figure 1 consists of a layered hierarchical representation of the key stakeholders that are involved in multimodal/synchromodal transportation. This model is adjusted from the TRAIL layered model developed by [18].

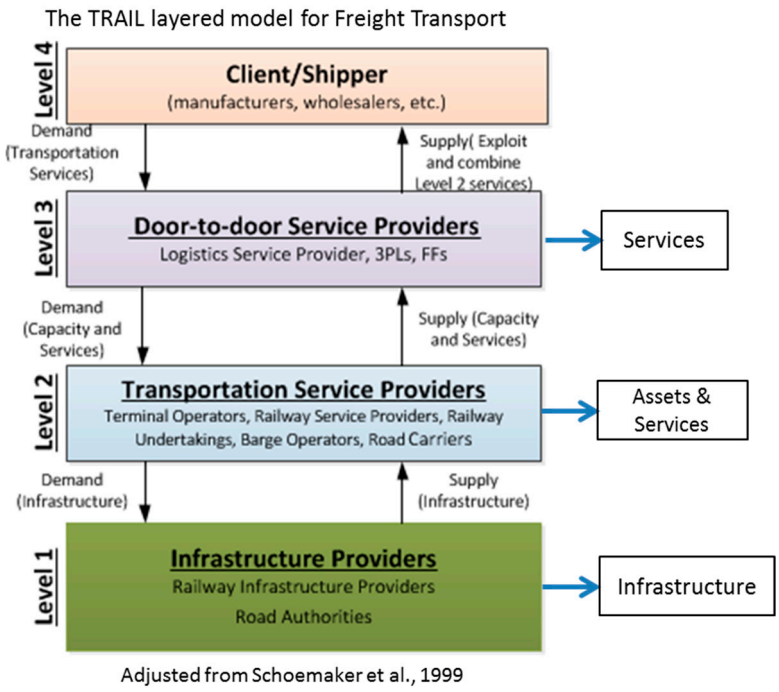

Figure 1. Stakeholder relationships in European freight corridors, adjusted from [18].

The stakeholders engaged in the first level provide the necessary infrastructure for the modes to operate. This can include stakeholders such as road, rail, and waterway infrastructure providers and port authorities. The next level includes the provision and management of assets and services to offer the necessary transportation by single modes of transport. The stakeholders that combine the services of the Level 2 stakeholders to offer door-to-door delivery of shipments from an origin to a destination are on Level 3. Note that in the case of unimodal and multimodal transport (parallel modes), Levels 2 and 3 may overlap. The last layer, Level 4, consists of shippers and receivers who are the freight owners and demand a certain level of offered services. The decision-makers in this fourth level set the destination, cost, and quality constraints of the transport services. The actors of each level set the demand that should be supplied by the stakeholders of the level below.

Door-to-door intermodal transport requires the vertical integration of actors, while, as we proceed to more advanced synchromodal services, the horizontal integration of actors is necessary [19].

2.2. Synchromodal Corridor Management Concept

For the purpose of this paper we focus on the first level of the infrastructure providers that includes the providers of "stationary resources" such as transport infrastructure (road and rail network, inland waterways, and trans-shipment modes (e.g., terminals)) [8]. In addition, the assumption is made that, on a strategic level, the necessary decisions on infrastructure have been made. A network where the three modes are available and there are enough links to support the shift between modalities is considered. We define synchromodal corridor management as the process of integrating the control of the three different modes aiming at orchestrating transport flow in a manner that ensures the efficient utilisation of the network and deals with planned and unplanned disruptions.

While multimodal transportation requires vertical collaboration between the different layers, efficient synchromodal services go one level further and demand horizontal integration amongst the stakeholders of one layer. Synchromodal transport, however, requires the development of collaboration strategies between the different actors that operate in every network. Each multimodal chain consists of various companies that have different incentives, resources, and capabilities. The coordination of these actors is considered as one of the most important governance enablers of synchromodal

transport [19]. Horizontal information exchange amongst the infrastructure managers and vertical information exchange between the infrastructure managers and the service providers on the capacity, services, and disruptions in the network is regarded as a new form of collaboration between the actors [8].

2.3. Synchromodal Information Exchange

The provision of this new synchromodal service therefore requires the alignment of resources in a way that guarantees maximum utilisation and high customer satisfaction levels. The integration of actors and services in synchromodal transport provides more possibilities to handle disruptions [19]. In addition, cooperation between the service providers and the infrastructure managers permits the adoption of corrective actions and the adjustment of schedules and decisions related to mode or route choice when an unforeseen event occurs [20]. Integration of the different actors through the exchange of information is not yet customary. Nonstandardised and segmented data among the actors as well as organisational and legal barriers hinder their collaboration. New information markets need to emerge that support the standardisation of data and the harmonisation of information systems [8]. Researchers have been focusing on the development of ICT infrastructure such as the Synchromodal Control Tower [21]. However, they disregard the decision-making processes of the actors involved and fail to take into account the unfamiliarity of the actors with this new synchromodal concept [13].

