Exploring the Value of the Analogy between the Physical Internet and the Digital Internet

by

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Submitted to the Delft University of Technology as partial fulfilment of the degree of Master of Science in Complex Systems Engineering and Management

To be defended in public on August 21, 2020

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Preface

What will probably stick with me for many years is how frequently we all use analogies. I chose this thesis topic, as I was intrigued by the idea that supply chains could be similar to the internet. To find out more, I had to start at the very beginning by researching the value of analogical reasoning. After writing about analogies, I started to notice the vast number of analogies that are used in daily life up to a point where I encountered them everywhere. I noticed how analogies are used in the classroom by educators, in the grocery store by marketeers and at home by my friends and family in casual conversations. Being aware of all the analogies, I also noted that some made more sense than others.

The analogy that struck me most this year is the analogy Donald Trump, Emmanuel Macron, and Boris Johnson used when comparing Covid-19 to a war. With the virus as the enemy and healthcare workers as front line warriors, I can see why the analogy is appealing. I have learned how the choice of analogy can influence the way we think about something and the way we experience situations. When Covid-19 hit the Netherlands, people got scared, felt alone or experienced difficulties adapting to the idea of self-isolation. I was no exception to this, as the pandemic created some unique and challenging circumstances. During this time, I received many acts of solidarity. I am grateful for my friends and family frequently reaching out and for the supervisors of this thesis to regularly check in on me and my thesis progress.

I want to thank the Port of Rotterdam as an organization for offering me a valuable internship opportunity. I especially want to thank Pieter de Waard from the Port of Rotterdam for his critical thinking and for offering me the opportunity to go to the ALICE meeting in Vienna. Likewise, I want to thank Lóri Tavasszy for his support and helping me getting acquainted during this meeting. The trip has been a great success for my recruitment efforts. I like to express my gratitude for Tobias Fiebig his support and his efforts to make Internet technologies understandable. I want to thank Jafar Rezaei for helping me to better understand the research gap regarding analogy usage for new concepts. Finally, I want to thank Patrick Fahim for preventing my train of thought from derailing and keeping me on track. *See what I did there...*

Sharon van Luik
Dordrecht, August 2020

Summary

Introduction
Currently, logistics networks are often fragmented, meaning organizations have their own networks, and these networks lack interconnection (Sarraj, Ballot, Pan, & Montreuil, 2014). This lack of interconnection, together with other inefficiencies, cause negative externalities. Montreuil, Meller, & Ballot (2010) noted these inefficiencies and describe a vision in which supply chains are more economically, environmentally, and socially efficient. Consequently, they proposed a system where supply chains are worldwide interconnected, which is known as the Physical Internet (PI).

The PI merges different research areas from supply chain management research, such as collaboration, standardization, and information flows. The word Physical Internet derives from the Digital Internet (DI). In this analogy, data packages that move over the Internet are compared to how cargo could potentially move over the world. Since its literary introduction in 2010, the PI has gained much traction. Many parties have shown their interest in the concept, and many publications followed. Although the perks of the PI seem very promising, academics still find it hard to give more context to the analogy between the DI and the PI. As it is unknown to what extent and for which aspects the analogy is useful, this thesis answers the following research question:

"What is the value of the analogy between the Digital Internet and the Physical Internet, to further develop the Physical Internet?"

To answer this main research question five sub-questions are formulated:

1. *What is the value of analogical reasoning for new concepts?*
2. *What are the similarities between the DI and the PI, according to experts?*
3. *What are the differences between the DI and the PI, according to experts?*
4. *How do the PI experts perceive the DI?*
5. *Can we potentially learn from the DI to overcome barriers in developing the PI?*

By answering the first research question, we aim to determine if reasoning using an analogy is useful for developing and shaping new concepts or ideas. The answers to questions two and three create a better understanding of the strength of the DI-PI analogy. With question four, we aim to find out what perception PI experts have on the DI and if there are any misconceptions about the workings the DI. The last question aims to find out what barriers there currently are to reach the PI, and if they can be overcome using the analogy.

Methodology
For this research, we used a qualitative research approach. Fifteen PI experts were recruited based on their scientific publications and affiliation with the PI. The experts were interviewed according to a semi-structured interview protocol. The interviewees were asked to elaborate on the differences and similarities they see between the DI and the PI. The interviews were coded using a thematic coding process. After the coding, the interviewee's perception of DI was validated. The results were used to reflect on the value of the analogy using an Analogy Functionality Model.

Creating an Analogy Functionality Model
In our literature search, we have three ideas that are important in analogical reasoning. Firstly, more relevant similarities result in a stronger analogy. Secondly, more relevant differences result in a weaker analogy. And thirdly, limited knowledge on the target or the source domain results in a weaker analogy. We also identified four purposes of using analogies, a persuasion purpose, an

explanatory purpose, an inspiration purpose, and a design purpose. With these two findings, we created an Analogy Functionality Model. This model aims to communicate the relationship between different purposes of analogies and the required level of strength of the analogy. We argue that every analogy has a breaking point where the analogy becomes dysfunctional, and when we make an analogy, we must be aware of where that point is. Once we know this, we must consider if it is safe to use an analogy to design a target case.

Differences and Similarities According to Experts
Most interviewees describe similarities related to the standardization of transportation units (packets, frames, packages, containers), interfaces, and protocols. Other frequently mentioned similarities are the bundling and splitting of transportation units, the high level of automation in both networks, and the decentralized organization of the networks. Another frequently mentioned similarity is the feeling of carelessness and security users experience when they use the network. Some interviews also identified similarities concerning the sharing of assets, the flexibility of rerouting a transportation unit, and openness in terms of joining the network. The difference that is most frequently mentioned by our interviewees is the replication of a data packet, which is done in the DI but impossible or unfeasible in the PI. Other differences that were frequently mentioned are the differences in the cost structures, transmission speed, and the network's overall evolution.

Perception of the Digital Internet
We validated various assumptions PI experts made on the workings of the DI. In our validations, we found out that some interviewees had a perception of the DI that deviated from reality. Some interviewees gave an accurate explanation of the working of the DI, while others experienced difficulties when explaining specific technologies. Most interviewees were able to explain DI technologies but on a very aggregated level. When it comes to common perceptions that may deviate from the truth, four interviewees assume that packets split up after which multiple packets follow different routes to find out which route is the fastest to the destination. Additionally, four of the interviewees assume that packets are being bundled or clustered together for transportation.

Barriers to Transform into the Physical Internet
According to the interviewees, there are specific barriers we need to overcome to move towards the PI. The most frequently mentioned barrier is the lack of willingness of logistic service providers to engage in horizontal collaboration. Other barriers that were mentioned are barriers to collaborate to realize the standardization of protocols and transport units. Another barrier discussed is the lack of transparency in the network when it comes to information about underutilized capacity or client information.

Assessing the Physical Internet Analogy
The results point out that the interviewees have different interpretations of the PI. Also, various interviewees value the analogy differently, ranging from highly dysfunctional to highly fruitful. Using our findings, we reason the DI-PI analogy has limited value. One should be careful when applying analogies due to its limitations. The breaking point of an analogy is when the analogy becomes dysfunctional and depends on the strength of the analogy. Due to the limited strength of the DI-PI analogy, proved by the many differences between the DI and the PI, the analogy breaks when one aims to use the analogy for designing the PI.

Conclusion and Recommendations
We conclude that the DI-PI analogy has limited value. This thesis argues that the DI-PI analogy's value is limited to using the analogy for persuasive, explanatory, and inspirational purposes. We do not recommend exploiting the DI-PI analogy further for designing the PI, as the analogy is not strong enough, and using weak analogies may the target case at risk. Academics and the industry are recommended to bring their efforts elsewhere and not exploit the DI-PI analogy. As an avenue for future research, we suggest focusing on overcoming collaboration barriers that have been addressed by our interviewees. Additionally, an exciting avenue for further research could be to further refine the Analogy Functionality Model.

Contents

1

Introduction

Currently, logistics networks are often fragmented, meaning organizations have their own networks, and these networks lack interconnection. Distribution networks, production networks, and supply networks are all part of a logistics network. The supply chains that are currently formed are intertwined but often not connected (Sarraj, Ballot, Pan, & Montreuil, 2014). This lack of interconnection, together with other inefficiencies, cause negative externalities. Montreuil (2011) noted these inefficiencies and has a vision in which supply chains are more economically, environmentally, and socially efficient. This is why he proposes a system in which the logistics web is worldwide interconnected, which is known as the Physical Internet.

When looking at the level of interconnection, digital networks have reached an exceptionally high level of interconnection. The Internet, as we know it, is an efficient network of networks in which data packages move relatively cheap, efficient, and secure. This was the motivation for Montreuil, Meller, & Ballot (2010) to propose a metaphor in which the Digital Internet is compared to the potential future of logistics. In this metaphor, they translate the way in which data packages move over the Internet to the way in which cargo could potentially move over the world. They recognized the heterogeneity in supply chains as they have seen before in the development of computer networks. Initially, the Internet started as a small network, and eventually, it became a grand network where heterogeneity was replaced with homogeneity (Sarraj et al., 2014). The metaphor is known as the Physical Internet (PI). The formal definition that Montreuil (2011) gave the Physical Internet is "an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces, and protocols". The aim of PI is to enable an efficient, sustainable, adaptable, and resilient logistics network. In this metaphor, e-mails are, for example, compared to physical goods and routers to logistical hubs. It gives us an understanding of a new paradigm where cargo is shipped over the world, similar to a way in which data flows over the Internet. Similar to a network of routers forming the digital Internet, a network of logistical hubs forms the base of the Physical Internet. Products moving through this open and interconnected network belong to different parties, who are all part of this interconnected network. As a result, parties can collaborate fully on a horizontal as well as a vertical level. According to Sarraj et al. (2014), this forms new opportunities for optimization as a shipment route can be optimized for the whole network. This optimization may lead to many positive effects, such as higher loading factors of modalities and more efficient and sustainable shipments.

Since its literary introduction in 2010, the Physical Internet has gained a lot of traction. Many parties have shown their interest in the concept, and many publications followed. Although the perks of the PI seem very promising, academics still find it hard to give more context to this analogy between the digital Internet and the PI, as can be seen in the next section.

1.1. Research context & Literature review

In this section, a definition is given to what we understand to be the Physical- and the Digital Internet in this thesis. The section will then continue with an overview of the work that has been done on the analogy between the Physical Internet and the Digital Internet.

1.1.1. Definition of the Physical Internet

In this thesis, the Physical Internet will be referred to as the PI. The term was first used on the cover of The Economist (The Economist, 2006). In this case, the term was solely used as a headline and did not describe the PI as we know it today. The PI is a novel concept that aims to optimize the logistical processes to create more efficient supply chains (Treiblmaier, Mirkovski, & Lowry, 2016). It is a concept that merges different research areas form Supply Chain Management (SCM) research, such as collaboration, standardization, and information flows. In this thesis, we use the most recent definition of the PI, which is "a global logistics system based on the interconnection of logistics networks by a standardized set of collaboration protocols, modular containers and smart interfaces for increased efficiency and sustainability" (Ballot, Montreuil, & Meller, 2014, p.23).

1.1.2. Definition of the Digital Internet

To make a clear distinction between the PI and the 'regular' Internet, we will refer to the Digital Internet (DI) for what otherwise may be known as the Internet. The DI is an open distributed network infrastructure and is about the interconnection between networks in a way that is transparent to the user (Montreuil, 2011). Additionally, it allows the transmission of formatted data packets in a standard way, which allows them to move through heterogeneous equipment respecting the TCP/IP protocol (Kurose et al., 2013). In the publications written about the analogy, several aspects of the DI are discussed, ranging from technical aspects, such as protocols, to more socio-technical sides, such as the development of the DI and the business models behind it. Because different publications highlight different aspects from the DI, we refrain from using a formal definition in our thesis. Thereby we allow the PI experts, which we interview in a later stage of this thesis, to freely interpret the DI.

1.1.3. Prior work on the PI analogy

The next sections present an overview of prior work on the analogy between the DI and the PI. For this purpose, a literature review is performed by means of using relevant references of two key publications found by using a search string. At the start of our literature review, we aimed to look for the comparison between the DI and logistics as it currently is. However, being unable to find relevant results, we continued to look for the comparison between the DI and the PI.

As a starting point, academic databases are used, such as the *TU Delft Repository* and the academic search engine *Scopus*, searching for the terms 'Physical Internet' and 'Digital Internet'. As a result, two articles were found, of which one a literature review by Treiblmaier et al. (2016). From here, the references of the aforementioned publications were checked to find new relevant publications. In this literature review, materials published prior to May 2020 are considered. We screened all results according to their applicability, which in this case, is a useful comparison to the DI. Underneath the key publications on the comparison between the DI and the PI are discussed.

Montreuil, Meller, & Ballot (2010) wrote about the PI in a conference proceeding in which they propose the PI as a paradigm change that enables us to rethink the current logistics networks and to move to a system that works like the DI. This is, according to the authors, a system where networks are interconnected by a common operating framework, which makes it easier to breakdown transport and handle loads. Additionally, they elaborate on the PI container, which is a container to carry physical goods that is explicitly designed for the PI. The authors describe how a PI container carries information and make the comparison to a MAC address in the DI, which functions as a unique identifier.

Montreuil (2011) published a paper in which he suggests to exploit the metaphor to the DI to develop the PI vision. He explains how the DI has exploited the physical world before, by, for example, using a metaphor such as building an 'information highway', which was a popular term in 1990 and referred to the Internet telecommunications network. The paper points out that now is the time to use the metaphor in the opposite direction and use the DI for the development of the PI. Additionally, the paper points out the advantages of standardization on the Internet and compares

it to the standardization in the physical world by means of 20- and 40- feet containers. Other comparisons the author makes between the DI and the PI are the way how the DI offers secure solutions to transport information flows and how the DI relies on certifications of protocols to enable a multitude of actors to use the system. Montreuil (2011) states that the PI does not aim to copy the DI, but rather means to inspire the creation of the PI vision that provides sustainable solutions to logistics problems. The paper does not elaborate on how and to what extent the analogy can be exploited.

Montreuil, Ballot, & Fontane (2012) have introduced the open logistics interconnection (OLI) model, which is a framework based on the Open System Interconnection (OSI) framework, which is commonly used to analyze ICT systems. The authors state that the OSI framework has been instrumental in shaping the DI, which was their motivation for creating the OLI framework. The paper emphasizes the advantages of the layered structure framework and expresses the need for a more detailed version of an OLI framework.

Montreuil, Meller, & Ballot (2013) wrote about the foundations of the PI. They use concepts such as encapsulation, interconnectivity, and standard coordination protocols from the DI as foundations for the PI. They used these concepts as inspiration for the PI. The information on how the foundations are derived from the DI is given on a very aggregated level, and it remains unclear if we should further exploit the DI to develop these foundations.

Sarraj et al. (2014) were the first to dive somewhat deeper in the analogy and state that there are strong similarities between DI and logistics, despite the differences in the type of objects transported in the network. They focus on the interconnection potential of logistics networks, by means of a model. Their analogy is based on the interconnection of networks, the structure of networks, and the routing of objects in these networks. As a limitation of their findings, they argue their research is exploitative, and details are left out, such as containerization and the usage of routing protocols.

Aroca & Furi (2017) studied the analogies between routers and logistics hubs. More specifically, they analyzed the types of routers and the hierarchy of these routers. Next to that, they analyze the types of hubs in logistics and their structures today. They use this analogy to make an operation model for hubs that aims to ease the creation of routing algorithms for these hubs.

Dong & Franklin (2018) study the PI on the basis of the DI. They propose a conceptual framework for the PI network routing with the DI as a foundation. They translated the eleven elements from the digital Internet to the logistics web. These elements include actors such as users, carriers, and service providers, as well as actions such as collaborations. Additionally, they found differences in the DI and the PI related to metrics such as cost, time, and schedules. The comparison suits the research objective of the authors and is, therefore still very general. The authors find out that the PI needs to solve reachability problems as well as an optimization problem. They propose a network model by using graph theory to support the development of the PI.

Gontara, Boufaied, & Korbaa (2018) have conceptualized a Border Gateway Protocol (BGP) for the PI. To do this, they looked at the DI and recognized that both the DI and the PI have Autonomous Systems. These Autonomous Systems are in the DI connected with a BGP. The authors have copied and adapted this protocol to fit the PI.

Lastly, in 2020 Treiblmaier et al. have conducted another literature review on the PI. They describe how their results lead to a major question regarding the right approach to realize the PI's vision. They state the DI might be helpful in this case due to its 'layered nature', which, according to the authors, makes it possible to improve specific aspects of the DI without disruption the other layers in the system. They suggest a similar structure could be beneficial for the PI so researchers can improve specific aspects of the PI without disrupting the whole system.

As can be seen, prior research has analyzed several main components of the DI and compared these with their respective counterparts from the logistics system on a general level. Although some

publications state it is worthwhile to further exploit the analogy between the DI and the PI, the number of publications is still very limited. It remains unclear to what extent and for which aspects the analogy is useful. To fill this research gap, the following research question is formulated:

"What is the value of the analogy between the DI and the PI, to further develop the PI"?

By answering this research question, we aim to offer a direction for future research and determine if further exploring the analogy helps us move towards the PI.

1.2. Research questions

To answer our main research question we divided it into five sub-questions. Figure 1.1 presents a research flow diagram and Figure 1.2 depicts what sub-question refer to which topic.