Within the context of the above challenges, we designed a game concept to first increase the awareness of the actors on this innovative concept of synchromodal corridor management and then to use information sharing to assist infrastructure managers to orchestrate an efficient synchromodal transport network.

3. Methodology: Simulation Gaming

Simulation gaming is an evolving research method for the study of complex systems. Simulation gaming is understood as a conscious endeavour to reproduce the central characteristics of a system in order to understand, experiment with, and/or predict the behaviour of that system [22]. It is a method in which human participants enact a specific role in a simulated environment [23]. Duke's work [22] on simulation gaming as a research method focused on military applications in the early 1960s. He lists the following characteristics of simulation games that make them apt for research.

- It is easier and **cheaper** to study and experiment a problem within a simulation game than in reality.
- Simulation games make certain phenomena more **visible** for **observation** and measurement in an otherwise complex, chaotic real-world system.
- They allow for the design of **controlled experiments** that would be impossible in the real world, enabling researchers to gain elaborate insights into how the system operates.
- Simulation games offer a **safe** environment to produce laboratory analogues of dangerous phenomena that we need to explore.

Communication and cooperation are basic prerequisites needed in the highly complex and competitive transportation system to allow for adopting a synchromodal approach. Gaming fosters communication between players, which makes it a valuable method for supporting social learning processes. Above that, simulation gaming has strong potential as a research method, as it is engaging in nature, can increase participation, often comes as a computational model that automatically allows for data collection, and enables manipulation and control through a researcher [24]. Simulation gaming allows for deep insights in existing systems, is able to make players aware of certain challenges and problems [25], and enables the observation of player behaviour [26]. As with every research method, simulation gaming also shows some limitations when used for rigour analysis. When playing the game, a certain dynamic evolves which is hardly to be defined beforehand, as the experiences, skills, and expectations of the individual players have an impact on the play situation. Another type of game reality is developing when the game is played [27], which can differ from the interpretation intended

by the game designer and researcher. In the following section, we show how we applied the method of simulation gaming along with additional tools to study the challenges and opportunities related to synchromodal corridor management.

3.1. Problem Exploration through the Game Design Process: The Five C's

Synchromodal corridor management is an innovative approach towards bringing flexibility and sustainability to freight transport networks, as mentioned in the introduction. The unprecedented and complex nature of this approach gives rise to uncertainty, lack of awareness, and consequences of its implementation among the involved stakeholders and overarching institutions [9]. These types of networks can be classified as socio-technical systems—complex systems that involve physical–technical elements and networks of interdependent stakeholders [16]. The involvement of numerous stakeholders in freight transportation and the complex and subtle relationships formed between them show characteristics of a complex socio-technical system. One of the main challenges in such systems is the impossibility of assessing and understanding the situation in its entirety for design, analysis, and decision-making [16]. This aspect is also referred as the decision quality in complex systems by Duke and Geurts [23]. They went on to prove that simulation gaming has the capability to improve decision quality and explored the challenges and opportunities of innovations or policy measures in complex systems such as freight transport networks. Duke and Geurts [23] proved that simulation games can address the following criteria related to complex systems, known as the 5 C's:

1. **Complexity**: Socio-technical systems are complex, generating a lot of uncertainty. Socio-technical systems are composed of numerous elements and forces. As a result, the number of factors and variables that the actors need to consider while making a decision to solve a problem is very large and complex.
2. **Communication** is one of the most essential yet challenging characteristics of complex systems, and is usually referred to as the concept of information management and information exchange.
3. **Consensus:** Stakeholders in socio-technical systems may come from different backgrounds and can have potentially conflicting values and principles. The actors need to resolve their differences to achieve a common goal, usually through a lengthy and difficult negotiation process.
4. **Creativity** (Innovation): Socio-technical systems are characterised by constant change. The effects or consequences of decisions made by the actors are not clear immediately. Therefore, actors need to anticipate the future state of a situation to make suitable decisions.
5. **Commitment to action** is often an emotional part of decision-making by stakeholders which does not necessarily arise from a logical standpoint but more from their values and norms. In socio-technical systems, it is hard to get the 'right' amount of commitment from various stakeholders to work on a new solution.

Synchromodal corridor management shows characteristics in line with these 5 C's. The synchromodal concept requires cooperation of and information sharing by a large number of actors in an uncertain and competitive environment [8]. These actors do have their own goals and values, and they have to build up consensus to a certain level in order to realise synchromodal transportation. It is also quite a new approach, requiring the use of innovative techniques such as smart contracting [9]. This requires trust and commitment from the actors involved [1].

In order to explore and understand synchromodal corridor management against the challenges of the 5 C's, we have developed a game known as "Modal Manager". In the literature, there are examples of several 'operational games' that are used for exploring and aiding decision-making, planning, and policy implementation in specific situations [28]. To be more specific, operational games can be used for policy formulation, dress rehearsals or actual testing of plans, sensitivity analysis, commentary on plans, demonstration of plans, idea generation, changing attitudes, model testing, establishing communication, etc. ([28,29]). Klabbers, in [30], compiled an extensive list of various disciplines and departments in academic research that use simulation games for a variety of academic

and research purposes. In comparison, we can describe our game as an operational game that was designed to explore the decision-making and performance of modal managers under uncertain and dynamic situations.

In the following subsection, we will introduce the game design process of the modal manager game.

3.2. The Game Design Process: The Modal Manager Game

We applied a participatory game design approach in collaboration with 12 infrastructure managers (3 rail, 5 road and waterway, 4 port authorities) together with 4 researchers, 2 research consultants, and 2 game designers. We chose this approach to engage subject matter experts together with researchers and designers to explore the information management strategies in order to foster effective and sustainable corridor management. The aim of the participatory design process in close cooperation with the stakeholders was twofold. First, we aimed to develop a valid, meaningful game experience that fosters the transfer of what can be learned with the game to the real system. Secondly, we used the game design process itself to support the discussion around a relatively new and highly complex topic, and to make the stakeholders aware of the variety of aspects related to it.

The game design process started with a so-called game storm, a brainstorm technique particularly designed for the design of Microgames, and for the definition of the related research problem and the requirements for the game, as illustrated in Figure 2. Microgames are short simulation games that support situated learning for a specific problem statement and can be used for research (as illustrated in [25,27]). The game brainstorm session was held with ten stakeholders (road, rail, and waterway infrastructure managers; port authorities) from the Dutch transportation domain, and four researchers with expertise in synchromodal transportation.

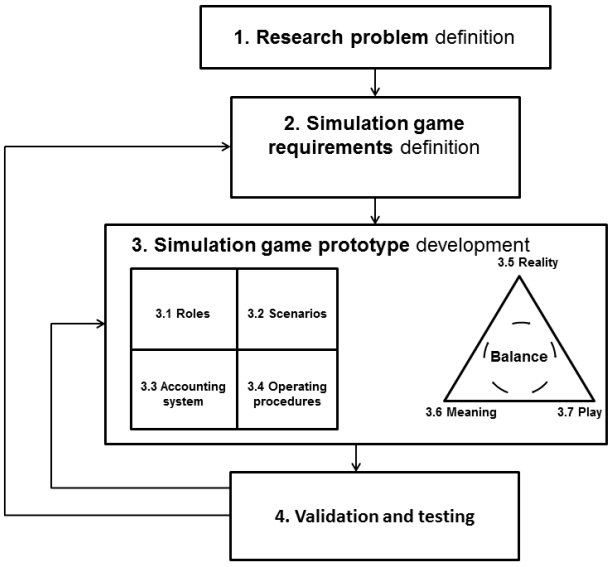

Figure 2. Game design process for the modal manager game, adapted from [31].

We will describe the game design process based on the elements described in Figure 2. We have already discussed the research problem together with a game brainstorm for understanding the game requirements. We will now proceed to describe the iterative game prototype development shown in the third stage in Figure 2. The game consists of roles, scenarios (various cases that need to be tested), operating procedures (rules of the game), and an accounting system (scoring schema). These aspects are designed using the triadic game design approach of [32], who proposed that a game needs to be balanced for reality (real-world representation), meaning (the purpose of the game), and play (the ability of the game to be interactive, immersive, and engaging). We will start by describing the roles in the game.

- **Roles**

The main roles in the game are of infrastructure managers of different modalities (rail, road, and waterways) and the Logistics Service Providers (LSP) who use the network to ship freight. Given the short and single-player characteristic of a microgame, it was decided that the player him/herself would play the role of infrastructure manager, while in-game simulated agents would represent the LSP. There are about 50 simulated LSPs in the game and they are divided into three groups, where each of the three groups has different priorities when choosing a particular modality. One group is focused on cost reduction, another group on sustainability, and the third group on reliability. However, these LSP groups are not visible for the player, function in the backend of the game, and make decisions based on their priorities.

- **Operating Procedures**

The various actions that a player can take to ensure an effective network with reliable services and sufficient modal split to ensure sustainable freight transport operations have to be defined as operating procedures in the game. Since information management is the key focus area of this research, we discussed various options that could be incorporated in the game which we wanted to test for their effectiveness. The following options were shortlisted as the most desired aspects to be embedded in the game:

1. **Informing**—The infrastructure manager can inform logistic service providers about usage of the network, disruptions, and possible consequences (e.g., congestion).
2. **Advising**—Based on the observed network status, the infrastructure manager can advise logistic service providers on certain measures, e.g., taking an alternative route.
3. **Directing**—Based on the network status, and possible disruptions such as maintenance work, the infrastructure manager can actively direct the logistic service providers' actions, e.g., closing a bridge.
4. **Doing nothing**—After analysing the network situation, an infrastructure manager can choose to do take no action—do nothing.