1. *What is the value of analogical reasoning for new concepts?*
   By answering this question, we aim to find out if reasoning using an analogy can be useful for developing new concepts or ideas. We answer by looking at literature on analogical reasoning and by looking at examples where analogical reasoning has been used. We aim to find out what the value of analogical reasoning can be. Is analogical reasoning useful when further developing a concept? Or might it be useful for communicating the new concepts? Or maybe we find out that analogical reasoning can be useful for other purposes. The answers to these questions may help us understand if analogical reasoning is useful for developing the PI.

2. *What are the similarities between the DI and the PI, according to experts?*
   By asking PI experts about the similarities between the DI and the PI, we will gain a better inside into their understanding of the analogy. Additionally, we can get an insight into how strong the analogy is, according to experts, and we may find out if there are certain aspects in which the analogy makes more sense than others. The latter can provide us with future research ideas.

3. *What are the differences between the DI and the PI, according to experts?*
   By asking experts about the differences between the DI and the PI, we get a better insight into which aspects the analogy does not hold. This knowledge may help exclude the usage of certain features of the DI to further develop the PI.

4. *How is the DI perceived by the PI experts?*
   With this question, we test the knowledge that PI experts have on the DI. This information is useful because PI experts often use analogical reasoning when talking about the PI. Knowing if they have a good understanding of the DI will help us value their analogical reasoning. If we, for example, find out that there are many misconceptions about the DI by PI experts, we may questions the value PI experts give to the analogy.

5. *Can we potentially learn from the DI to overcome barriers in developing the PI?* With this question, we aim to understand what potential lessons can be learned from the DI for the PI. And if one can use the DI to further develop the PI.

Figure 1.2 presents the context of our research area. With research questions one, two, and three, we aim to find out more about the analogy between the PI and the DI and the value of the analogy. The answers to these questions can deliver valuable insight for both the PI and the DI, which is why the arrow in Figure 1.2 between the PI and the DI is bi-directional. With the fourth research question, we aim to find out what perception is PI experts have of the DI. This perception is depicted as (DI'). In our last question, we will only look at lessons we can learn from the DI to develop the PI, not the other way around, as this is out of our scope.

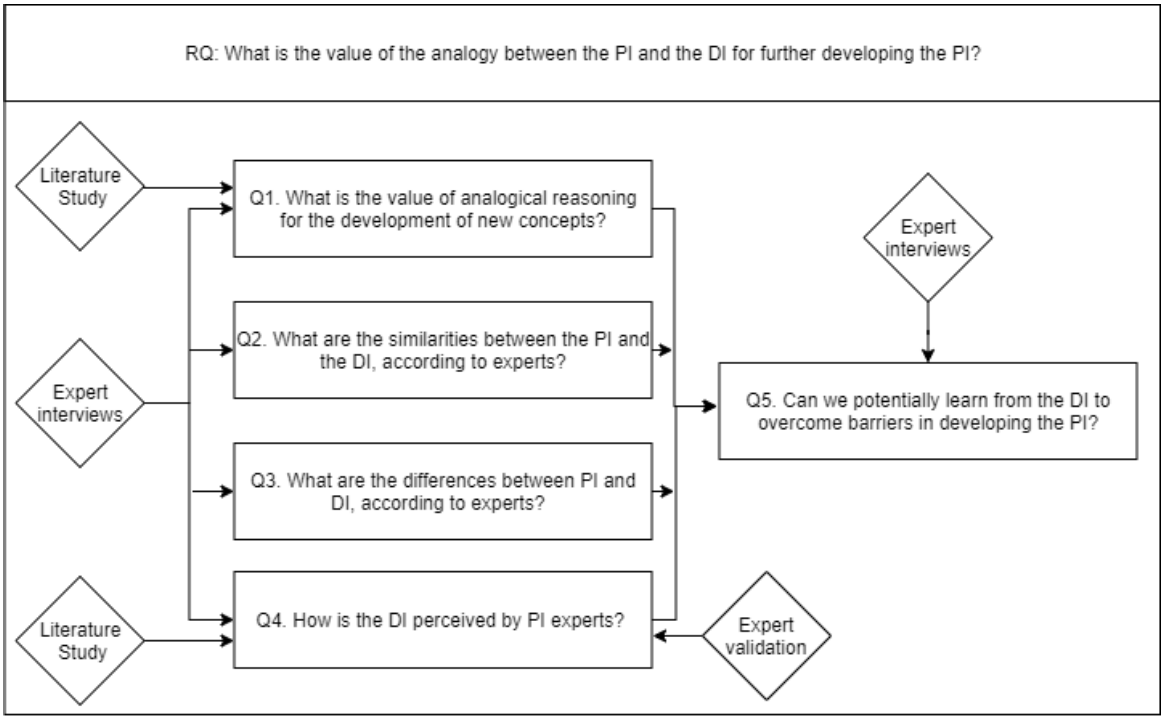

Figure 1.1: Research Flow Diagram

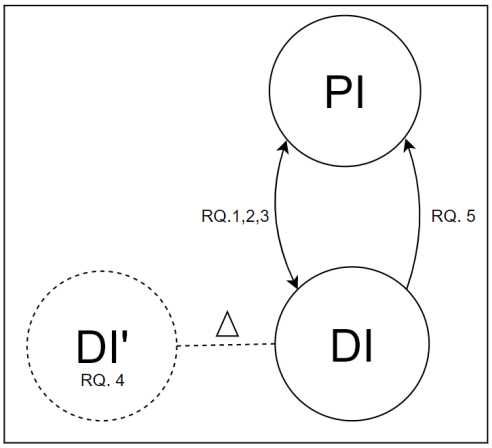

Figure 1.2: Research questions in their context

1.3. Societal and Scientific Relevance

Finding out what the value is of the analogy is highly relevant from a scientific and societal perspective. From a scientific point of view, this is relevant for further developing the PI. The PI literature review by Treiblmaier et al. (2016) stated that for the PI to move forward, it is crucial to create a shared understanding of the PI domain. This research can contribute to this shared understanding with regards to the DI-PI analogy. If there is indeed value in the analogy, we may create a pertinent research avenue for theory-building. If there is only limited value, we may suggest taking research interest in the PI elsewhere. A third scenario may be that thinking in terms of the analogy may not have any value at all and even slow us down in moving towards the PI, which would be a valuable outcome for future research.

From a societal point of view, this research is also helpful regarding the development of the PI. The PI is very promising in terms of creating a more efficient and sustainable supply chain network, and this research contributes to future endeavors in moving towards the PI. Additionally, this research may be helpful to create a clearer picture of what the PI with regards to the analogy implies, which may foster the adoption of the PI in the industry and in transport-related authorities such as the Port of Rotterdam.

1.4. Thesis outline

In Chapter 2, the methodology for the thesis will be explained, and the research approach to answer our sub-questions. Chapter 3 provides a theoretical background on analogical reasoning and present different functionalities of analogies. Also, the Analogy Functionality Model is introduced. Chapter 4 draws an overview of our interview results and codebook. In Chapter 5 and Chapter 6, the similarities and differences of the analogy, according to experts, are presented. In Chapter 7, we discuss the assumptions PI experts make about the DI in their reasoning about the analogy. Chapter 8 is about how different experts interpret the PI in different ways, and Chapter 9 presents an insight into what PI experts think are barriers to cross for moving towards the PI. In Chapter 10, we highlight how the group of PI experts value the analogy, and we discuss our findings in relation to the main research question. In Chapter 11, the results are interpreted, and the implications and limitations of our findings are discussed, after which if conclude this thesis in Chapter 12.

2

Methodology

2.1. Methodology

In this section, the methodology applied in this thesis is discussed. Firstly, we will elaborate on our research approach and give a background on how our research questions came about. Secondly, the research methods used for tackling our sub-questions are explained.

2.2. A derivative of the mental modal approach

In this research, we look at the comparison between DI and PI based on the knowledge of experts. With this, we aim to find out what the mental models are of several experts. A mental model is a projection of reality. **?** describes a mental model as an image of the world around us that is like a model carried in our heads. This model is not complete but consists of selected concepts and relationships. In our case, the PI experts will each have their own reasons to argue for the existence or nonexistence of an analogy between the DI and the PI. This is their so-called mental model. We found the mental modeling approach suitable as it has been used for research before that is in many ways similar to our research. Zunde & Hocking (2012) have used mental models to elicit a person's mental model of a computer-based system. The foundations of the mental modeling approach were laid by Kelly (1955). According to Kelly, a person perceives and interprets events, systems, or objects using his or her own personal construct system. Zunde & Hocking (2012) have made a methodology to find out the mental models of research participants. In this methodology, they advise the following:

- The *generation of a role and a short list* is an activity that has to be done before interviewing the research participants. The goal is to provide a list of short sentences that should help the interviewee to generate a specific object of the domain of interest.
- A second step is the *generation of constructs* in this step, the interviewee is presented with three objects at the time and asked in why two objects are similar and different from the third. The interviewee is then asked to name the reason for this.

Zunde & Hocking (2012) used this method in their research to find out what the mental model was of people using spreadsheets, and the shortlist they created was about spreadsheet functionalities they wanted the interviewees to compare. We inspired our research method on the work of Kelly (1955) and Zunde & Hocking (2012). A significant difference between their research and our research is that we aim to find out the mental model of two systems instead of one system's functionalities and relations. This is why we do not apply the full mental model approach, as described by Kelly. Instead, we derive certain elements from steps 1 and 2 of the approach. Like Kelly, we also made a shortlist for our interviewees to generate objects for the interviewee to discuss. Subsequently, we ask our interviewees to compare the object they have generated. The experts' mental models will give us an idea about how they perceive the analogy between the DI and the PI. A step we add in our research method is that we validate the perception of the interviewees on the DI and find out if it differs from the ground truth.

2.3. Research approach

Formulating our research questions was an iterative approach, as is depicted in Figure 2.1. At the start of this research, we aimed to determine the value of the analogy between the DI and the PI. After collecting and interpreting data on the value of analogical reasoning, we found out that one needs relevant and relational similarities to make a good analogy. After this finding, we tightened our research questions. When finding out that many interviewees were not aware of the workings of many aspects in the source domain, we went back to the literature to see if this had any effect on the value of the analogy. We found out about the influence of the lack of knowledge of the source domain on the analogy. As a result, the research questions were adapted.

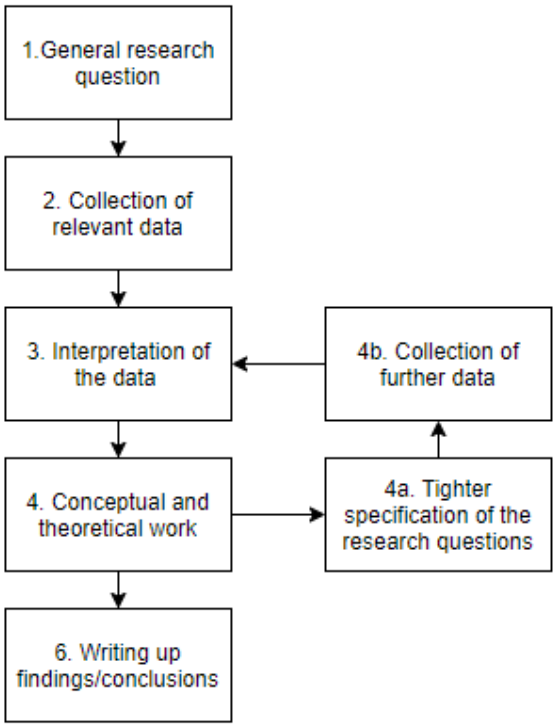

Figure 2.1: Research question development

For this thesis, a qualitative research approach is chosen to gather our data. In the data analysis, deductive reasoning is used. In deductive reasoning, a researcher will make observations from an existing domain and draws a conclusion from these observations (Bryman, 2012). This best fits our research question as we observe PI experts and draw conclusions from their knowledge.

2.3.1. Data gathering

The data for this research is gathered by desk research and expert interviews. To answer the first sub-question, we conducted desk research and did a literature study on analogical reasoning. When searching for literature on analogical reasoning, the number of results is extensive. We used the following search strings: 'Analogical Reasoning', 'Analogical Reasoning Pitfalls', 'Metaphor Pitfalls', 'Analogical reasoning limitations', 'Metaphor limitations', 'Analogical Reasoning Innovation', 'Design by Analogy' and 'Analogy Scientific Discovery'. In the results of these search strings, we looked at the ten publications with the highest number of citations. The search strings were used in the *Web of Science* and in the *TU Delft Repository*. Additionally, all references in the analogical reasoning

section of the *Standford Encyclopedia of Philosophy* are used to get a general overview of the field and the history of analogical reasoning.

To answer the remaining research questions, we conduct fifteen interviews with PI experts. In these interviews, we use a semi-structured interview protocol (Appendix A). We choose a semi-structured interview because it provides the participants with a leeway to respond. Additionally, it gives the researcher the freedom to ask questions that are not included in the interview protocol. The interview protocol was formulated in an iterative process that is recommended by Bryman (2015) (Appendix A). In this process, the interview protocol is tested and revised several times to come to a final interview protocol. The goal of the interviews is to find out what the DI-PI analogy entails, according to experts. This resulted in the most fundamental question in our interview protocol, which is: "What does, according to your knowledge, the analogy between the Physical Internet and the Digital Internet entail?". With this question, we expect the experts to compare the source case (DI) and the target case (PI).

To get a full picture of our experts' mental model, we stimulated them to further elaborate on the analogy by asking about specific elements from the PI. We have derived a shortlist of elements from the work of Montreuil et al. (2013), where he describes ten PI foundations. From the ten foundations, we generated questions that will help the interviewee to elaborate more. For example, one of the PI foundations described is *standard collaborative protocols*. We used this to formulate the question: "Do you think there is an analogy on standard collaborative protocols?" As prescribed by Bryman (2012), we tested the interview protocol. We tested the protocol with a test group of our supervisors at the Port of Rotterdam. In these trials, we found out some PI foundations caused confusion. This is why we simplified and reduced the number of foundations to a point where they fostered a conversation about the analogy instead of the PI foundation itself. This resulted in four questions in which participants are asked if they see an analogy based on connecting different networks, implementing standardization, following protocols, and modularization or encapsulation of shipments. During the interview, the participants are always encouraged to be as elaborate as possible, and throughout this interview protocol, follow up questions are asked on topics related to our research questions. Once the interviewees describe a certain analogy, he or she is asked to explain how the technology they describe works in the DI. The descriptions of the technologies were later validated with the help of desk research and the supervisor of this thesis. Additionally, the interviewees are asked about their profession, their area of expertise, and their interest in the PI.

When recruiting the participants for this research, the aim was to have all the key authors of the PI represented in our participant group. To identify the key authors, we search for the authors of the most cited PI publications. Secondly, we recruited participants preferably come from various institutions that are academic as well as non-academic. Thirdly, half of the participants that are recruited preferably have a background in computer science and half have a background in logistics. With these two criteria, a list of 18 names was made. All 18 researchers were approached with an e-mail invitation to participate in this research. Seven of them have replied positively. To find more PI experts, I went to a meeting of the *Alliance for Logistics Innovation Trough Collaboration Europe* (ALICE) in Vienna, which was dedicated to the PI. During this event, several speakers were invited to participate in the research, of which six experts eventually participated. During the interviews, two more experts were recommended by the current participants of the research. These experts both agreed on participating in this research as well.

2.3.2. Data analysis

For our data analyses, we use a coding process that is also frequently used in the grounded theory, which is a form of qualitative research that studies empirical data and thereby creating a new theory. Despite that we do no aim to build a new theory, there are certain elements that we can derive from grounded theory, as they are suitable for our research. In grounded theory, participants are recruited based on their affiliation with the process we like to research. A large diversity in the backgrounds of participants will help to develop a well-rounded theory. We aim to do the same in our research

as we looked for a diversity of backgrounds for our interviewee group. Next, data is collected with methods that best fit the research gab. Once the data is collected, coding is used to analyze the data. In this case, coding is the naming of segments of data with a label that simultaneously categorized, summarizes, and accounts for each piece of data (Charmaz, 2014). Like in grounded theory, we start with open coding in which we form different data categories. The comparison of different categories will gradually help us analyzing the assumptions of our participants. Secondly, we will use themetic coding in which we determine the core categories. With these core categories, one will be able to see what the dominant similarities and differences are in the DI-PI analogy, according to experts.

2.4. Ethics

For this research, approval was granted with the TU Delft Human Ethics committee. In order to get this approval, a data management plan was made, which explains how interviews are recorded and how data of the participants are stored. Also, a consent form was made. In the informed consent, the interviewees were made aware that in the interviews are recorded and that their names and institutions will be made anonymous in this thesis. We also provided them with information about our data management plan so that they can consent to how the data generated and the interview is stored. In the data management plan, we explain how the recordings of the interviews are destroyed after transcription and that the anonymous transcription will be stored at a safe location at TU Delft. The list of the names of the interviewees is only set available to the supervisors of this thesis.

3

Creating an Analogy Functionality Model

This section will present the results gathered to answer *sub-question 1.'What is the value of analogical reasoning for the development of new concepts?'* We will first present a theoretical background on analogical reasoning, after which different purposes of analogies are discussed. Lastly, the pitfalls of analogies are described, and an Analogy Functionality Model is presented.

3.1. Background

Analogies are used for many purposes, and we can detect them in many different fields. They are used by scientists, teachers, designers, engineers, and many other professions. However, the usage of analogies is not limited to a professional context, as people are known to use analogies frequently, and even animals are known to reason using analogies (Fagot & Thompson, 2011). The type of thinking that relies on analogies is called analogical reasoning. In an analogy, two objects or systems of objects are compared according to their similarities. In this comparison, there is a source case from which information or meaning can be transferred to a target case. This comparison is also referred to as mapping, which involves placing different objects and relationships between objects in the analog into correspondence with the target (Krawczyk, 2018). After an analogy is mapped, new inferences can be made, also known as an analogical argument. An analogical argument cites similarities between two systems of objects to conclude that further similarities exist between the systems. In an analogical argument, we state that *X* is like *Y*, because they share properties *a,b,etc.* Therefore, *X* probably has property *c* since *Y* also has property *c*.