The **Inform** option of the infrastructure managers corresponds to a network information system where the information is displayed and accessible to all LSPs. The interpretation of the information is subjective, and its consequences are unknown to LSPs. This mode of information sharing can be related to developing a common operational picture among stakeholders related to a given situation using shared displays [33]. The **Advise** option allows inframanagers to share only relevant information to relevant LSPs by explaining the consequences of the provided information. Salmon [34] asserts that in time-pressed situations such an approach is effective since it doesn't create information overload among stakeholders. With the **Direct** option, an infrastructure manager enforces a certain route for the LSP.

We checked the options with the subject matter experts before incorporating these actions into the game. While the first two and the last measures were valued as realistic actions, the third one was not valued as realistic. Infrastructure managers do not have the power to direct the traffic, or actively intervene in the decisions of the logistic service providers. As the modal manager game is meant to provide an experimental environment to test and discuss alternative solutions, it was decided to implement the third option. This enables the researchers to observe the impact of the distinct measures in comparison with each other. We will now present the scenarios against which these measures will be used and tested.

- **Scenarios**

The infrastructure managers provided more than twelve scenarios that could affect the operations in a freight corridor. They provided the following fifteen cases that could be represented in the game

in order to experiment with the various information sharing. As a second step, researchers and stakeholders developed a list of possible scenarios based on realistic situations and incidents in the Dutch transportation network. The fifteen scenarios described below were simulated and included in the game. We will not mention the actual names of some of the places and infrastructures for confidentiality reasons.

1. Disturbances on an alternative rail route while the main route runs on low capacity due to maintenance works.
2. Exploring alternative routes to avoid congestion for inland shipping in a major port.
3. Blockage of the connection between a major inland waterway connection and a rail terminal.
4. Proactive solutions to look into alternative rail solutions against high and low tide situations in inland waterways.
5. Alternative transport solutions when there is a low tide at a major port.
6. Disturbance in a railway classification yard close to a port.
7. Port railway lines have to be restored after suffering from subsidence, which will create disturbances due to the maintenance works.
8. Blockage of railway tunnels along the railway connecting a port due to maintenance works.
9. Blockage of railway tunnels along the railway connecting a port due to an incident.
10. Implementation on an information portal to assess lead times for different modalities.
11. Policy to advise on major maintenance on corridors (time span 1–2 years) over the modalities.
12. A proactive approach towards bridge and lock operation based on demand rather than fixed schedules.
13. Hazardous goods transport using inland waterways during disruptions.
14. The situation where infrastructure managers could fulfil the role of neutral 'integral managers' in order to better coordinate the supply and demand of infrastructure capacity and transport capacity.
15. The 5C hub (Cross Chain Corridor Control Center): The companies that provide services at the hub together manage all the information needed to synchronise corridor connections.

The fifteen cases have been categorised based on the type of measures (operational, tactical, or strategic) they require to be solved. They are represented in graphical format in Figure 3 in terms of the different information measures (inform, advise, direct) that could be helpful in dealing with these disruptions. These cases are introduced as either planned or unplanned disruptions in the network.

The game has several difficulty levels and options represented by missions. In the Modal Manager game, Mission 1 is played from the perspective of one infrastructure manager (either road, rail, or waterway) who can only inform, while one or two planned disruptions appear in the network. Mission 2 has again one mode infrastructure manager who is able to both inform and advise while three or four planned disruptions occur. Mission 3 has one infrastructure mode and the possibility to inform, advise, and block to cope with three or four planned disruptions, and two unplanned disruptions in the network. In these missions, we inserted scenarios 2, 10, 11, and 12 (see page 10 and Figure 3). In the final mission (4) the player controls all three modes (synchromodal corridor manager) and has all options available while many planned and unplanned disruptions occur in the network. The scenarios simulated in this mission are 1 to 8 and scenario 11 (see page 10 and Figure 3). The players need to deal with the disruptions using the inform, advise, and direct measures.

The result of the design process is a digital, single-player game consisting of different missions, representing a network of road, rail, and barge transport routes together with the various intermodal terminals in a hypothetical transport corridor in the Netherlands, as shown in Figure 4. The player assumes the role of an infrastructure manager, and has to deal with four Logistic Service Providers (LSPs)—LSPa, LSPb, LSPc, and LSPd—who are simulated agents within the game. Each of the LSPs is modelled in a way that they make route choices based on their respective priorities: for LSPa,

reliability is more important; for LSPb, sustainability; and for LSPc, cost-effectiveness. LSPd introduces an element of randomness without a clear priority. Their preferred route choices are colour-coded for the player's reference. In the next subsection, we will give some more information on the game scoring mechanism.