Analogies come in different shapes and sizes, but a relevant distinction that can be made is the between positive, negative, neutral, and hypothetical analogies. Keynes had made this distinction in 1921, and it has been used ever since. According to Keynes (1921), the foundation of a positive analogy is in the similarities between the target domain *T* and the source domain *S*. When *P* is a list of accepted propositions *P1,....,Pn* then the corresponding propositions of the target domain are *P*1,...P*n*, which can be shortened as *P**. If *P** is also accepted to hold in the target domain, we can state that both *P* and *P** are accepted, and the analogy is a positive analogy. In a negative analogy there are propositions that are holding in *S*, which are *A1,...,An*, or *A** The propositions that hold in *T* are *B1*,...,Bn**. When the propositions *A** do not hold in *T* the propositions *B** do not hold in *S* we speak of a negative analogy. A third possibility is a neutral analogy; this happens when it is unknown if accepted propositions of *S* hold in *T*. The other option is that the analogy is hypothetical. In this case, there is a hypothesis (*Q*) in a neutral analogy on the similarities or dissimilarities of accepted propositions in *S* and *T*. This implies that it is plausible that *Q** holds in the target, due to similarities between *T* and *S*, despite the differences between *T* and *S*.

3.2. Evaluation of an analogy

Table 3.1 represents all analogical arguments, but it does not say anything about the quality of the analogy. Despite advances in constructing analogical arguments, no literature implies a set of rules

Table 3.1: Augmented tabular representations of a hypothetical analogy by Keynes (1921)

SOURCE (S)	TARGET (T)	
P	*P**	(positive)
A	*~A**	(negative)
Q		
	*Q**	(plausible)

to make a valid inference based on an analogy. Bartha (2019), among others, has formulated a reason for this. When *S* is the source domain and $n \geq 1$ in *P1,...,Pn* the analogy would be positive. *Q** will hold in the target domain with $p > 0$. Bartha (2019) argues that this is a non-starter as it only states a requirement that says there has to be a 'nonempty positive' for $p > 0$. He states that not every similarity increases the probability of the conclusion, as some similarities may be irrelevant. The similarities that are found must be relevant for the analogy. For example, a car should be able to fly based on the analogy between a blue million dollar car and a blue million dollar jet is a bad analogical argument, despite the similarities that both objects are valued at the same price and share the same color. In this case, the price and color are not relevant to its ability to fly. The relevance of similarity (or a dissimilarity) can only be determined by its context. Various logicians and philosophers have identified commonsense guidelines for evaluating and interpretation analogies, among which, Robinson (1930); Stebbing (1930); Copi et al. (1990); Moore & Parker (1988); Walton & Hyra (2018). The most dominant criteria are:

1. More relevant similarities result in a stronger analogy.

2. More relevant differences result in a weaker analogy.

3. Limited knowledge of the source or the target domain result in a weaker analogy.

If an analogy has a high degree of similarity, it will become easier to transfer knowledge from the source domain to the target domain. Different similarities can be distinguished in analogies. Firstly, there may be similarities between attributes in the source domain and attributes in the target domain. If there is little attribute similarity to the analogy, it may be challenging to find a suitable target analog (Bartha, 2019). Secondly, there may be similarities in terms of relational similarity. The number of relational similarities will determine how useful an analogy is, as more relational similarity will make it easier to transfer relevant knowledge from one domain to the other domain (Krawczyk, 2018). A relational similarity implies a relation between two attributes in the source case that may also exist between two attributes in the target domain. Figure 3.1 represents a simplified version transferring attributes and relations from the source to the target case. While more similarities result in a stronger analogy, more differences result in a weaker analogy. Bartha states that in strong analogies, the number of differences should not outnumber the number of similarities. However, we have not found literature on specific rules for ratios between the similarities and the differences. Thirdly, people that make and interpret the analogy should be knowledgeable about the source and the target domain; this will give them a better chance of finding relevant similarities and differences (Walton & Hyra, 2018).

3.3. The different roles of analogies

Analogical reasoning is described as crucial for recognition, learning, discoveries and creativity (Vosniadou & Ortony, 2011). In the literature, we have found four different purposes of analogical reasoning. We will now elaborate on these different purposes by illustrating several examples found in the literature.

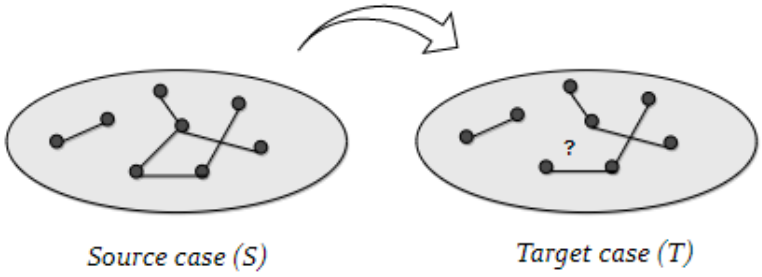

Figure 3.1: Transferring information from the source to the target domain

3.3.1. Inspiration purpose

Analogies are known to inspire people to come to new ideas, which is why analogical reasoning may stimulate scientists, designers, inventors, or entrepreneurs to develop new concepts, ideas, or products. Many rapports of creative scientists suggest that the development of new theories depends on an analogy drawn from a different domain (Hadamard, 1945). Likewise, computer scientists and mathematicians have developed algorithms inspired by nature, as natural processes often result in optimization, and many scientists try to understand and model these processes. Below is an example of analogies that serve an inspiration purpose.

The Ant Colony Optimization

The Ant Colony Optimization is one of the many algorithms inspired by nature and is the foundation for solving many optimization problems, such as Internet Routing and Vehicle Routing (Monmarché et al., 2010). The cooperative behavior of ants inspires it. Ants always operate in groups and can communicate via pheromone chemicals. They leave these chemicals to inform other ants about their position while moving through space in search of food. These chemicals arrange themselves in a certain order when they cool down, which allows the chemical its low energy state. If an ant is successful in finding food, they leave the pheromone on their way back. In some ant tribes, the amount and the quality of the pheromone give information about the quality and the quantity of the food. As a result, other ants take shorter paths and paths that lead to better food, as such, ants can find an optimal solution. This phenomenon has been modeled by making an analogy between the chemicals' behavior in thermal equilibrium and the behavior of the objective function of an optimization problem. The algorithm's first application was to solve a traveling salesman problem by aiming to find the shortest round-trip (Dorigo & Colorni, 1996). Although real ants' behavior has inspired the algorithms, there was a need for artificial ants to solve problems more complex problems. As a consequence, extra capacities like memory and the capacity to depositing a quantity of pheromone equal to the quality of the solution were added to the artificial ants. Despite the biological inspiration, new algorithms that derive from Ant Colony Optimization are less biologically inspired and more and more accommodated to the need for better algorithms. However, some of the core principles are still included, such as the need for a colony and the cooperative behavior endorsed by the pheromone trail (Dorigo & Stützle, 2019). The Ant Colony Optimization is one of the many examples where analogies have served as an inspiration and are later adapted to better fit the needs of the target case.

3.3.2. Explanatory purpose

The foundation of learning is memorizing existing bodies of knowledge and use these foundations in combination with new facts to learn something new (Vosniadou & Ortony, 2011). Analogies can be excellent teaching tools and can be readily applied in classroom settings (Krawczyk, 2018). As a result, teachers and authors often use analogies and draw on the content provided by a source case. In this situation, one must use a well-understood source analog and compare this to a less-understood

target analog (Duit, 1991; Curtis & Reigeluth, 1984; Gentner & Holyoak, 1997). Comparing two domains enables someone to identify similarities and differences in relations between relations in the sources and the target case (Iding, 1997; Gentner & Holyoak, 1997). For this reason, analogies are thought of as a tool to help people learn who are unfamiliar with the target domain (Donnelly & McDaniel, 2000; Duit, 1991). The following examples depicted analogies with an explanatory purpose.

Explaining the Higgs Boson
In 2013 P. Higgs and F. Englert did a theoretical prediction on the Higgs Boson. Their work concerns a phenomenon in particle physical about a Higgs field that exists with its associated boson, which has to do with particles and the mass that they possess at different times within the Higgs field. This Higgs field is challenging to describe and difficult to be understood by the general public. As a result, the British minister of science announced he would award a bottle of fine champagne to someone who can explain the Higgs field to the general public (BBC News, 2012). A physicist called D. Miller was able to claim the prize by making up an analogy. He compared the Higgs field to a cocktail party. He compared the particles in a Higgs field to the people at the party and described the dynamics in the Higgs field, by describing the dynamics between them. He sketched a scene by stating that many people are attracted to a famous person when a famous person suddenly joins the party. As a result, the mass is altered by the people occupying the space around this person, similar to the elements in a Higgs field, giving mass to a particle. Miller described that a boson is similar to a rumor shared between the party guests. This rumor is temporary, altering the people's spatial arrangements in the room as they are spreading the rumor, which is comparable to a boson manipulating the Higgs field. With this analogy, a complicated phenomenon has been made understandable and easy to remember for non-experts.

The Plum Pudding Model
Soon after the discovery of the electron J.J. Thomson made a model in 1904, with this model, he aimed to explain an atom's organization. According to him, the negatively charged electrons may be embedded within a larger, positively charged spherical field. He assumed that the electrons were stationary and compared them to an English dessert, similar to a raisin muffin and known as a plum pudding. The representation of an atom became known as the Plum Pudding Model of Thomson (1904). In this case, the raisins from the source domain are compared to the electrons in the target domain, and the bread is compared to the positively changed mass. In 1910 an experiment was conducted in which highly dense alpha particles were fired through a golf thin foil to see if the particles would scatter. According to the Plum Pudding Model, the number of scattered particles should be very limited. However, the opposite happened. Most of the alpha particles passed through the foil and the ones that did not do that deflected in extreme angles. The Plum Pudding Model lacks sufficient mass to deflect these particles, which is why the Plum Pudding Model was eventually discarded. This analogy is an example of a dysfunctional analogy that is discarded due to relevant differences between the source and the target case.

3.3.3. Persuasion purpose
Analogies can also be used as a tool to increase the effectiveness of conveying a message in public speaking and persuasive writing. We use analogies to make speech or text more memorable, colorful, and interesting as they have the power to clarify and trigger emotional reactions(Krawczyk, 2018). There are countless examples of how an analogy can help persuade people to come to action or help people get used to a new idea. Bellow, we provide two situations where analogies demonstrated a persuasion purpose.

Persuasion by presidents
One of the first conceptualization of charisma was the quality of leaders to gain and persuade devoted followers (Weber, 1964). In 2005 Mio, Riggio, Levin, & Reese (2005) performed a study in which they compared US presidents by analyzing 36 presidents. Their hypothesis implied that speeches that contain analogies are perceived as inspiring as they stir up emotional connections while persuading the public to come to action. According to previous research, of these 36 presidents, 17 were referred

to as high charismatic and 19 as low charismatic. In these speeches Mio et al. sought the use of analogies. They found out that highly charismatic presidents used almost twice as many analogies than low charismatic presidents. These results suggest that analogies are important for inspiring the audience.

Persuasion by Apple
While our previous example is concerned with analogies in speech and its connection to charisma and attracting followers, analogies can also convince people to get used to a new idea. An example of this is Steve Jobs making the use of Apple computers more acceptable by making the applications more similar to the real world (Pollack, 2018). He achieved this by making analogies between a workspace in the real world, which is the source case, to a workspace in the virtual world, which is the target case. As an example, Apple used the word files for sections where users could store their documents. By doing so, the suggestion was made that users can move folders just as easily as in a physical workspace; this gave the user a sense of familiarity to a domain they already know.

These examples show different ways people can be persuaded by analogies to change their minds or come to action.

3.3.4. Design purpose
Analogical reasoning has proved to be a powerful tool of inspiration for creating innovative designs (Chan et al., 2011). Many breakthrough ideas in the design area are triggered by analogies where solutions from a source domain are transferred to a target domain (Herstatt & Kalogerakis, 2005). As such, analogies are often used to come to creative ideas. A good example is the frequently used brainstorm technique referred to as *Synectics*, which stimulates problem solvers to look for solutions used on similar problems outside the target domain (Gordon, 1961). Making an analogy fosters new inferences and promotes problem-solving in new insightful ways. When analogies are used to design, we call it design-by-analogy. Many publications have been made regarding design-by-analogy, especially in industry-related journals, where design almost always refers to designing a technical artifact. When a designer uses an analogy to design a new object, they must find a suitable source case by looking at the design requirements. From this source case, the relevant aspects of the design can be extracted and mapped across to the target. They can be transformed when appropriate and incorporated into the design. We will illustrate this in the following two examples.

Designing a new express ATM function
Maclean, Bellotti, Youngl, & Moranz (1991) looked at the role of analogies in design endeavors and studied the design of an ATM. The designers of this ATM wanted to give the ATM an express function for busy times of the day. When the ATM is in express mode, it can only handle cash withdraws and no other requests. To do this, they used the supermarket express lane as a source case. From this analogy, they also drew the idea of light above the ATM that indicated the ATM is in express mode. The ATM could then switch between express mode and full-service mode, and the customers would know due to the light indicator. The design requirements that are satisfied by this option include visibility and speed. On one side, the bank wants to speed up the process, on the other side, the customer needs to know what is going on and needs to be made aware the ATM is in express mode.

Designing a new assembly line
In the beginning of the 20th century, Ford Motor Company was looking for ways to expand its production capacities to meet increasing demand. Ford engineer William Pa Klann visited the Swift & Company slaughterhouse where the carcasses of pigs were butchered as they moved along a conveyor. Klann noted the efficiency of people specializing in removing the same piece from the carcasses by performing the same movement in a repetitive matter (Klann, 1996). In this case, Klann used the slaughterhouse as a source case and the Ford manufacturing plant as a target case. As a result of Klann his analogy, the moving assembly line began operation in October 1913 and continued to evolve after that. In this example, the analogy objects are different as a slaughterhouse, and a car manufacturer come from different domains. Additionally, the process is different as the

slaughterhouse functions as a disassembly line and the ford manufacturing plant as an assembly line. Despite these differences, we can identify a common goal: an efficient transformation of objects carried out by multiple workers.

In these design examples, we can see that one can copy particular elements from the source case to the target case.

3.4. Limitations of using analogies

When applying analogies for inspiration, explanatory, persuasion, or design purposes, the literature also implies several limitations when using analogies. We will first give an overview of the risks of using analogies, followed by an example of what may go wrong when one is unaware of these limitations.

While analogies are often used to enhance comprehension and stimulate learning, they can also cause misconceptions. Many researchers have described the risk of developing misconceptions about the target domain (Duit, 1991; Kaufman et al., 1996; Zook & Di Vesta, 1991; Brown & Clement, 1989). Misconceptions arise when people transfer irrelevant concepts from the source domain to the target domain. Zook & Di Vesta (1991) proved this by conducting an experiment among third-grade students. According to their findings, students who have learned by analogies came up with more incorrect inferences, because they use irrelevant relations form the source case. Additionally, Treagust et al. (1998) have found out that student often transferred attributes and relations literally, which is also a source of misconceptions. These misconceptions may cause incorrect ideas that must later be unlearned.

Gentner & Stevens (1983) explained how some analogies might be more effective than others when explaining a particular component of a new concept. They found out that students who try to understand electric currents understood resistors more clearly when the teacher compared it to a moving crowd. Likewise, students understood the working of electric circuits in a battery better when it was compared to flowing water. Additionally, an analogy is often multi-faced when we apply it to complex situations; this may cause the analogy to have different meanings for different audiences. When different audiences interpret analogies differently, it becomes challenging to create a shared understanding of the target domain (Taber, 2001). Another form of a misconception that may occur is the misconception of understanding (Treagust et al., 1998; Gentner & Stevens, 1983). When a simple analogy explains a complex matter, one may be satisfied with this simple explanation. This may refrain them from fully understanding the target case. As a result, students may have a false sense of comprehension. Likewise, when one does not properly understand the source domain, he or she may also get a false understanding of comprehension. Finally, it is proven that an analogy is only useful to learn from if the learner has a good comprehension of the attributes and relations in the source domain (Duit, 1991).

Another risk of using analogies is the risk of fixation. As discussed previously, analogies may foster the generation of new and creative designs. However, using analogies also comes with the risk of design fixation. Design fixation inhibits creativity as it is triggered by focusing on existing paths and solutions (Chan et al., 2011). When someone is fixed on the source case, there is a risk that irrelevant knowledge is translated to the target case and that the designer is cut off from new ideas or impulses that may come from different sources.