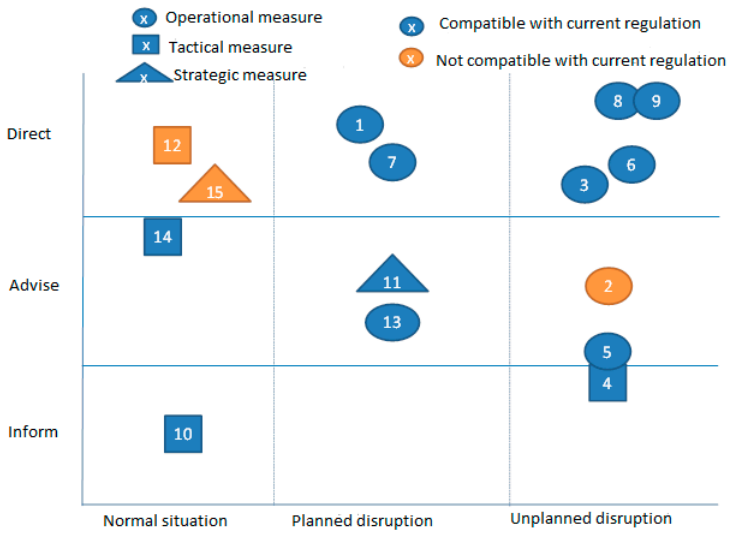

Figure 3. The fifteen scenarios inserted in the game against the different types of disruptions and the various information measures necessary to solve them. The number on the graph corresponds to the scenario number.

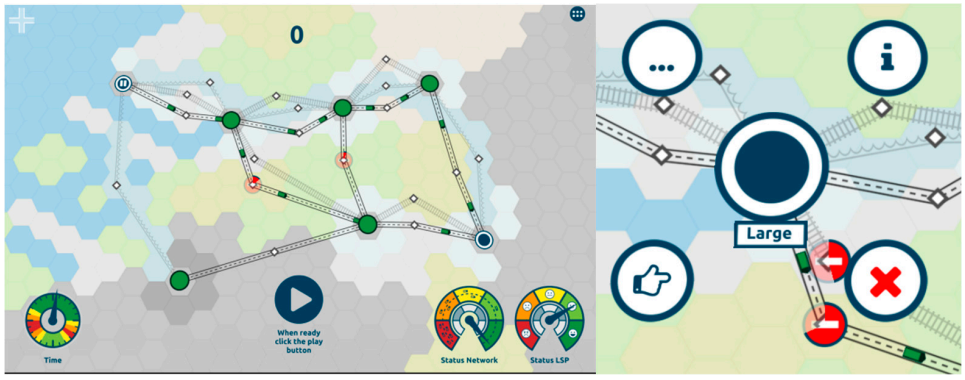

Figure 4. Screen shots of the modal manager game.

Accounting System

The accounting system of the game was defined as the scoring mechanism in the game. In the modal manager game, we created a trade-off between the performance of the system and the happiness of the LSPs. We made the assumption that the information management regime of the infrastructure managers has an effect on the priorities of the LSPs. We evaluate the total performance of the player using two parameters: (1) the performance of the network and (2) the satisfaction of the LSPs.

- The **network performance** consists of the lost vehicle hours for the three modes and the nodes:

- A: Lost Vehicle Hours on the Road—Between 0% (0) and 100% (1) (of a given maximum)
- B: Lost Vehicle Hours on the Railway—Between 0% (0) and 100% (1) (of a given maximum)
- C: Lost Vehicle Hours on the Waterway—Between 0% (0) and 100% (1) (of a given maximum)
- D: Lost Vehicle Hours on the Nodes—Between 0% (0) and 100% (1) (of a given maximum)

A, B, C, and D are the lost vehicle hours on the three modes and the nodes as calculated by the game. To get an overview, however, of the total network performance, we add the gained vehicle hours that are calculated by substituting the lost vehicle hours from (1). The overall score for network performance calculated by Equation (1) is then

$$\text{Network performance score} = (((1 - \text{A}) * 1) + ((1 - \text{B}) * 1) + ((1 - \text{C}) * 1) + ((1 - \text{D}) * 1)). \quad (1)$$

- The **LSP satisfaction score** is divided into three parts

- E. Shipments arriving on time—Between 0% (0) and 100% (1)
- F. Transportation costs—Between 0% (0) and 100% (1) (of a given maximum)
- G. Trust in the Modal Manager—Between 0% (0) and 100% (1) (of a given maximum)

An additional performance indicator is the percentage of shipments that arrive on time. In this case, a delay in the network will automatically lead to shipments arriving late. To calculate this percentage, we used the normal travel time (already known) on a given route. When a vehicle leaves the port, we know at what point in time it should arrive at its destination.