Thirdly, there is a risk that the wrong knowledge is transferred from the source to the target case, which may affect the target domain in a negative way (Maclean et al., 1991). This is the point where an analogy becomes dysfunctional. As can be seen in Section 3.2 there are no concrete criteria that indicate what a particular attribute or relation has to comply with to be suitable for knowledge transfer. Consequently, it is hard to value the strength of a specific analogy, but it can also be difficult for the user of an analogy to transfer the right knowledge. Pollack (2018) gives an example of where the wrong information is transferred from the source to the target case. He illustrates what

used to be the sentencing system in California: 'three-stikes-out'. He explains how this was an easy system to understand as it derived from the US favorite sport: baseball. Since baseball is known as a fair sport, the 'three-stikes-out' sentencing had a sense of justice to the public. Although many argue the system itself was far from justified as the type of crime did not matter, and minor crimes would be punished equally to major crimes. In this case, people may have wrongfully transferred a sense of justice from the target to the source case. This is an example of ethical issues that may occur when transferring elements from a source to a target case. An example that is closer to our thesis topic is the analogy of the information superhighway. This analogy uses physical highways for cars as a source domain and telecommunications infrastructure as the target domain. The analogy gained much attention in the nineties, after Gore (1991) used it. Gore used this analogy in his article *Infrastructure for the Global Village*. Borgman (2003) argues that the highway analogy is misleading as it skews the public understanding of who bears the cost of the construction of the Internet. The construction of a physical highway is paid by the government, whereas the Internet was created by a combination of public and private funds. This is an example of where an analogy may be useful for one aspect, but not for other aspects, such as governance.

3.5. Analogy Functionality Model

So far, it is described that analogies have different purposes and different analogies have different levels of strength. There is a point where one must depart from the analogy before it becomes dysfunctional. This breaking point is different for every analogy, and it also may be different for different parts of the analogy itself. For example, at the end of this research, we may find out that there is a certain aspect in the DI-PI analogy where the analogy may be valuable. Likewise, we may found out that the analogy becomes dysfunctional for other aspects due to a large number of differences. For this research, a model is created, which gives an overview of the different functions of analogies in relation to the required strength of the analogy and the influence the analogy has on the target case.

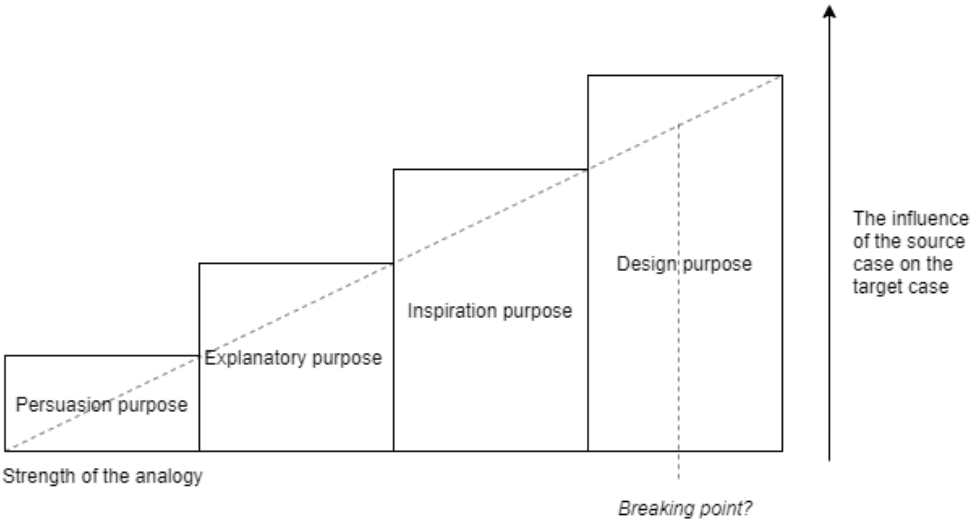

Figure 3.2: Analogy Functionality Model

The model shows that different purposes have different influences on the target domain. In the case of analogy usage for persuasion or education, the user's aim is often not to change the target case. As a result, the changes in the target case will be minor and often indirect. When using an analogy for an inspirational or design purpose, the user often intents to improve the target case, so the effects on the target case may be much more significant. We will explain the analogy's effects on the target case for the four different purposes that we have distinguished earlier.

- **Persuasion purpose** When one uses an analogy to persuade an audience about a certain idea, the use of the analogy has a minimal effect on the target case. This becomes clear by our previous example of where Apple uses familiar tools to attract people to use their desktop. From the source domain, apple used many familiar words and icons such as trashcans and scissors for their target domain. However, the names and the icons of the functionality have not changed the functionalities of the desktop itself; it only made the functionalities more familiar to the users. This is why using an analogy for a persuasion purpose has little to no effect on the target case.

- **Explanatory purpose** As becomes apparent in Section 3.3.2 a source domain can be used to explain a phenomenon in the target domain. This may affect the target domain in an indirect matter. In our example of the Plum Pudding Model, students were educated on an atom's organization by an analogy that later appeared to explain an incorrect organization of atoms. When an incorrect analogy spreads, there may be a possibility that others build on that analogy for further research or industrial applications. The magnitude of the effect depends on the audience of the analogy. Also, when the audience is active in the field of the target domain, the effects may be bigger than when the audience has minor affiliation with the target domain. This is why using an analogy for an educational purpose only has an indirect effect on the target case.

- **Inspirational purpose** When using an analogy for inspiration purposes, the source domain is used to inspire change or improvement in the target domain because the source case has a certain quality that we aspire the target case to have. In our example of the Ant Colony Optimization, we see that an algorithm is developed to be used for optimization purposes in different target domains. Although the algorithm is inspired by nature, new algorithms that derive from the Ant Colony Optimization are less biologically inspired and more and more accommodated to the need for better algorithms. In this example, ant colonies inspired and improved optimization algorithms, which affected the target domain of optimization algorithms.

- **Design purpose** We argue that when using an analogy to design, the source case has a big influence on the target domain. When one designs by using an analogy, one goes beyond inspiring the target domain, as one copies elements from the source domain. In the example of the ATM, it is explained how an ATM designer copied the idea of a light indicator from supermarket express lanes. When one would use the analogy between a supermarket express lane and an ATM solely as an inspiration purpose, one might develop more generic lessons, such as design requirements or functionalities. One could have concluded that an express lane is working very well in supermarkets, so one should also have express lanes for ATM machines. Alternatively, in supermarkets, the express lane can be easily found by costumers, so costumers using an ATM should easily recognize a machine in express mode. When we use analogies to design, we go a step further by copying the idea of light indicator to fulfill design requirements. In this thesis, we refer to an analogy's design purpose when one copies attributes or relations between attributes directly from the source to the target domain. In this case, the source case directly affects the target case and changes the design of the target case. This is why the design purpose has the biggest influence on the target case, as shown in our model in Figure 3.2.

This model aims to identify the relation between the magnitude of the effect of the analogy on the target case and the required level of strength of the analogy for different analogy purposes. The bigger the consequences of a dysfunctional analogy are on the target case, the more careful one should be when applying the analogy. We argue that different analogy purposes require different levels of strength. For instance, when one uses an analogy for persuasion, the analogy may still be functional when the analogy is of moderate strength, meaning, the source domain and the target domain are similar to a minor extent. Suppose we, for instance, use an analogy for design. The analogy is only functional when the analogy is strong, meaning, the analogy has a high number

of relevant similarities and a low number of relevant differences. A key takeaway from this model is that at some point, the analogy becomes dysfunctional. This point is different for each analogy and depends on the number of relevant similarities and differences. The less relevant similarities between the source and the target case, the sooner the breaking point will come. With this model, we try to explain that when one uses an analogy to design, the analogy must be stronger than when using the analogy for other purposes. The more similar a source and a target domain are, the later the analogy becomes dysfunctional, and the more the analogy can be exploited.

Limitation of the model

Firstly, this model argues that different applications of an analogy have different effects on the target domain. That being said, some target domains allow for change, while others are more static by nature. This is why the model is only applicable to the target domains we can form, influence, or design. Secondly, the model only focuses on the effect of the target domain, as this is the topic of our research. However, we must not forget that a target domain may also become a source domain. In this research, we look at the DI as a source domain and the PI as a target domain. In many examples, the analogy in reversed like in, for example, the analogy about the Internet superhighway. Thirdly, the graphic representation of the model depicts a linear relationship between the required strength of the analogy and the source domain's influence on the target domain. This relation may be linear in some cases, but in others, it may be exponential. Also, the steepness on the line may vary from case to case. Lastly, there may be exceptions in which analogies used for persuasion have a major impact on a target case, or analogies used for design have a limited effect on the target case. Despite these limitations, we found this Analogy Functionality Model to be useful in answering our research question.

4

Results Summary

4.1. Participants

As a result of our recruitment efforts, we have found 15 experts who were willing to participate in this research. Six of our interviewees have been recruited at the ALICE meeting in Vienna. Seven of our interviewees have replied on the recruitment e-mail in which they were invited to participate. Two of the interviewees have been introduced to me by interviewees that are already participating. Six of our interviewees have an educational background in a topic related to ICT or computer science. All of our interviewees are currently working in the logistics domain.

4.2. Interviews

Four of our interviews were conducted in real life, and the remaining eleven interviews were conducted over virtually over Skype or WebEx. The length of the interview depended on the time the interviewees had available. The average length of the interviews is 46 minutes, with the shortest interview lasting 25 minutes, and the most extensive one hour and 45 minutes. Six of the interviews were conducted in Dutch and ten in English.

4.3. Coding & Codebook Overview

After the interviews were conducted and recorded, the interviews were transcribed word-by-word. They were analyzed uses a structural coding approach. Three hundred three codes were made based on the quotations of the interviewees. The 303 codes were bundled into 60 groups, which are presented in our codebook. The table underneath indicated the different groups in our codebook. The groups were formed based on common themes in the interviews, instead of being predefined by our research questions and interview protocol. This approach gave us the chance to find out additional relevant information that was not anticipated by our interview protocol.

In the next chapter, we will present the interviews' results by an elaboration on the code groups that relate to similarities between the DI and the PI. In Chapter 6, we will present our interviews' results by elaborating on code groups regarding differences.

Table 4.1: An overview of the interviewees, their roles and background

Participant	Role	Background
Interviewee I	Non-academic researcher at a German Institute with an interest in innovative ICT solutions for logistics and manufacturing	Computer science
Interviewee II	Non-academic researcher at a Dutch institute, with an interest in supply chain collaboration and cross chain control centers	Logistics
Interviewee III	Non-academic researcher at a Dutch Institute, with an interest in IT architecture in transport, ports and customs operations	Informatics
Interviewee IV	Professor of Industrial engineering at a Dutch University with an interest in the role of ports in the Physical Internet	Logistics
Interviewee V	Professor at a French University and french head of the PI initiative with interest in future supply chain and production systems	Logistics
Interviewee VI	Entrepreneur whose business aims to orchestrate collaboration in supply chains to bundle shipments in the beginning of the chain	Logistics
Interviewee VII	Professor at a Belgium university with an interest in supply chain dynamics, inventory management and production smoothing models	Logistics
Interviewee VIII	Professor at an American University with interest in engaging academic, industry and governments leaders in the PI and further develop the PI	Logistics
Interviewee IX	Research Fellow at a FMCG conglomerate with an interest in supply chain innovation and PI realisation	Logistics
Interviewee X	Assistant professor at a German university with interest in innovation in information and operation management	ICT and Logistics
Interviewee XI	University lecturer at a Dutch university with an interest in the transportation of non-standard goods in the PI	Computer science
Interviewee XII	Professor at a Dutch university with an interest in coordination for sustainable global supply chain, synchromodal transport networks and inter-organisation systems in logistics	Logistics
Interviewee XIII	Adjunct professor of logistics and academic director with an interest in the application of modern management techniques to supply chains, sustainable business models, green logistics and cloud based supply chain management	ICT and Logistics
Interviewee XIV	Non-academic researcher at an Austrian institute with an interest in dynamic transportation systems and transport optimization, healthcare logistics, meta-heuristics and hybridization techniques	Computer science
Interviewee XV	Professor in operations management at an Austrian university with an interest in industry 4.0, circular supply chains, humanitarian logistics and integrated capacity and inventory management	Logistics

Table 4.2: Code groups from the code book

Code groups	**Number of quotations**
Acknowledgement of lack of expertise	4
Alternative analogy	4
Barrier Solutions	4
Barrier: Bundling/Splitting	2
Barrier: Changing standards	2
Barrier: Collaboration	26
Barrier: Ethics	2
Barrier: Governance innovations	8
Barrier: Homogeneous Cargo	2
Barrier: JIT	1
Barrier: Knowledge	1
Barrier: Modularization	1
Barrier: Necessity	3
Barrier: Business model innovation	6
Critical view points on the analogy	10
DI assumption	24
Difference between DI and PI in evolution	5
Difference between DI and PI in modularity	3
Difference between DI and PI in speed	8
Difference between DI and PI the need for modes	4
Differences between DI an PI number of ISP LSP	1
Differences between DI and PI in bundling	5
Differences between DI and PI in costs	5
Differences between DI and PI in duplication	8
Differences between DI and PI in loads	7
Differences between DI and PI in planning	9
Differences between DI and PI in routing	2
Differences between DI and PI in storage	1
Differences in attributes	1
Drivers to collaborate	4
PI characteristic: Modularization	11
PI characteristic: Asset sharing	4
PI characteristic: Automation	7
PI characteristic: Bundling	2
PI characteristic: Cargo parameters	1
PI characteristic: Connecting users of the transport networks	1
PI characteristic: Interconnected networks	6
PI characteristic: Openness	7
PI characteristic: Ownership	2
PI characteristic: Standardization	1
PI characteristic: User experience	1
PI characteristics: Different views of what PI should do	2
Research emphasis on PI functionality	1
Research emphasis on PI Governance	3
Similarities between DI and PI automation	4
Similarities between DI and PI in Attributes	9
Similarities between DI and PI in bundling/splitting	6
Similarities between DI and PI in decentralized organization	5
Similarities between DI and PI in encapsulation	9
Similarities between DI and PI in optimization	2
Similarities between DI and PI in routing	6
Similarities between DI and PI in sharing assets	5
Similarities between DI and PI interconnected networks	3
Similarities between DI and PI mutual dependence	1
Similarities between DI and PI Openness	4
Similarities between DI and PI Standardization	10
Similarities between DI and PI user experience	7
Similarity between DI and PI Flexibility	3
The formation of the PI analogy	4
Value of the analogy for the future	11

5

Physical Internet Similarities

In this chapter, the results are presented on the similarities between the DI and the PI, according to PI experts. Some of these similarities were presented by the interviewee by their own initiative; others were presented as answers to a question from the interview protocol. During the interviews, many interviewees described how they see similarities between relations in the DI and the PI. By this, we mean the interviewee draws a similarity between process characteristics that involve multiple attributes. Table 5.1 gives an overview of the differences. Twelve of the similarities were made by interviewees with a computer science or ICT background, and 22 of the similarities were made by interviewees with a logistics background, the remaining two similarities were made by interviewees with a mixed background. We will now present the results one by one.

Table 5.1: Attribute and relational similarities between DI and PI

	Code Groups on Similarities	Mentioned by interviewee
Attribute	Similarities in actors, hubs and modes	I, VIII, V, XIV
	Similarities in packets and packages	I
Relational	Similarities in bundling and splitting	II, III, I, V, VII, VII, IX
	Similarities in organisation	V, VI, XIII, XIV
	Similarities in standardization	II, VI, VIII, IX, XII, XIII, XV, XIV
	Similarities in automation	III, VII, VI, XI, XV
	Similarities in openness	VI, XIV
	Similarities in sharing assets	VII, XV
	Similarities in user experience	II, IV, VI, XIV, XI
	Similarities in flexibility	IV, XIV

5.1. Similarities in attributes

Interviewee I described how he did a workshop with people for the logistic domain in which they explored the DI domain. They recognized that there was an analogy in terms of actors. There is a sender, a receiver, and a packet or package. **Interviewee V** compares transport modes in the PI to interfaces in DI. The interviewee explains that in order for a packet to move from A to B, it uses the technology of the DI network, and the same principle happens in the PI. When a package needs to get from A to B, it uses a boat or a truck, and these modes function as interfaces between A and B. **Interviewee VIII** describes the analogy between a router and a PI hub. He explains there are similarities at two levels. Firstly, they function as a physical transshipment point where packets or packages arrive and transfer. Secondly, they function as a decision-maker and route the packet to the next destination. **Interviewee XIV** also recognizes that both DI and PI make use of hubs and service providers. He explains how service providers in the DI and the PI may have different software components and hubs may even have different software versions; however, they are still using the same interface and the same standards, which is why they can still operate.

All of our interviewees compared the data packet in DI to a package or shipment in PI. Some of the

interviewees compared the structure of the data packet on a deeper level. **Interviewee I** adds that goods in the PI must look the same to the system that operates it, which can be similar to the 'header' of data packets, which always looks the same. **Interviewee XIV** gives a detailed explanation about the set up of a packet. He explains there is a source address and a destination address, and there is information, such as time-to-live, which is about how long a data package should be available in the DI, and determines how long we should try to send it to the receiver, he explains. Furthermore, he explains: "You have some information on checksums so that you cannot manipulate the data, which is the inside of the container, and there is information on the size of the container. And then you just sent the data package, and since you have this address sticker at the beginning of their message, which is understood by everyone, it is very easy to forward". The interviewee envisions the PI containers should have a similar set-up.