A literature review on the factors that influence freight-transport-related choices showed that LSPs value cost above reliability, i.e., shipments arriving on time ([35–38]). Hence, to calculate the LSP satisfaction score (Equation (2)) we used the weights 1 and 0.5, respectively, to describe the influence of cost and reliability on LSP satisfaction. Trust—an important KPI (Key Performance Indicator)—is not only a tool to measure modal manager performance, it is also a decision-making tool for the LSP. Higher trust means that the LSP will sooner choose to follow the advice of the modal manager. Since this is such an important game mechanism, we decided to increase the factor of trust to 2.5 when calculating the LSP satisfaction score. The LSP satisfaction score is thus calculated by Equation (2).

$$\text{LSP satisfaction score} = (\text{E} * 0.5) + ((1 - \text{F}) * 1) + (\text{G} * 2.5) \quad (2)$$

Then, we sum the two scores to calculate the total score of the player in the game.

$$\text{Overall Score} = (\text{Network Performance} + \text{LSP satisfaction score}) * 1000 \quad (3)$$

At the end of the game, the players not only get their total scores, but receive an overview of the effect of their decisions with relation to modalities, as shown in Figure 5.

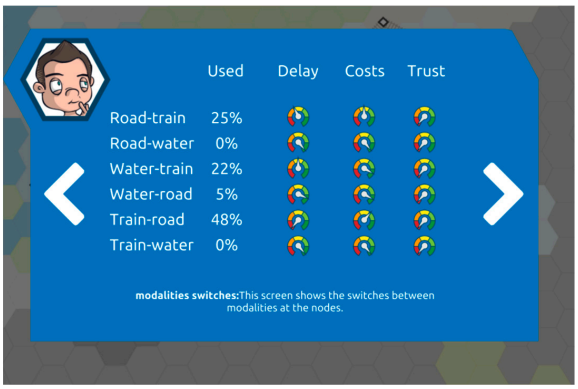

Figure 5. Debrief screens with the modal split.

3.3. Setup of the Gaming Session

To validate the Modal Manager game, we used infrastructure managers of various modalities in the Netherlands. The game is part of a workshop which starts with a briefing lecture about corridor management by the facilitator.

The participants fill out a pregame questionnaire that collects their demographic information, their expectations from the workshop, and their current attitudes towards synchromodal corridor management. Then, they play the different levels of the modal manager game by choosing the role of either a road, rail, or waterway modal manager, as shown in Figure 6.

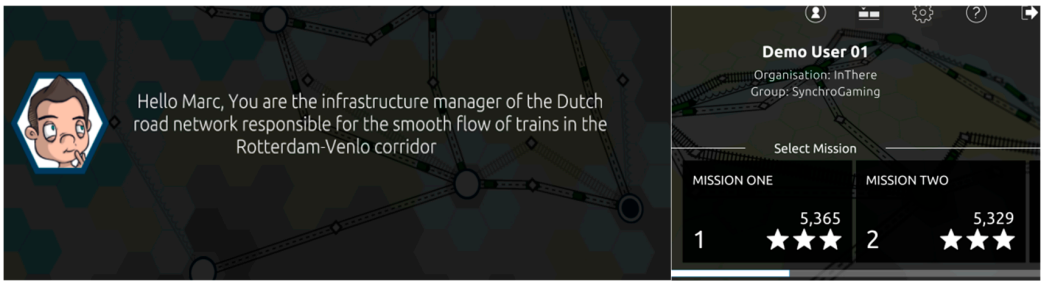

Figure 6. The starting screen of the game describing the role of the player and the mission number.

After each level, the facilitator invites the participants to reflect on the gameplay and relates it to real-world applications. After the first round, the facilitator starts the discussion on current practices in synchromodal corridor management, and the advantages and challenges of the different measures available in the game.

After the second round, the discussion includes the benefits of keeping LSPs happy, ways to build trust with LSPs, and challenges and opportunities in balancing network performance and LSP happiness levels. After the end of the last round, participants discuss the ways to collaborate with infrastructure managers of other modalities and highlight the challenges and benefits of doing so. The session concludes with an elaborate debriefing where the facilitator collects the experiences of the participants through an interactive discussion and a postgame survey. Additionally, possible solutions towards synchromodal corridor management are discussed. The game session is expected to yield quantitative results from the in-game data relating to the player decisions and survey data on attitudes and preferences. Qualitative results include observations of the gameplay and recording of the debriefing sessions. A brief impression of the game session is shown in Figure 7. Participants also fill in a postgame session survey to reflect on their game session experiences. The results of the observations, together with the insights form the game design process itself, will be discussed in the following section.

Figure 7. Modal manager game session in progress.