5.2. Relational similarities

5.2.1. Similarities in bundling and splitting

Interviewee II mentioned a similarity regarding the splitting of packets. He states that when we send something over the Internet, it is split into small packets, and in the PI, the same thing is supposed to happen with shipments. **Interviewee III** describes how packets move over the DI. 'First, an e-mail is split into packets; these packets enter the network in a random sequence. In this network, there are routers that sort the packets, and if there are a lot of packets on a link, latency may occur. In the PI, this a similar thing happens, and a queue is created, which is also a form of latency. To accommodate this, you need to make room for queues, which we also see throughout the current logistics system. In addition to splitting Interviewee III also states that packets may be bundled before they travel over a link, which he refers to as multiplexing. **Interviewee I** also describes this technology and compares container ships to deep-sea cables. He describes how smaller packages are all packed together and sent via a cable as one larger packet, similar to how containers are stacked on a containers ship. **Interviewee V** describes how loads on the Internet are split into small packets and how loads in the PI can also be split up into smaller units. **Interviewee VII** also describes how messages in the DI are split up into packets via a TCP/IP protocol. **Interviewee IX** describes the same technology and phrases it as: "The Internet protocol introduced this concept of data packets so whatever this information is, it may be voice communication, picture or detailed e-mails, they are broken up in single data packs, and these data packs are routed in different ways over the Internet via the path of least resistance, and then they are assembled at the other side". Both **Interviewee V** and **Interviewee IX** recognized that splitting might also happen in the PI, but not in an exactly similar way because physical packages can not be duplicated when lost. **Interviewee VII** describes that according to the analogy in PI shipments should be split up just like data is split up on the Internet

5.2.2. Similarities in organisation

Interviewee XIV describes he believes the PI is similar to the DI with regards to a decentralized approach. He describes how in a decentralized approach, you have just hubs and spokes between hubs, and the hubs decide if a container or a data packet is transported along the next step with a truck or a vessel. 'So the decision power recites in the hub, and it is not the forwarder or the shipper that decides upon the whole logistics chain,' he argues. **Interviewee V** mentioned the analogy between the DI and the PI works if you look at the structure of the networks. With structure, he means the way the networks are organized and how data or goods can be put in a package, which can be sent to a router. The interviewee further explains how one should have a contract with a company to handle these packages as one has in the DI with an Internet provider.

According to **Interviewee XIII** the analogy is based on connecting networks together, and it is built on the idea of packet switching. He explains if you think of the DI as a network that moves electronic boxes, the DI is similar to the PI. And the idea of the analogy is to generate the efficiency that you see in the movement of electronic packets. He explains that packet switching is a technology in which

you have a distributed control system that basically resides in your switches. “These switches have some form of intelligence and knowledge of the nearby network. So when a pack comes with an address on it, what they try to do is combine it with other packets going in the direction of that address and coupling that with their knowledge of what available passageways are out there to get closer to that address.” He further explains how the switches assemble these things and then send them on. “From a similar perspective, you would expect that in the PI, the nodes are warehouses or cross-dock operations or port operations that act similarly. They take in the incoming packets and identify where they are going, reassemble them in outgoing shipments and send them down the most economical lanes based upon their knowledge of the near network that would get them closer to their final destination.” The interviewee compares a router with a two-sided input mechanism, with on one side the inbound messages which queue up. “Then, depending on where they are going, they are switched to outgoing channels that will queue up the packets again and then send them out in a regular sequence base on how the router is set up,” he explains. He compares this to cross-docking operations in logistics.

Interviewee VI believes that the analogy between the PI and the DI implies that there is a network of networks where everything is linked and which is accessible to everyone. When asked about how he sees interconnected networks in the DI, he explains that actors developed standards and protocols to work together, and that is how networks are interconnected.

5.2.3. Similarities standardization

The most frequently mentioned similarity between the DI and the PI is standardization. **Interviewee II** describes the importance of using standardized protocols in the PI similar to in the DI. He mentioned the PI should have a standard set of rules when it comes to transshipping a container, and everyone should comply with these rules. The ones that do not comply with these standards will be unable to use the network, he explains. **Interviewee IX** has a similar perception of standardization and adds that in the current logistics system, we already have some standards, such as the sizes of maritime containers. **Interviewee XV** likewise makes a comparison to maritime containers and explains there must be some sort of standardization in the PI just like the DI. He points out that there is already a kind of standardization in current logistics in the form of containers. He points out the in the 1960s, the first container was sent to Europe, and an accident happened at the European side because they did not know how to handle a container yet. “The accident caused a media scandal, and after this, the infrastructure was build around containers, and the Germans were able to handle maritime containers.” He explains that this example illustrates that a good standardization idea might not be successful if only one side uses it. **Interviewee XIII** recognizes the need for standardization of protocols in the PI and the DI. He describes that in the DI, there are thousands of protocols, but the main protocols that are used for managing the flow of traffic are specified by the routing manufacturers. He explains that similar to the PI; it does not matter what goes on inside a router of a physical hub; what matters is what goes on at the boundaries. According to Interviewee XIII, this means that inbound traffic is handled uniformly and that outbound traffic is handled uniformly with outer routers and that this is generally managed in the TCP/IP protocol. “IP, in this case, is the link management and TCP being the end-to-end management, so these are the things that are important,” he explains.

Interviewee VI describes there are certain standards and protocols that are developed on the Internet. “At one point in time, there were actors in the DI that developed protocols together, which were a set of rules that decided how data packets were transported.” He explains how the same is suppose to happen in the PI, so competitors must come together and make standards just like in the DI. As an example, he mentions the TCP/IP protocol, but could not describe the exact workings of the protocol.

Interviewee XIV acknowledges that there are similarities in standardization between DI and the current logistics system. He first describes that interfaces in the DI all follow the same standards, and because of this, old DI nodes can still handle the traffic despite all innovations in the DI. He

then describes the standardization in the current logistics system in terms of the standard sizes of euro pallets and sea freight containers.

Interviewee VIII also says it is interesting to look at how packets are standardized in the DI. He explains if you send an e-mail from A to B on the Internet, the e-mail is composed out of data packets, and these packets are as standardized as possible. According to the interviewee, the standardization makes it easy for the network to handle the packets and run them through the network and regroup them in the end. **Interviewee XII** mentions a similar need for standardization in the PI as it is done in the DI.

5.2.4. Similarities in automation

Interviewee XI talks about automation as the most appealing part of the PI analogy. He envisions the PI to be like the DI: fully automated, and users can send their shipments by the push of a single button. **Interviewee VII** explains that sending a shipment over the PI should be like sending an e-mail. "When sending an e-mail, your data will be split into packets using a standard TCP/IP protocol, and the packets are automatically routed to the final destination." **Interviewee VI** and **Interviewee III** also recognize that transshipment in the PI should be automated, so there is no human intervention in transporting goods from A to B. **Interviewee XV** acknowledges there may be some similarities between the DI and the PI in terms of routing and the objective function of a routing protocol. He assumes the basic methodology behind it is quite similar. However, there may be differences in the aim of optimization, he acknowledges. "In the PI, we will aim to optimize transportation in different ways and will avoid losing packets, as we can not duplicate them; this will be different in the PI," he explains.

5.2.5. Similarities in openness

Interviewee VI describes how the PI should have an open character in which everyone has access to the network via a service provider, which makes the threshold to use the system low. **Interviewee XIV** also mentioned the PI should be open like the DI in the sense that everyone that complies with the standards should be able to join the system. **Interviewee XII** describes how the PI should be open and for all traffic that complies with the standards. He explains the DI works in a similar matter, as an American server is unable to reject all Internet traffic from China.

5.2.6. Similarities in sharing assets

Interviewee VII mentions that PI actors use each other's networks just like in the DI. As an example, he states: "When I sent you an e-mail from here to Delft, the e-mail will travel over my own network, but also on other networks." According to **Interviewee XV**, the PI and the DI have in common that assets are shared. He gives an example of Internet cables that pass through the Atlantic Ocean and are shared by multiple parties. He reasons that although users of the asset may be competitors, they have found a way to share it. The interviewee presumes the parties that use the Internet cable share the costs and maybe even share the revenues. Additionally, he states that if one partner steps out of the collaboration, because he does not want to partner anymore, the Internet does not collapse. The interviewee acknowledges he does not know how this works, but he can think of a similar example in the code-sharing of airplanes, which he describes is a kind of collaboration where resources are shared.

5.2.7. Similarities in user experience

Interviewee IV describes that for her, the analogy implies that the current logistic systems will transform into a system like the Internet, where not everything is set into contracts regarding how a container is transported. She explains that in the PI, it is important for the users to receive a certain quality of service, which implies that when they send a shipment, they should be certain that the receiver receives that good. When using the DI, she assumes that when she sends data over the DI, she knows data can follow various alternative routes depending on the state of the network.

She explains that as an end-user, she does not care about this, and the PI should be similar in this matter. By that in the interviewee means that when there is an obstruction in the PI, packages will automatically be rerouted. Maybe this alternative is not the shortest path, but as an end-user, you do not have to made aware of this constantly. She explains the user should not have to care about what happens in between, just like when you send an e-mail. “When you send an e-mail you worry about the text in the e-mail. At the moment you send the e-mail, you trust that it will arrive in the same format where you want it to go.” **Interviewee XIV** uses the same example and emphasizes on the carelessness of a sender about how an e-mail travels to the receiver. For **Interviewee XI**, automation is the most appealing part of the analogy, and he also explains the carefree situation he experiences when he sends an e-mail. **Interviewee II**, likewise, uses the example of an e-mail but emphasizes the trust the sender has in the network to deliver the e-mail according to his or her expectations. He reasons the same level of trust would be desirable in the PI, so a sender can trust that his package will meet the receiver within required parameters, such as time and costs. The aspect of trust in also highlighted by **Interviewee VI** who talks about the ease of using the DI, where one does not need to worry about how data reaches the receiver and via what networks. He envisions a similar kind of trust that users will have in the PI.

5.2.8. Similarities in flexibility

A few interviewees mentioned how the network should be resilient by being flexible and offering alternative routes through the network like in the DI. **Interviewee IV** described how the PI network should be able to facilitate flexibility by routing shipments through the links and hubs that have capacity at a moment in time. She explains how the route that packets take over the Internet depends on the busyness in the network. **Interviewee XIV** mentions that the PI should provide real-time decision making. The interviewee explains that if something goes wrong, one should be able to anticipate and re-plan the route of the shipment. And not only when something is wrong, but one should also be able to adapt a route when there are better routes available.

In this chapter, we learned about the various similarities between the DI and the PI, according to experts. Most interviewees drew similarities between the standardization of transportation units (packets, frames, packages, containers), interfaces, and protocols. Other frequently mentioned similarities are the bundling and splitting of transportation units, the high level of automation in the network, and the decentralized organization of the networks. Another frequently mentioned similarity is the feeling of carelessness and security users experience when they use the network. Some interviewees also identified the sharing of assets, the flexibility of rerouting a transportation unit when necessary, and the openness both DI and PI offer in terms of the ease of joining the network.

6

Physical Internet Differences

In this chapter, the results are presented on the differences between the DI and the PI, according to PI experts. Some of these differences were presented by the interviewee on their own initiative, and others were presented as an answer to a question from the interview protocol. During the interviews, many interviewees described how they see differences between relations in the DI and the PI. Table 6.1 gives an overview of the differences. Fifteen of the differences were mentioned by interviewees with a computer science or ICT background, and 15 of the differences were made by interviewees with a logistics background, the remaining two differences were made by interviewees with a mixed background. We will now present the results one by one.

Table 6.1: Attribute and relational differences between DI and PI

	Code Groups on Differences	Mentioned by interviewee
Attribute	Differences in the number of providers	II
	Differences between packets and packages	II, IX, XI, XII
Relational	Differences between DI and PI in evolution	I, III, V, XV
	Differences in speed	I, VII, IX, X, XI, XIV
	Differences in the need for modes	IV, IX
	Differences in splitting and bundling shipments	VI, XIV
	Differences in costs	I, V, IX, X, XI
	Differences in replication and duplication possibilities	I, II, III, IV, V, IX, X, XI, XII, XIV, XV
	Differences in planning and decision making	I, III, V, XIV

6.1. Differences in attributes

6.1.1. Differences in the number of providers

Interviewee II assumed there is a limited number of providers in the DI compared to the number of providers in the PI. He explains that if one would like to send a package from the Netherlands to Spain, there is a vast amount of companies that can provide that service, as opposed to the DI, where you may have a small number of providers.

6.1.2. Difference in between packets and packages

Interviewee IX points out that there is a difference in standardization between data packets and physical packages. He explains how physical packages are different in shape and sizes. Interviewee IX recognizes that cargo pallets are an exception, but also states that cargo pallets are different in height and composition, which makes it difficult to stack pallets. “As a result, you need special procedures for each pallet, which is time-consuming and stops good cargo combinations from happening.” Interviewee IX explains how the standards in container sizes are a better example as they are almost always 20’ or 40’ containers, and the protocols for handling them are all the same. **Interviewee XI** also recognizes the heterogeneity in physical goods, as there are many different types of shipments like bulk shipments or the shipment of livestock. The interviewee mentioned

he researched the potential of the PI for transporting high-value goods such as gold or diamonds. He concluded that the PI was not suitable for this kind of transport as it requires a non-standard approach.

Interviewee XIII also recognizes the difference in cargo shapes and sizes. He explains that the analogy between DI becomes dysfunctional at this point. The interviewee emphasizes that not everything is a consumer good and the vast majority of tonnage that is shipped not similar to consumer goods, but objects or bulk in different shapes and sizes, such as cars or steel rolls. He emphasizes that these items will never go in a standardized box, but need to be transported in an alternative matter.

Interviewee II states that there are not only physical differences but also differences in shipping requirements. He explains that different physical packages may have different shipping requirements in terms of costs, time, and emission. He envisions that in the PI, based on these requirements, the best route is chosen. Which he presumes is different in the DI. Additionally, **Interviewee I** points out that there is a difference between the DI and the PI when it comes to the applicability of protocols, due to the high number of exceptions in logistics, he thinks it is going to be hard to copy protocols. **Interviewee XII** also points out that there is heterogeneity among containers in terms of their specific requirements as some containers are handled with more priority than others. Another difference interviewee XII describes is that the value of a package in the PI is purely economic and easy to monetize, whereas the packets in the DI have a different kind of value.

6.2. Relational differences

6.2.1. Differences in evolution

Interviewee XV talked about the evolution of the Internet from his memories. He mentioned the starting point for the evolution was different for the DI compared to the PI. He mentioned that the DI was completely driven by an academic setting, which made it a 'nerdy' environment. The academic world was trying to connect and exchange information. He motioned the Internet started out with a UNIX environment, which was a small tool where you could do a little bit of everything and send it to a big group of people. He emphasized that this implies there was no commercial interest behind the evolution of the Internet, or at least not in the beginning. He made an analogy to bitcoin as a technical solution that was available, but nobody had an idea of how to do business with it. In the early 90', he said, "one could write messages and communicate, but only in text, and gradually more things were added, and commercial interest was developed later. In the PI, it is different as logistics business models already exist". Interviewee XV sees this as a fundamental difference. **Interviewee I** mentioned there is a difference in the history of the DI and the PI, which is why the DI has a more collaborative character. He also mentioned the DI started with universities that connected and provided access to their students. He said the purpose of the DI was to share information and collaborate, and when the Internet started, it was not driven by commercialization like it is today. So when the Internet, and especially the first protocols and the first infrastructure was there, they really wanted to collaborate. Additionally, he said, the aim was to make a global network, but no one had the money to invest in building their own network form the US to Europe, so they started to look for partners. "After that, people started to found their own companies and they were operating exchange points and earn money by routing traffic". Whereas in logistics, he mentioned, people have their own assets, and from that point, we need to get to PI. **Interviewee III** mentioned that due to the way in which DI emerged, it has an open governance structure, which is different from the starting point of the PI.

Interviewee V also acknowledged the DI and the PI come from different points but highlights a different perspective. He stated that in the beginning, there were already major telecom players in each country, which were sometimes also monopolies, and they have been involved as players to be part of the Internet quite naturally. He points out that in logistics, this is the complete opposite as the logistics market is highly fragmented and so the PI starts with a ton of players.

6.2.2. Differences in speed

Interviewee XI states the DI and the PI are different in terms of transmission speed. 'In DI transmissions go with the speed of light, or at least quasi- the speed of light, so it is instantaneous.' **Interviewee VII** also mentioned that in the DI information moves with a very high speed compared to the PI, and information about the object in the PI moves much faster than the objects themselves. **Interviewee IX** states there is a difference in transit time. According to interviewee IX, transit times do not matter in the digital world because data travel almost with the speed of light. As an example, he explains how you can have a few seconds delay in a video stream, but that this is a different time scale than a transit time of six weeks between China en Europe. According to the interviewee, this implies that transit times are a part of the architecture of the system in PI. He sees this as a complete departure from the analogy and explains this with the following example: 'Take an e-mail from which the packets travel through the Internet via different channels. A packet may be sent via Eindhoven and another via Germany and then to here. The packets will get together in a matter of seconds. This does not matter. Now imagine you are sending an assembly kit to make a vessel at a shipyard, and this is divided into six containers. This shipyard will not be able to start the construction if they miss a critical piece, so they may have to wait until the sixth container arrives." Interviewee IX states this is a huge difference between DI and PI as it highly affects the scheduling and proper management of goods, and as long as there is transit time, you have to manage the PI differently from DI. **Interviewee X** also mentioned the difference in transit times from the perspective of a broken link in the network. He explains if packets have to be rerouted due to a broken link the user may not even realize this, whereas in the PI lead times my be delayed dramatically. **Interviewee I** shares his idea. **Interviewee XIV** also recognizes the difference in magnitude regarding time; however, he emphasizes that in the DI transportation is not instant and that there is still a transfer time, but instead of two days, it may be two milliseconds. With these two milliseconds, there may be a chance of incidents that affects transport capacity, just like in the physical world.

6.2.3. Differences in the need for modes

Interviewee IV explains that the PI uses different transport modalities, and as a result, not every hub is compatible to handle any kind of traffic. Terminals and logistic hubs must be equipped to handle trains, boats, or trucks wheres this is not the case in the DI. **Interviewee IX** describes a similar difference. He explains that you can not route packets the same way as we route containers because, in the DI, there are no modes like trucks of trains. "You can send a digital signal anytime you want depending on the bandwidth, of course, but the bandwidth is continuous. So a piece of data can leave my computer at any time I want. In the physical world, you are not able to ship goods continuously," he explains.