3.4. The Modal Manager Game Validation

The validation and testing aspect of the game design method, although illustrated as a final step, is iterative along every stage of the game design process. The problem owners or the end consumers of the

modal manager game are the infrastructure managers of the various modalities (rail, road, and water). The game was designed in close collaboration with experts in the field of freight corridor management. Therefore, we believe that the role of these experts in the verification and validation of the game is crucial. Although Peters and van de Westelaken in [39] opine that validation in the traditional sense is hard to apply to simulation games, they agree that the adapted version of Raser's [40] validation principles of psychological, process, structural, and predictive validity can be applied for simulation games. The explanation of these validity principles is as follows:

1. **Psychological or face validity**—A simulation game should provide an environment that seems sufficiently realistic, otherwise the players might display a completely different behaviour than they would in real life. This could be interpreted as face validity of the game.
2. **Process validity**—The processes in the simulation game need to be isomorphic to those observed in the reference system.
3. **Structural or construct validity**—A simulation game is valid to the extent that its structure (the theory and assumptions on which it is built) can be shown to be isomorphic (the model and the system need not be similar, but congruent) to that of the reference system it represents.
4. **Predictive validity**—The simulation game should have the capacity to make a good estimate of what can happen in the reference system, given a specific scenario or situation. This is usually done by recreating known situations in the game, and by comparing the results of the game to those of the real situation [39].

However, others ([39,41,42]) argue that, with respect to simulation games, validation is not the activity of testing against one or more standardised criteria of validity. Rather, it results from the motivation and objective to design and justify the various steps in a research project. They take a constructive approach, where they move away from standardised validity criteria, and view validation to be a line of reasoning that supports the design, selection, and use of research instruments and methods [42]. Instead, they focus on working systematically, discussing explicitly, and testing extensively together with experts and end users.

In addition to iterative and continuous verification during the design process, we further validated the game design with experts with a pilot gaming session which is explained in the following section. We will present the qualitative results derived from the gaming session in terms of observations, and extensive discussions with expert infrastructure managers.

4. Results and Discussion

Due to the complexity of the freight transport system and the existence of often-competitive relationships between the actors, information provision is often hindered. We presented simulation gaming as a problem exploration and strategy experimentation research method. Games can represent changing scenarios, helping stakeholders to develop individual and team awareness which is understood as a prerequisite to successful decisions ([43,44]). In our game design, we allow stakeholders to experience the consequences of certain measures to handle the complexity of synchromodal corridor management. We defined those measures as the ability of infrastructure managers to inform, advise, and direct other stakeholders in the network, namely, the logistical service providers. The aim of the infrastructure managers is to keep the capacity of the network high and its use up. The satisfaction of the LSPs and their trust in the information provided by the infrastructure managers are intermediary aspects influencing the decisions of the stakeholders. The extent to which the right amount of information is given at the right time and in the right way (informing, advising, directing) influences the likelihood that the LSPs will follow the information, and the ability of the infrastructure manager to maintain the capacity of the network without congestion.

A simulation game always represents a simplified version of reality, yet a safe environment to experiment with [45]. This is also true for our game. Still, the game showed a high level of complexity. To avoid ending up with players being frustrated about the high level of complexity of the problem to

solve, the game was embedded in a session with break-in briefings and an informed debriefing in the end. In this way, players were enabled to reflect on what they experienced in the game, and to translate this back to alternative solutions towards synchromodal corridor management in the real world.

We have developed the modal manager game together with 12 transportation domain experts, 4 researchers, 2 research consultants, and 2 game designers. We gathered qualitative data along the game design process through observations, discussions during game design, and test sessions, together with an evaluation survey of the effectiveness of the game and the gaming process. We discussed earlier that since information management in socio-technical systems is complex, we embarked on a game design process to reflect the 5 C's of complex systems in the deployment of information management policy for effective and sustainable corridor management. We will now present our results from the observation of the iterative game design process to check if the 5 C's have been reflected within the game.

1. **Complexity**: Unfortunately, the unfamiliarity of the players with the concept of synchromodal corridor management increased the complexity of the game. The players stated that it was difficult for them to understand the concept and that they were frequently unable to relate themselves and current practice to the gameplay. One important issue we also identified is the complex scoring mechanism that did not permit the players to understand the direct effects of their actions.
2. **Communication:** During the debriefing part of the session, infrastructure managers highlighted the importance of communication. We found that the communication among inframanagers was more desired than between inframanagers and LSPs. This again reflects the actual situation where the managers of the different modes—especially road and rail—do not share information and do not collaborate even when making decisions on strategic and tactical levels. For example, when planning maintenance work, infrastructure managers' lack of communication could result in situations where planned disruptions occur in two alternative modes simultaneously, creating huge delays in the network.
3. **Consensus:** Infrastructure managers expected the game to be a panacea that would solve their communication issues among themselves. Each player, depending on the mode he/she was representing, had different perspectives, gameplay information needs, and hindrances, so it was difficult to build a consensus between the players. On the other hand, each player provided the team with useful insights on the prerequisites to enabling information exchange within the mode they were responsible for. Finally, all the experts agreed that at this point what infrastructure managers believe to be the biggest advantage of synchromodality is the ability to cooperate when they have to deal with planned and unplanned disruptions.
4. **Creativity:** One of the key issues here was the introduction of new measures. During the first round of discussion when designing the games, it was very tough to introduce new information sharing measures and regimes because experts always raised the issue of legality. These objections led to a more realistic game with limited experimentation.
5. **Commitment to action**: All the stakeholders admitted that there is no clear path laid regarding the implementation of a synchromodal corridor but they wanted to continue to put their efforts towards achieving synchromodal corridor management.