6.2.4. Differences in splitting and combining shipments

Two interviewees described a difference in how and why bundles of cargo can be made in the physical world as opposed to the digital world. According to **Interviewee VI**, the aim of combining shipments is to better utilize the occupancy of containers and vehicles. The interviewee says he is aware that data in the DI can be split up and describes that eventually, data gets reassembled. He emphasizes that in the DI, the splitting of data works and that the users trust the system. The also interviewee says that in the PI, there is certain modularity to be found where you can combine smaller shipments to bigger shipments, which enables better utilization of logistics capacities. He describes how different shipments from different shippers can be combined for transshipment and acknowledges he is not aware of how this works in the DI. The interviewee does not see a strong necessity of splitting shipments in the PI. He believes bundling shipments in the PI has more value than splitting shipments and, therefore, is unable to see an analogy when it comes to splitting and combining shipments. "I do not see the necessity to split up cargo because if you make a good combination of shipments at the beginning of the chain, I do not know if it is necessary to split it again; also, there is a risk that you may never consolidate the pieces at the end" **Interviewee XIV** shares this opinion as he recognizes that one of the PI characteristics is the use of standardized modules that can be

joined together and build up a larger module. According to Interviewee XIV, this is not done in the DI, as one large piece of data may be split up into smaller pieces, but they are not joined together for transport.

6.2.5. Differences in costs

Interviewee V describes the difference in marginal transportation costs. He states that in the DI, the marginal costs are close to zero and explains that is all the equipment and infrastructure financed as an investment, after which the cost of sending a packet is close to zero. In the PI, he describes, there are always going to be marginal costs such as loading costs and fuel costs. **Interviewee X** also describes the low costs of transferring digital information as this is, according to the interviewee, close to the energy costs for sending the data. He describes that the revenues from the DI are not coming from operating a single byte of digital information, and the costs for users are usually based on a flat rate of a certain bandwidth. In logistics, the revenue comes from operating single cargo pieces, and the costs for the user involve shipments costs and handling costs. **Interviewee XI** makes a similar distinction by stating that a physical movement will always have a price, and an e-mail does not cost anything to send.

Interviewee I makes a difference in investment costs. He explains how in the DI, infrastructure investments are expensive and are usually financed by a company. For example, if a new deep-sea cable must be built from the Netherlands to the US, there are high investment costs, but afterward, sending packets over that line has minimal costs, he explains. In logistics, it is the other way around, he describes, as companies use an excising infrastructure and when they are planning a new logistics network, they usually build new hubs, but not new links.

Interviewee IX mentions another type of difference regarding costs between the DI and the PI, as he points out that lost packets on the DI do not cost anything to duplicate, whereas lost packages in the PI will cost a lot of money to duplicate. Interviewee IX also makes a footnote to this command by stating there may be exceptions to this rule when margins are exceptionally high. As an example, he draws a comparison to the pharmaceutical industry, as the margins are very high in that industry, and 'duplicating' cargo will be relatively inexpensive.

6.2.6. Differences in replication possibilities

The difference which is most frequently mentioned by the interviewees is that DI offers the possibility to duplicate and replicate packets in a very limited amount of time and costs compared to the PI. **Interviewee II** states the fastest route in the DI is found by sending duplicates of packets through different routes and measure which one arrives first. He explains this is impossible and undesirable in the PI. **Interviewee XV** made a similar argument and stated: "If you have an e-mail, there are more or less clones of the e-mail that are sent through different streams or paths of the DI and the first one wins, more or less." He describes this is a big difference compared to the PI as it would be undesirable to send multiple products, where the first one that arrives 'wins.' Interviewee XV explains an exception to this regarding Just In Time (JIT) delivery wherein rare occasions multiple products are sent by different routes, and the first one that arrives is used.

Interviewee I also describes that replication is not desirable in the PI, whereas it is very easily done in the DI in case of a broken link or if a host is not available. According to Interviewee I this is one of the reasons why you cannot copy protocols one-on-one from the DI to the PI. **Interviewee XIV** describes how data can get lost on purpose when there is congestion in the DI network. Sequentially, the same data can be replicated and send via different hubs, which is different from the PI. **Interviewee XI** states a container is unique, and you can not replicate it. As an example, he illustrates a container with 100 kilos of tuna, which is impossible to replicate. **Interviewee X** also points out this difference and states that it is difficult and costly to replicate physical goods, which is why they are often insured. **Interviewee III**, **Interviewee V**, **Interviewee II**, and **Interviewee XV** likewise state that packets can easily be replicated in the DI opposed to packages the PI.

Interviewee IV argues how we may be able to learn something from the analogy between the PI and the DI; however, he explains it is better not to copy the DI for the PI. As an example, the interviewee mentioned how packets could sometimes bounce back and forth between servers and explains how this is not a favorable situation for the PI from a sustainability perspective.

Interviewee IX describes how losing a container in the logistics world can be an 'administrative nightmare,' especially when, in the case of international shipping, as customs are involved. "Losing a packet on the Internet is very normal, as it can replicate it very easily," he describes.

6.2.7. Difference in planning and decision making

Many interviewees explained that they see a difference in the organization regarding how packets or packages move through the network. **Interviewee I** explains how in order for the PI to work, you need a type of pre-planning before you send shipments into the network. He explains how one should communicate to hubs in the network that a shipment is coming because one needs space and infrastructure to store the physical goods. "In that sense, it is much easier to receive a lot of digital information than to receive several containers". **Interviewee XIV** has a similar argument in which he emphasizes that the sooner you know what shipments are sent, the better the chances are to efficiently bundle shipments to move over the network. He argues that pre-planning is required as opposed to the DI. **Interviewee III** emphasizes the need for planning to use the PI. According to him, there must be a party that checks if there is enough capacity in the network. **Interviewee V** says in the DI, the state of the network is known almost at the same speed as you carry the load. He states that in the DI, you can send a packet without knowing if there is a route to the destination. "In the PI, you must know if there is capacity available before you reach a hub, as it is undesirable to send the goods back or wait for free capacity".

In this chapter, we learned about the various differences between the DI and the PI, according to experts. The difference that is most frequently mentioned is the replication of packets, which is done in the DI but impossible or unfeasible in the PI. Other differences that were frequently mentioned are the differences in the cost structures and the differences in transmission speed. In addition, three interviewees talked about the different evolution of the networks, which, according to them, accounts for the collaborative nature of the DI as opposed to the PI.

7

Perception of Digital Internet

We aim to find out how what perception PI experts have of the DI and if these perceptions differ from the actual workings of the DI. Using these results, we will answer the question: *How is the DI perceived by the PI experts?* in the discussion.

During the interviews, the interviewees explained what differences and similarities they think are in the analogy between the DI and the PI. During the interview, the interviewees were stimulated to elaborate on the workings of specific technologies of the analogy they have mentioned. As a result, the interviewee either elaborated on the technology on their own initiative, the interviewee elaborated on the analogy after being asked to elaborate, or the interviewee was asked to elaborate but was not able to.

In Section 7.2, we present the different assumptions people made about the DI. These assumptions are validated. In Section 7.3, we present an overview of the questions the interviewees were not able to answer or were unsure to answer. We will now first introduce the different layers of the DI, which we use in our validation.

7.1. The different layers of the DI

In this Section, we will briefly introduce the OSI and the TCP/IP model, as we use the vocabulary of these frameworks in our validations sections.

The Open System Interconnection reference model (OSI) was created by the international standards organization in 1984 to provide a common basis for the coordination of standards developments (ISO/IEC, 1994). It aims is to enhance the interoperability of communication systems with standard protocols. The OSI framework allows us to break down different components of network communication systems. The model creates a common language and enhances a common understand of the workings of the Internet network. The model consists of seven layers, and each layer serves a higher layer and is served by a lower layer. As a result, the highest layer in the framework is offered the set of services needed to run applications (Zimmerman, 1980). One of these applications is e-mail, which is used as a frequent example by many of our interviewees. The seven layers are described in appendix C.

The TCP/IP model is another approach for dealing with digital network interconnection. This framework consists of two protocols. Firstly, the Transmission Control Protocol that allows devices to communicate, secondly, the IP protocol that controls the routing of information between devices. The TCP/IP model originally had two layers, a transport layer and a network layer. Later the application layer and the network access layer were added (Dostálek, Kabelová, Shirodkar, & Parekh, 2006). The core of this model remains the network layer, which deals with the details of the routing of data through networks. In this way, the network layer is very similar to the network layer of the OSI framework. The TCP/IP framework is, in many ways, similar to the OSI framework. Firstly the network and the transport layers are similar layers with somewhat similar functions. Secondly, the functionalities of the network access layer can be recognized in the link layer of the OSI framework. Lastly, the application layer encompasses functionalities from the application layer, presentation layer, and session layer in the OSI framework.

7.2. DI perception

Appendix B presents an overview of the assumptions the interviewees made about the DI when they talked about either a similarity or a difference in the analogy between the DI and the PI. We will now discuss these assumptions and validate them.

7.2.1. Assumptions about splitting and bundling packets

More than half of our interviewees mentioned how in the DI data can be split into packets. These interviewees recognize that splitting physical shipments is a characteristic of the PI; still, not all interviewees agree on its effectiveness. The following assumptions were made on splitting data into packages.

- "If you look at a general level, you can really think about the analogy. Take the example if you send something on the Internet. We split the load in small packets. We do exactly the same thing in the logistics to better utilize capacity." (**Interviewee V**)
- "The Internet protocol, in particular, introduced the concept of data packets so whatever the information is, it may be voice communication, pictures or detailed e-mails, they get broken up into single data packs are routed in different ways over the Internet via the path of least resistance and then get assembled at the other side." (**Interviewee XI**)
- "When you send an e-mail it is split into packets, these packets enter the cable in a random order also different packets can be bundled on the Internet, this is what they call multiplexing." (**Interviewee III**)
- "So if you have small packets, you sent them, and if they are going via this long-distance lines, they are put together. But that is just copying data and not really manipulating." (**Interviewee I**)
- "Well, the basic idea of the PI container is that you can have different modules that can be joined together to build one larger model, all standardized. This is not done in the DI. One large chunk of data may be split up, but these packages are not joined together. So here the PI goes further". (**Interviewee XIV**)
- "An e-mail is first broken down into these different frames, and they can move via different routes through the Internet individually" (**Interviewee X**)

The first two quotations are solely about splitting data into smaller packets, while the other three quotations also involve bundling. Firstly, we need to make the distinction between layers in TCP/IP, because an e-mail belongs to a different layer than a data packet. As discusses in the previous section, TCP/IP is a set of communication protocols that are used on the Internet that specifies how data is packed and transmitted. There are four layers in TCP/IP, which are the link layer, the Internet layer, the transport layer, and the application layer. An e-mail belongs to a different layer than a data packet. We will elaborate on the e-mail example of **Interviewwee III**. When an e-mail is sent, the mail server of the sender aims to find out what the appropriate outbound relay is for the destination. The outbound relay receives the e-mails from the main server and destines that to the appropriate outside mail address. Now a connection to that client opens. After that, the mails server is checked, and a connection to the host is made, where a protocol such an SMTP is used. Over that protocol, the e-mail is then delivered. In the background of this process, data packets are routed from the workstation of the sender to a router, which sends the packets over the Internet. The mail exchanger record indicates to what specific IP address an e-mails needs to be sent and get the IP address of that server. Then the routers on the path determine the path the data travels by, and again there is an SMTP by which the e-mail is sent.

As becomes clear by this example, multiple processes occur on multiple layers. On the transport layer, where the packets belong, the packets are indeed split up and individually routed over the network. However, if we look at the application layer that is sitting on top of the transport layer, we

do not see the e-mail was split up, and the e-mail is still one unit. Meaning, our interviewees are mostly right when they state e-mails are split up into packets. However, we have to keep in mind the different layers of the Internet in which, at that application layer, the e-mail is still one unit. Knowing this, we can confirm that **Interviewees I, III, XI, and XIV** have a perception of the Internet that corresponds to the reality when it comes to splitting packages. **Interviewee X** describes a similar process but uses the word frame instead of a packet. A frame is also a unit of transmission, but it belongs to a different layer. A frame exists in the link layer and is build up out of a link-layer header followed by a packet (IETF, 1989).

Interviewee V explains that in the DI packets are split up just like in the PI to utilize capacity. He is indeed right that data is split into packets, and in the DI, this is also done to utilize capacity. We, however, must be aware that different packets have different functionalities, as there are packets that facilitate connections, and there are packets that carry information the sender wants the receiver to have. To begin with, packets are split because of TCP/IP. TCP/IP enables a tree way handshake process, which is used to make a connection between a server and a client. In this process, both the sender (server) and the receiver (client) need to exchange acknowledgment packets to establish the connection. This means the server receives a packet from the client, and the client receives a packet from the server and again sends a packet to the server. Once the connection is established, the communication process starts. And other packets are exchanged.

The reason why packets are switched in the DI is similar to the reason interviewees have mentions cargo must be split in the PI. Both in the DI and the PI packets are split to comply with a certain capacity. The main difference is that in the PI, there are standardized sizes of packages. In the DI, likewise, there are standardized sizes of packets, but there the size of the packet may also be adapted to a capacity of an MTU. An MTU is a maximum transmission unit; this is the size of the largest data unit that can be sent off in a single data transmission. The largest size of the MTU is 1500-byte, with an exception to high-performance networks that may have up to 9000b-byte MTU. What may happen is that a protocol from a higher level sends packets that are of a larger size than the 1500-byte. In order to comply with this capacity, the packet must be split into a smaller size. For the efficiency of the network, it is beneficial to create packets that are as large as possible because every packet has a certain overhead such a the header of a packet. This implies one can transport less small packets than large packets when one aims to utilize the bandwidth of a link efficiently. Still, packets are split up in the physical layer to comply with the MTU. Here again, we have to make a distinction between different layers, as an MTU is a maximum transmission unit of a link, but there is also a maximum segment size (MSS) that specifies the largest amount of data communications a device can receive in a single TCP segment. The MSS is part of the three-way handshake in TCP/IP, where it is announced what the MSS is. With this, we can confirm that the perception of **Interviewee V** on the motivation of splitting packets corresponds to our validation.

Interviewees I, III, and XIV have a different perception when it comes to the bundling of data and packages. The ground truth to this, again, depends on what layer we use. **Interviewees XIV** is right in the sense that packets are not bundles, they are only split. The multiplexing mentioned by **Interviewees III** indeed refers to a form of bundling, but it does not bundle packets per se. There are two types of bundling in the DI: packet switching and multiplexing systems. Packet switching is a process in which data is divided into packets, and each packet is individually routed along a pathway to the receiver. The majority of network pathways are only able to facilitate one signal at a time, which is why packets are sent in series. The difference with multiplexing is that multiplexing supports multiple signals and, therefore, provides a simultaneous transmission. Multiplexing can indeed be seen as a form of bundling. However, it happens on the physical layer. As the physical layer is about sending signals and not data packets **Interviewee I** and **Interviewee III** made an incorrect assumption and **Interviewee XIV** made the right assumption.

7.2.2. Assumptions about the replication and duplication of packets

In the previous section, we explained how an e-mail in the application layer could be multiple packets in the transport layer. In this section, we elaborate on why packets are replicated.

- "On the Internet, a message is duplicated and send via different channels to the receiver. It is undesirable in the PI to duplicate containers and see which route is the quickest like on the Internet." (**Interviewee II**)
- "In the DI data packets sometimes get lost, then all you need to do is to send a message that the packets need to be reproduced" (**Interviewee XI**)
- "In the DI, it is possible to duplicate the messages and duplicate the data and send it several ways. And the best one will fight through the Internet and reach the target, and if another one also reaches the target it will just be thrown away, and you cannot do this with physical stuff" (**Interviewee XIV**)
- "I know how this is organized in DI. That is where it ends with the analogy. I would say because we know that in the DI, things are sent a couple of times. And if you have an e-mail, there are more or less clones of the e-mail that are sent through different streams, paths in the digital Internet. And the first one wins more or less." (**Interviewee XIV**)
- "An e-mail is first broken down into these different frames, and they can move via different routes through the Internet individually. However, in the Digital Internet for each standard unit of cargo, there is a value, so if you lose that one, there is a loss." (**Interviewee X**)

Interviewee XIV, **Interviewee II**, and **Interviewee XIV** made the assumption that information is duplicated and sent through different routes to the receiver. Although in the DI packets can indeed be replicated it this does not happen to find the quickest route. The exception to the rule is multiplex TCP , which is a relatively new technology. In multiplex TCP, a device with multiple network connections, for example, a 4G and a wifi connection, can utilize both connections simultaneously. As the three interviewees talk about the Internet in general and not about this specific application of multiplex TCP, we can neither confirm nor deny that their perception is in line with reality. When it comes to replication, the assumption of **Interviewee XI** and **Interviewee XI** is in line with the actual workings of the Internet. In our previous section, we elaborated on the MTU. When the size of a packet exceeds the size allowed by the MTU, the packed in destroyed and will be replicated by the sender.

7.2.3. Assumptions on routing

We have covered some routing assumptions already in the previous section, and we will now continue with three assumptions on the process of finding new routes.

- "When a link is broken, data can find a different route through the DI network. This may be interesting for goods in the PI as well, as they find their own way through the network by their own intelligence." (**Interviewee VI**)
- "Messages are sent via a standard TCP/IP protocol, and then they are automatically routed with the use of algorithms." (**Interviewee VII**)
- "A router can be looked at as a two-sided input-output mechanism on one side come the inbound messages and they queue up. And depending on where they're going, they are switched to outgoing channels that will queue up the packets again and then send them out in a regular sequence based on how the router is setup. So this is very much like a cross-dock operation in logistics" (**Interviewee XIII**)

Interviewee VI makes the assumption that data follows an alternative route through the network when a link is broken and states it may be interesting for the PI to also have goods with an intelligence. The perception this interviewer has is partially in line with reality. The assumption that data

follows an alternative route through the network in case of obstruction is true. However, units of data on the Internet like bytes, frames, or packets are not intelligent. The assumption of **Interviewee VII** that routing algorithms are used to route messages is true. As mentioned before, IP routing is a routing algorithm that is used for the transfer of data. The algorithm uses a routing table, and by means of this routing table, selects the next router the data is supposed to go to. **Interviewee XIII** gives an explanation of the the workings of a router that is in line with reality.

7.2.4. Assumption on standardization

The following three assumptions are about the standard format of packets in the DI.

- "The reason why the Internet works so well is because packets are standardized and so when you can handle a packet, you can fundamentally be a node." (**Interviewee XI**)
- "The PI uses standardized packets just like the DI, this is why all routes are accessible for all packets" (**Interviewee XII**)
- "In the IP protocol, you have these standardized packets. And the first part of the container, which is the address label is standardized, and everyone is going to understand what is written there, and you have things like the source address and the destination address, but you also have information like time-to-live, and you have information on the size of the container. And when one sends the data package, and it has this 'address sticker' at the beginning of the message, which is understood by everyone, it is very easy to forward." (**Interviewee XII**)

Interviewee XI states that due to standardization, you can be a node if you are able to handle a standard packet and (**Interviewee XII**) states that due to standardization all routes are accessible for all packets. The word packet is often used in different layers of the OSI model, but strictly spoken, a packet only exists in layer 3, a frame exists in layer 2, and a datagram exists in layer 4. The components of a packet depend on the used communication protocol, as different protocols use different elements. Because the elements in a packet depend on a protocol, the format of a data packet is per definition standardized as a protocol in itself is a standardization. When it comes to routers, it is indeed true that when a router complies with the standards, it can be part of the Internet and function as a node. **Interviewee XII** explains how a data packet has an address and other elements, like time-to-live (TTL) and packet size. An IP packet consists of a header section and a data section. Interviewee XII rightfully states that the header information of a packet is understood by everyone.

7.2.5. Other assumptions

- "I assume that in the DI parties put their competitive differences aside and develop standards just like the TCP/IP protocol (**Interviewee VI**)
- "The DI works in a similar matter as the PI, as an American server is unable to reject all Internet traffic from China. According to my knowledge, this is all very anonymous" (**Interviewee XII**)
- "If you send a package from here to Spain, there may be more than a 1000 service providers that can do that for you, I do not think that is the case in the DI." (**Interviewee XII**)
- "There is a phenomenon in logistics that may come awfully close to the DI, it is called switching and in implies that containers with the same goods switch to a different receiver during their travel. (**Interviewee XII**)

Interviewee VI talks about how parties put their competitive barriers aside to collaborate and develop standards. Nowadays, Internet standards are created and published by the Internet Engineering Task Force (IETF), and the most fundamental of the Internet Standards are the ones defining the Internet Protocol. The IETF is an open community of network designers and operators and others who are concerned with the development of the Internet. (**Interviewee VI**) is right by saying the standards are developed in collaboration between competitors. **Interviewee XII** has a perception

that is different from reality. A server is able to block certain traffic and also traffic from specific countries. **Interviewee XII** assumes that there is a limited amount of Internet Service Providers (ISP) compared to Logistics Service Providers (LSP). Like in logistics, there is a lot of diversity in the services a service provider can supply. Some may supply Internet assess, while others, for example are mailbox providers. Also, there are different levels of ISPs. About a dozen ISPs belong to the biggest ISPs and are operating as Tier 1 ISPs. Other ISPs operate on Tier 2 or Tier 3 level. When we look at the specific example of **Interviewee XII**, we can confirm his perception is true, as there are about 50 service providers available in Spain (ISP Today, n.d.). When it comes to the assumption of **Interviewee XII** about packets that switch to different final destinations during their travel, we are not familiar with such cases in the DI.

7.3. The knowledge level

In the previous section, we validated the comments our interviewees made about the working of the DI. We do this to find out if there are (common) misconceptions about the DI and get a better insight into how well our interviewees understand the source case in the PI analogy. During the interviews, the interviewees made assumptions about the PI, and in some instances, they acknowledged that they could not elaborate on certain technologies on the Internet. In this section, we give an overview of our findings related to this topic.

During the interviews, the interviewees were asked to elaborate on the technologies they mentioned when talking about a similarity or a difference in the analogy. **Interviewee II**, **Interviewee VII**, **Interviewee VI**, and **Interviewee XII** mentioned from the beginning of the interview that they are not familiar in the Internet domain. When (**Interviewee VIII**) was asked about his level of expertise about the DI, he said: “I think that I could never work as a Digital Internet engineer or something like this. But I think I know enough. I have talked with several people, and my knowledge on the level at which I play is sufficient for me.”

When being asked about routing protocols in the DI **Interviewee XV** acknowledged that he is not a specialist in the routing domain and does not know the exact workings; still, he was able to answer the question in which he focused on the differences between routing in DI and routing in PI. The interviewee also talks about code sharing in the airline industry as an example of collaboration but was unable to elaborate on similar construction in the DI.

Interviewee VII mentioned he know that the TCP/IP protocol exists but was not able to elaborate on what it does. **Interviewee VI** motioned the splitting of cargo as a similarity to the splitting of packets in the DI but was unable to explain why or how this was done.

Interviewee VII talks about flexibility and alternative routing as a similarity between the PI and the DI, but was unable to example how this works in the DI. The interviewee also talks about the difference between the PI and the DI, with regards to the compatibility of terminals with different modes of transport. When being asked if the Internet is modality free, he assumes that was the case, but acknowledges he does not know the answer as he is not an Internet specialist. **Interviewee XIV)** was also asked about routing and gave a similar response. The interviewee draws a similarity between the PI and the DI, and in his explanation, he mentioned how in the PI shipments might have different shipping criteria that have an influence on what the route the shipment will take. When being asked if these sorts of criteria can also be found in the DI, the interviewee acknowledged he was unable to answer that question due to his lack of expertise on routing in the DI.

In this chapter, we found out that there is a lot of diversity among interviewees when it comes to there perception of the DI. Some interviewees like (**Interviewee XIII**) gave an accurate explanation of the working of the DI, while others like (**Interviewee II, VI, VII, XIV, XV, and XII**) had more difficulties in providing an explanation on certain technologies. Other interviewees were able to explain DI technologies but on a very aggregated level. When it comes to common perceptions that may deviate from the truth, we noticed that four of our interviewees assume in the packets are split, after which

multiple packets follow different routes to find out which route is the quickest. Additionally, four of our interviewees assume that packets are being bundled or clustered together for transportation.

8

Different Interpretations of the Physical Internet

During our interviews, it became apparent that different interviewees have different interpretations of what the PI entails. The interviewees were asked to define what, according to them, the PI entails. This chapter presents an overview of these different interpretations.

Table 8.1: The interpretation of the PI

PI elements	Mentioned by interviewee
Modularization	IX, XI,
Openness	XI
Automation	III, VI, VII, X, XI
Decentralization	XI
Sharing assets	IV, VI, VII, XI, XII
Connected networks	I, IV
Standardized transportation units	XI, XII

Interviewee XI describes the PI to have four elements. The first element he describes as the *modularization* component. He describes modularization as the possibility to put containers together in an efficient matter. "This modularization requires standardization, but also digitization or computerization of the container itself," the interviewee describes. Additionally, the interviewee mentions that containers should be connected by the Internet of things. **Interviewee IX** also sees how modularization can be a part of the PI. However, he describes this as interlocking different shipments together in a chain as opposed to placing smaller sized containers in larger sized containers. **Interviewee III** also mentioned that modularization and standardization of packages are a part of the PI.

Another element **Interviewee XI** describes is openness, by this, the interviewee implies that the PI should be accessible for everyone who wants to use it. He describes that customers and shippers should be able to easily get a market entry point and that service providers, transport hubs, and container owners should be able to join the PI easily. Additionally, he argues how transportation standards should be public, and every actor should be able to adopt these standards. **Interviewee IV** also mentioned openness, and when asked to define the PI he responded: "The PI is a fully open and connected logistics network where concepts of the sharing economy are fundamental."

Interviewee XI also describes automation as an important element of PI. According to the interviewee, this implies that one can push a button, and a transportation unit arrives at the receiver without any human intervention. **Interviewee XV** describes the PI as a system where one does not have to organize the distribution of goods and information. Instead, he describes that everything in the network is optimized in an automatized matter. **Interviewee X** describes how the PI is like a large autonomous logistics network, which gives the most and the highest level convenience to the actors who are using it. He describes how the network is running on an algorithm and is able to

realize the best flexibility and costs for its users. **Interviewee II** also describes automation elements and describes the PI as a logistics system where a sender of a package decides the sending and the receiving address. The interviewee further describes that the package itself will communicate with transport modes and stakeholders to find the most efficient and effective route. **Interviewee III** describes how work done by humans in logistics will eventually be eliminated as a result of automation in the PI. **Interviewee VI** also emphasizes on automation and additionally defines the PI as an Internet for physical goods, which holds elements of integration, automation, sharing, and optimization of networks.

The fourth element **Interviewee XI** describes is decentralization. By this, he means the PI should be agent-based, and as a result, the coordination of PI will be an emerging behavior of local areas op optimization and coordination.

Interviewee IX describes the PI is a concept of logistics and specifically freight logistics, which implies that organizations do not have private supply chains or logistical arrangements. Instead, the interviewee describes how the PI proposes an asset sharing architecture where goods of different types of companies are pulled together in order to minimize losses in the infrastructure. **Interviewee XII** understands the PI aims to create shared infrastructure and storage capacity, which results in transportation units that can freely move across different paths. He also emphasized that the latter is also the aim of synchromodality. Additionally, the interviewee mentions the PI aims for standardized transportation units. **Interviewee VII** defines the PI as a situation in which transshipment is organized according to the same principles as the DI. According to the interviewee, this implies that organizations do use not only their own logistics networks, but also the networks of others. Another element he mentions is that the PI has an algorithm that enables automatic decision making that determines the best route a package can travel by.

When **Interviewee III** defines the PI, he describes that in the PI, users of transport networks are connected with the aim to reach optimal routing for goods. **Interviewee I** sees the PI as an instrument to combine different networks. He emphasizes how the PI is not a unique new network but more like federated networks that are still in control of different companies. “From an outside perspective, you will see something that looks like one network, or at least goods can seamlessly switch between networks,” he describes.

Interviewee XIV explains how he interprets the PI to be a vision that describes that cooperation between participants in logistics is needed. This might be a vertical collaboration, but also horizontal collaboration.

9

Barriers to Transform into the Physical Internet

In our coding process, it became apparent that many interviewees see barriers for logistics to transform into the PI. In this section, we will give an overview of these barriers identified by our interviewees.

Table 9.1: Barriers to move towards the PI

Barriers according to interviewees	Mentioned by interviewee
Horizontal collaboration barrier	III, XI, XIV
Collaboration barrier for creating standardization	I
Collaboration barrier due to a lack of digitization	II
Collaboration barrier for creating transparency	II, XV

Interviewee III stated that in the current logistics paradigm, parties intentionally do not collaborate as they are afraid to lose business. He describes enormous competition combined with overcapacity on the physical side, in terms of transport capacity by modes. He states that as long as the supply is higher than the demand side, there will be a barrier for parties to collaborate. As a solution to this problem, the interviewee describes the need for external drivers that force parties to collaborate, such as a Greendeal. According to the interviewee, LSPs are not willing to collaborate, and competitive companies such as large FMCG companies are also not willing to collaborate with their competitors to optimize their supply chains. He explains how if one looks at the DI, there are many efforts, and there are parties who try to guarantee the openness of the network. The interviewee describes the ongoing battle between carrier haulage and merchant haulage, where shipping lines, carriers, and LSPs all want to sit in the seat of the supply chain orchestrator. The interviewee also reflects on the PI being a network of networks and states that there are networks in logistics that do not have the incentive to collaborate. An example he talks about is DHL, which is, according to the interviewee, a fully closed network, owning their own assets and utilize their capacity to the fullest. According to our interviewee DHL therefore is unlikely to have an incentive to collaborate.

Interviewee XI also expressed collaboration barriers. He gave an example of previous malpractice of a collaborative effort between manufacturers and ISPs. In his example, the companies did a full collaboration analysis and made a joint bid for their business at different LSPs. One LSP won the bid, after which one of the manufacturers stepped out of the collaboration and asked the LSP they were currently working with to match the price. As a result, they fundamentally crushed the prices of the LSP, who decided to match the offer. The interviewee describes how he finds this behavior unethical and describes how this kind of malpractices withhold LSPs to collaborate, as they are afraid they lower the prices in a business where the margins are already very low. The interviewee explains how there is an enormous amount of resistance from LSPs to engage in the PI. In his conclusion of the interview the interviewee remarks that there might not be a need for actors to collaborate in the PI. As an example, he illiterates shipping lines put the containers from different companies together on

a ship and ship them to the other side of the world without having to talk to the companies. He emphasizes that transforming to the PI is a matter of a new go-to-market business model of the LSP and that this does not necessarily require collaboration.

Collaboration is also mentioned by **Interviewee XIV**; he states the PI is giving us a direction of what the current logistics needs to involve into. "The PI is showing us the direction, and the direction is the cooperation between partners and participants. This might be a vertical collaboration, or it might be a horizontal collaboration." **Interviewee XV** also mentions that collaboration efforts are necessary in the PI and states the without collaboration, it will be difficult to reach other aspects of the PI. Still, the interviewee said he is confident collaboration is possible. The interviewee also mentioned that a lot of technology is already available for moving towards the PI. However, companies have trouble changing their business models.

Interviewee X talks about how carriers are hesitant to share warehouses with each other, as they are afraid that the competitor can find out competitive information in terms of the amount of volume they forward. **Interviewee VII** also states how the usage of each other's networks is a good theoretical concept, but in reality, it remains very challenging. He thinks logistics actors are afraid that they are going to lose control of their supply chain if they become dependent on each other.

Interviewee I talks about standardization as one of the strengths of the DI and states he is not sure if logistics companies will ever adopt standardization bodies similar to the IETF and W3C in DI. These bodies are working on standards like, for example, HTML5. According to the interviewee developing a new protocol takes a long time, and it takes a long time to implement a new protocol, but still, it works. He states that it is an example of the DI in which companies are working together who are direct competitors, but it is successful because they are looking at the infrastructure. "They want to have a working infrastructure with all participants in the DI." He explains that this is different from the logistics world where everyone says, "It's my network", "It's my infrastructure," and "These are my assets." The interviewee says there must be something similar in the PI to these standardization bodies. He explains it must be an organization that is not owned, neither dominated, by one company, and it must be a cooperation between competitors. The interviewee asks himself the question of why this cooperation between competitors does not exist, in the same way as in the DI. He reasons that in logistics, parties never needed to collaborate. He mentions the existence of standardization bodies in logistics like DTLF, but states that they are more concerned with how to digitize the freight papers, than how to open up networks of competitors and how to make it free of discrimination and allow seamless access to those networks. The interviewee concludes that there are efforts to connect networks in the industry, but these efforts are mostly concerned with how to increase the connectivity of a specific company. He says he is convinced that big LSPs or Ports are thinking about how to organize their internal networks so that it becomes easier to link with new customers and new suppliers. However, according to the interviewee, these endeavors are self-centered.

Interviewee II says that transparency is one of the barriers to move forward the PI as parties are not aware of free capacities if the logistics network. According to the interviewee, there is little information about demand and capacity in the logistics chain. "This lack of transparency is something that needs to change.", he states. Another barrier is trust; according to the interviewee, actors need to trust that their cargo is handled in the correct matter, which is why there rely on contractual agreements. 'In the future, we have to move away from direct contracts and move to more flexible ways of collaborating. Another barrier that is mentioned by **Interviewee II** is the lack of digitization in the logistics sector. He states that digitization efforts are limited and scattered, making it challenging to adopt new technological solutions. **Interviewee XV** names the transformation of existing business models as a barrier for collaboration. He reasons that currently, LSPs are making money out of the lack of transparency in the market, which is why they are not eager to change their business model.

According to our interviewees, there are certain barriers we need to overcome in order to move towards the PI, the barrier that is most frequently mentioned is the lack of horizontal collaboration between LSPs.

10

Assessing the value of the Physical Internet analogy

As explained, three factors influence the strength of an analogy. These are the number of relevant similarities, discussed in Chapter 5, the number of relevant differences discussed in Chapter 6, and the understanding of the source domain, which is Chapter 7. This chapter will discuss the DI-PI analogy using the results of these chapters and the Analogy Functionality Model. We will first present an overview of opinions on the value of the analogy according to our experts and use this to reflect on our work in the discussion chapter.

10.1. The different opinions of the PI experts

During the interviews, some interviewees shared their opinion on the value of the DI-PI analogy. Various interviewees value the analogy differently, ranging from highly dysfunctional to highly fruitful.