Simulation gaming is a suitable method for influencing the decision-making of stakeholders. While informing is an easy mode of communication, it leaves a huge amount of freedom to the LSPs, and might result in low levels of trust and satisfaction as no alternative actions or decisions are connected with this measure. Advice might turn into a valuable tool applied to control synchromodal transportation while at the same time increasing customer satisfaction, as alternative solutions are illustrated. Directing might also lead to desired outcomes, when further developed towards an incentive structure. The selective information sharing would have been an interesting game design choice; however, it was strongly opposed due to the legal ambiguity of the solution. In the

current transportation network, infrastructure managers are quite restricted in the options of directing stakeholders towards certain routes, modalities, or times of transportation. When introducing these measures, the issue of legality was raised. Infrastructure managers are legally forbidden to provide selective information to the users of the network. The ambiguity of the synchromodal manager concept made it difficult for experts/infrastructure managers to provide us with sufficient guidance and feedback on the performance indicators that were relevant to the issue. The complexity of the final scoring mechanism made it even more difficult for infrastructure managers to relate to the game.

5. Conclusions and Future Work

Synchromodality is regarded as the next step towards a more sustainable freight transport system, and requires the horizontal and vertical integration of actors, modes, and services. Synchromodal corridor management presents several challenges based on its nature as a complex socio-technical system, comprising a large number of interrelated, often competing stakeholders. Information sharing in the complex freight transport environment requires insight into the needs of different stakeholders and a good understanding of the whole situation. However, interviews with the infrastructure managers from our research consortium together with a literature review revealed that the information management among stakeholders in freight corridors is still in its nascent phases.

While studying the best practices from the literature as well as discussing them with subject matter experts, we observed that these solutions are elegant on paper but complex to deploy in real-life situations. To take a first step towards more sustainable, flexible, and high-performing corridor management we need to explore and test suitable information management strategies. Therefore, we chose simulation gaming as our research method to create a controlled and interactive environment that permits stakeholders to identify, experience, and test various information management strategies for effective and sustainable corridor management. We developed a digital single-player game known as "Modal Manager". The game was played inside a gaming session where players were able to discuss their gaming experience and reflect on the innovative concept of synchromodal corridor management. We took the 5 C's into consideration while designing the game and the game design principles. However, during the debriefing discussion after the first gameplay session with Dutch experts, we observed that these principles were not fully reflected in the participants' responses. The most important finding, however, is that infrastructure managers have a very narrow opinion on the definition of synchromodality and its advantages. The very definition and the purpose of synchromodal corridor management was quite vague, ill understood, and conflicting at times. The participants of our session believed that synchromodality can only facilitate communication between the infrastructure managers to improve the planning of maintenance works and to better coordinate the different modes in case of unplanned disruptions.

For the adoption of synchromodal transportation concepts, it is crucial to modify the decision-making processes of inframanagers towards information sharing with vital infrastructure users. From the workshop results and extended discussions with the infrastructure managers, we found that the development of synchromodal network management has to evolve gradually from a more collaborative disruption management to a synchromodal corridor manager that has control over the modes and enables the synchronisation of services based on demand. The gaming session showed that legal disablers still exist, not only on paper, but also in the heads of the stakeholders, that hinder selective information provision to LSPs as well as the exchange of information between the infrastructure managers.

Our contribution provides an analysis of how the design process of a simulation game can foster discussion among content experts on a complex problem. We could show that during the design phase, valuable scenarios for further exploration could be developed. We further introduced how a game can and should be included in a holistic session, and what elements are needed to embed simulation gaming as a rigorous research method along with others, such as surveys and debriefing. Quantitative

analyses of the session outcomes were beyond the focus of this article and will be processed in a separate study.

Regarding future research, we aim to find solutions to simplify the scoring mechanism in an effort to decrease the complexity of the game. Road infrastructure managers identified the possibility for the game to be used as a training tool for traffic managers. In future, and with the help of the Modal Manager game, other measures could be developed together with the stakeholders, such as priority use of certain lanes on highways, subsidy of vital hubs in the network, or increase of rail capacity on distinct routes. Our overall objective for the future is that we would like to use the Modal Manager game within gaming sessions and workshops with stakeholders in order to raise their awareness on the complex issue of synchromodal corridor management.

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