During the interviews, some interviewees explained that we could use the analogy to further develop the PI and acknowledge there are too many differences to copy attributes or relations one on one. **Interviewee XIV** stated that she thinks there is still a lot we can learn for the DI, but copying certain principles would not be beneficial for logistics, such as sending packets back and forth over the same line. **Interviewee XIV** shares this opinion and compares the PI to a lighthouse. He explains, "The PI is like a lighthouse showing us the way, but as soon as you reach the lighthouse, you have a problem because it means that the ship has stranded." He explains how the PI, just like the lighthouse, can give us a direction, but one should not copy the DI due to the differences. He also uses the analogy to make an analogical argument. He argues that when one sends an e-mail, there are many parties involved to get that e-mail from A to B because the sender is most likely not connected to the same ISP as the receiver. He argues that because this technology of sending an e-mail works in the Internet, due to the collaboration of parties, it should also be able to work in the PI.

Interviewee XIII explains how the DI-PI analogy has the potential to change the way we think about transportation systems. He feels like the current thinking paradigms bottlenecked the logistics system, and PI has been able to change people's perspective. "It provides a way for people to see in another spectrum the kinds of transformation that we are aiming towards doing on the supply chain logistics side. It makes people say 'Wait that's been done somewhere else?'" he explains. He assumes that we have only exploited about two or three percent of what we should be exploiting from the DI-PI analogy so far. Lastly, he adds that he does not recommend copying the Internet, but he is interested in seeing if there are issues in the logistics domain that have been solved in the Internet domain. **Interviewee XV** also shares this perspective and adds that there is a lot to learn from the DI in terms of how to share revenues, how to build protocols, and how to manage flows.

Interviewee V explains how according to him, the analogy works well if you look at the structure; however, when you look for a practical solution, the analogy does not work because the characteristics are very different. **Interviewee IX** also explains we should be careful when using analogies. For example, he refers to a city distribution center project. It was tried to design distribution centers in

a similar way as a Port Authority that operates a port. The project failed due to differences between the two cases, he explained. **Interviewee XI** has a less positive opinion and states that for him, the analogy has reached its breaking point, and it could even be dangerous and misleading, as many people do not understand the PI nor the DI. He advises: "Forget about the metaphor. Think about the pragmatics. What do you want to achieve now?" As an example, he explains how neuroscience has computational models that are inspired by biology. And one of the analogies that people frequently use is the analogy of the human mind as a computer. The interviewee explains that neuroscientists think we should drop this analogy as there are too many differences. "Analogies can be useful to start to understand something but later may become a hindrance to understanding a phenomenon," he explains.

10.2. Applying the Analogy Functionality Model

In this section, we will return to our Analogy Functionality Model of Section 3.2. What becomes apparent in our previous section is that different interviewees have different perspectives on where the breaking point of the analogy is. When it comes to the purposes of analogies, the interviewees have described some of the purposes in their interviews.

There is a clear **persuasion purpose** in the DI-PI analogy. One of our interviewees explains how the analogy between the DI and the PI helps people to open up their minds and think about a whole new paradigm of logistics. He explains there are many inefficiencies in our current logistics operations, due to various bottlenecks. According to him, the analogy makes people realize that logistics can be a lot more efficient. He states that the DI has developed to a state that we could not even have dreamed of 30 years ago and. He explains how with the DI-PI analogy, people can see that it is possible to change a paradigm completely. The interviewee clearly refers to the persuasion purpose of analogies. And with regard to this persuasion purpose, we can see the PI has gained popularity in the academic world. The number of publications about the PI has grown over the years, and different events have been organized. The 7th International Physical Internet Conference is organized this year, and many universities and research institutes are involved in the topic. The DI-PI analogy has proved to be effective in persuading academics to further explore the topic.

Although the DI-PI analogy may not be meant for explanatory purposes we can also see an **explanatory purpose** of the DI-PI analogy. One of our interviewees explained that, in his opinion, the PI is a future and advanced state of the logistics network. "We use the DI to explain what this advanced state of logistics looks like," he explains. Two of our interviewees mention they lecture students on a regular basis and that the analogy can help people to understand a different logistics paradigm. Another interviewee explains how one should be careful when lecturing about the PI, as students may not have a proper understanding of the PI.

The **inspirational purpose** is most visible in the DI-PI analogy. Starting with the Economist's cover in 2016 and ranging to the various publications described in our literature research. As described earlier, many foundations of the PI are inspired by the DI, such as the connection and synchronization of networks, developing standards, and creating heterogeneous equipment that is respecting a certain protocol Montreuil (2011). However, it remains difficult to find out which foundations are inspired by DI and which foundations have already been part of the logistics agenda for years. Many of our interviewees described the analogy on an inspirational level. The similarities they describe are often generic and similar to design requirements. When the interviewees talk about the similarities, they elaborate on what the PI should do or be. For example, many interviewees mentioned the PI should be flexible, automated, and easy to use. In their argument, they refer to the DI, which, according to them, complies with these requirements. For example, several interviewees mentioned the PI should have a carefree user experience, just like the DI. Another example that interviewees mentioned is that they aspire to have full automation in the PI just as in the DI. These are examples of the design requirements that are inspired by the source case of the DI.

As discussed in Chapter 3 a **design purpose** goes further than an inspirational purpose. Where an

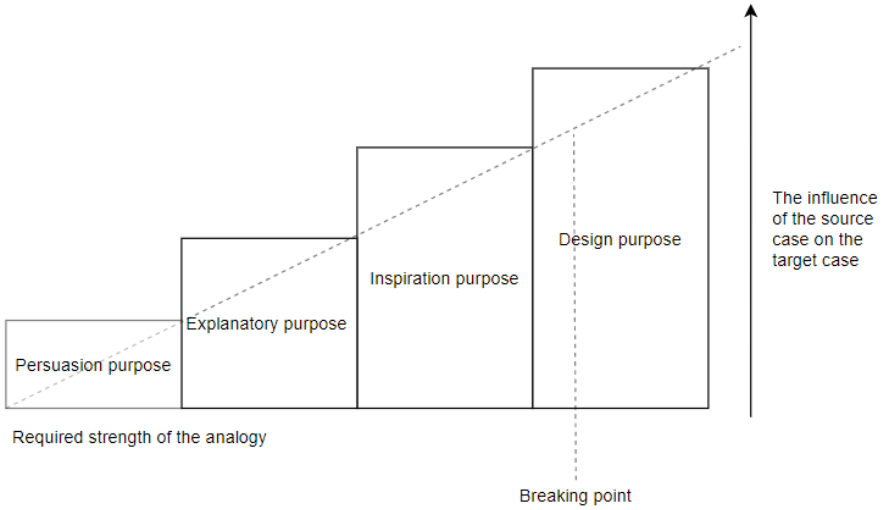

Figure 10.1: The DI-PI Analogy Functionality Model

inspirational purpose allows us to develop design requirements based on the source case, a design purpose copies aspects from the source case to the target case. Some publications demonstrate the design purpose of the analogy. As mentioned in our introduction chapter, Gontara et al. (2018) have developed a Border Gateway Protocol for the PI. To do this, they looked at the DI and recognized that both the DI and the PI have Autonomous Systems (ASes). These ASes are in the DI connected with a BGP protocol. The authors have copied and adapted this protocol to work in the PI. The authors also commented that the collaboration environment in the DI is different from the PI, which will make it challenging to implement the PI BGP. The interviewees did not explicitly mention elements or functionalities that can be copied from the DI to the PI.

As explained, one should be careful when applying analogies due to its limitations. As stated before, an analogy becomes stronger when there is a high number of relevant similarities compared to differences. In our interviews, we have found out there are many differences between the DI and the PI that cannot be overlooked. Our interviewees described close to an equal amount of similarities as differences. As discussed earlier, the relevance of the similarities and the differences is also important, as some may be more pertinent than others. However, the similarities do not outnumber the differences, and the differences given by the interviewees come from various angles and aggregation levels, as can be seen in our model, an analogy that is less strong results in an earlier breaking point of the analogy. Because the DI-PI analogy lacks strength, we argue the analogy is not suitable for design purposes. As became clear in this model, one can use the analogy to persuade, educate, and inspire; however, one should stop when one wants to use the analogy to design.

11

Discussion

11.1. Interpretations

Academics still find it hard to give more context to the analogy between the DI and the PI. And it was unknown to what extent and for which aspects the analogy is useful. This research explores the value of the DI-PI analogy for further developing the PI.

We found out that the strength of an analogy depends on the differences and similarities between the source and the target domain, and the knowledge one has of the source domain. The results of the interviews indicate there are many differences between the DI and the PI. There are differences mentioned concerning attributes and relations between attributes, ranging from technical to institutional differences. The interviewees also mentioned similarities. All similarities were described on an aggregated level. For example, four interviewees mentioned the convenient user experience that is currently offered by the DI and soon offered by the PI. Although the interviewees explain the convenience is a result of automation, they did not elaborate on which processes in the DI are automated, how they are automated, and how that is similar to the PI. The results also indicate that different experts have different levels of understanding regarding the workings of the DI. In many cases, interviewees made assumptions about particular technologies. After validating these assumptions, it became apparent that most interviewees found it was challenging to elaborate on their assumptions, and some assumptions were incorrect. Based on the results regarding the similarities and differences, it becomes apparent that the DI-PI analogy is not a strong analogy, which influences the analogy's value.

In this thesis, an Analogy Functionality Model is presented. In this model, four different purposes of analogies are used: a persuasion purpose, an explanatory purpose, an inspiration purpose, and a design purpose. In PI literature, we found several applications of the inspirational purpose. What became apparent in the interviews is that the DI-PI analogy is that interviewees pointed out to use the analogy to persuade and educate audiences. We argue that the magnitude of the effect a source case has on a target case depends on the purpose of the analogy. Moreover, different purposes require different levels of strength of the analogy. We argue a design purpose requires a strong analogy. Due to the lack of strength of the DI-PI analogy, this thesis concludes there is no value when it comes to a design purpose. By not using the analogy to design, one avoids the risks of transferring elements from the DI to the PI that are not suitable for the PI.

Chapter 3 explains how analogies can cause a false sense of understanding and can even cause misunderstandings. We found out that different PI experts have different interpretations of the PI. The is no proof to state that these differences in interpretations result from the quality of the analogy. However, as is confirmed by literature, analogies can cause misunderstandings about the target domain. This happens when one transfers irrelevant knowledge from the source domain to the target domain. Additionally, a lack of understanding of the source domain can lead to misunderstandings about the target domain. Given that not all PI experts have a good understanding of the DI domain, there may be reasons to believe that this causes the different interpretations of PI we discuss in Chapter 8. Another finding is that interviewees with a good understanding of the DI domain were able to state more differences than similarities between the DI and the PI. This can also be an

indicator that the DI and the PI domain are more different than they are similar.

Our results imply that academics, policymakers, and the industry should refrain from using the DI-PI analogy when further developing the PI and constructing road maps to move towards the PI. Whereas, the PI in itself may be very promising as a future logistics concept, according to this thesis, using the DI to further develop the PI is less promising. Instead, one could direct their efforts to overcome the barriers that are discussed by our interviewees. For the industry, it can be interesting to focus on new business models and collaborative models. Five interviewees mentioned the lack of willingness of logistic service providers to engage in horizontal collaboration. Other barriers that were mentioned are barriers to collaborate to realize the standardization of protocols and transport units. Another barrier discussed is the lack of transparency in the network when it comes to sharing information about underutilized capacity or client information. Our interviewees also briefly mentioned challenges regarding business model innovation, collaboration efforts, legal frameworks, routing optimization, implementing new standards, and digitization in the transport sector. These barriers are familiar in the literature and can all be recognized in the PI-based framework for future research by Treiblmaier et al. (2020). When one wants to overcome these barriers, one should treat the PI as a concept that solely belongs to the SCM domain and not the Internet domain.

11.2. Limitations

The conclusions of this thesis apply to the current state of the PI. The findings indicate there are different interpretations of the PI, and the PI is still in a conceptual phase. It is concluded that one must not copy elements directly from the DI to the PI at this moment in time to develop the PI further. However, when the PI is further developed, our findings do not exclude the possibility that there may be specific problems where the DI-PI analogy can be of value when it comes to digital solutions in the PI.

When interpreting the results, one must be careful not to look at the number of similarities and differences to determine the analogy's strength. We should instead look at the relevance and context of each argument. The similarities and differences that our experts describe are not mutually exclusive. For example, four of our interviewees referred to convenient user experience as a similarity between the PI and the DI; however, this user experience is likely created by automation, which may be enhanced by standardization.

It remains challenging to determine the strength of an analogy. Firstly, the results indicate various differences and similarities. However, we may question the reliability of these results as findings also indicate that many interviewees lack knowledge on the DI, which can make it challenging to make correct comparisons. Secondly, many differences and similarities are mentioned multiple times, but some are only mentioned once. Additionally, some interviewees described a particular element as a similarity, while others described the same element as a difference. This may be account for by the fact that interviewees have different interpretations of the PI. Another reason may be that different experts interpret analogies differently, and the researcher's interest partly determined the differences and similarities he or she came up with. Some interviewees focused on business models, while others focused on information systems or port logistics. Due to all these different lenses and different levels of detail our interviewees provided, it became challenging to find common opinions on differences and similarities. On the contrary, different perspectives may also have offered us a more extensive range of similarities and differences. To gather a more reliable list of similarities and differences, one could validate the list generated in this thesis through a focus group or the Delphi-method. This allows experts to iterate on each-others opinions. One can, however, question the necessity for this as most experts agree on differences, and different opinions can also be a result of the overall understanding and interpretation of the DI and the PI.

Finally, throughout this thesis, the design purpose of analogies is mentioned. It indicates a top-down approach that insinuates the PI can be designed; this in itself is an assumption that can be questioned.

11.3. Reflecting on the research method

Due to the structure of the semi-structured interviews, the interviewees had the freedom to provide the information they wanted to provide. Knowing the background of the interviewee may have caused bias during the research. One of the first PI experts interviewed has a background in computer science. When he was asked to explain a certain DI technology, he provided a very lengthy and accurate answer. Although the answer itself was useful, time was limited. As a result, the interviewees with a computer science background were not asked further elaborate once they described a DI technology in an accurate matter. To find out the full perception experts have in the DI, one would need to interview them for a longer time, as the DI in itself is a broad domain. Our current method, however, sufficed in finding out if interviewees have a basic understanding of the DI.

When validating the DI perceptions, we found it was challenging to determine what elements of the DI the interviewees were describing. The terminology in the DI is specific, and different terms belong to the different layers of the Internet and, therefore, have different applications. As some interviewees were not familiar with the DI vocabulary, it was sometimes difficult to interpret what they meant and how assumptions could be validated.

The freedom in the interview protocol resulted in additional information that interviewees presented by their initiative. As such, barriers to further develop the PI were discussed, although there were no questions in the interview protocol related to this topic. The interviewees often used the freedom they had to elaborate on different topics. While this information can be valuable, we must also be cautious when interpreting results that are not generated by the interview protocol. For example, two out of the fifteen experts said they have trouble explaining the PI to students who do not have a background in DI. This is a valuable finding. It could, however, be that other experts who give lectures do not experience this problem.

12

Conclusion

12.1. Conclusion

This thesis answers the question *"What is the value of the analogy between the DI and the PI, to further develop the PI?"*. The answer to this question is based on the conclusion of the five sub-questions.

1. *What is the value of analogical reasoning for new concepts?*
   Based on our findings, four different purposes of analogies are described: a persuasion purpose, an explanatory purpose, an inspiration purpose, and a design purpose. The findings indicate there are limitations to using analogies, and there are risks for the target case. Firstly, if the wrong information is transferred from the source case to the target case, it could negatively impact the target case. Secondly, analogies can cause misunderstandings about a target case. Thirdly, a designer of a target case can become too fixated on the source case, which is known as design fixation. To determine the strength of an analogy, three criteria are defined. Firstly, more relevant similarities result in a stronger analogy. Secondly, more relevant differences result in a weaker analogy. Thirdly, limited knowledge of the source domain results in a weaker analogy. We conclude by proposing an Analogy Functionality Model, which shows a relation between the required strength of the analogy and the magnitude of the impact on the target case for different analogy purposes. It is concluded that an analogy has value until it reaches a certain breaking point. Where this breaking point is, depends on the strength of the analogy.

2. *What are the similarities between the DI and the PI, according to experts?*
   We learned about the various similarities between the DI and the PI, according to experts. Most interviewees drew similarities between the standardization of transportation units (packets, frames, packages, containers), interfaces, and protocols. Other frequently mentioned similarities relate to the bundling and splitting of transportation units, the high level of automation in a network, and a decentralized organization. Another frequently mentioned similarity is the carefree feeling and security users experience when they use the network. Some interviewees also identified assets sharing, routing flexibility, and the openness of the networks as similarities.

3. *What are the differences between the DI and the PI, according to experts?*
   The most frequently mentioned difference concerns the replication of the packets, which is done in the DI but is impossible or unfeasible in the PI. Other differences that were frequently mentioned are the differences in the cost structures and the differences in transmission speed. Also, three interviewees talked about the differences in the evolution of the networks, which according to them, account for the collaborative nature of the DI as opposed to the PI. Differences in planning and decision making were also mentioned, as were differences in the splitting and bundling of shipments in the PI and data packets in the DI.

4. *How is the DI perceived by the PI experts?*
   We validated various assumptions PI experts made on the workings of the DI. In our validations, we found out that some interviewees had a perception of the DI that deviated from reality. Few interviewees gave an accurate explanation of the working of the DI, while others experienced difficulties when explaining certain technologies. Most interviewees were able to explain DI

technologies on a very aggregated level. When it comes to common perceptions that may deviate from the truth, we noticed that four of the interviewees assume that packets are split, after which multiple packets follow different routes to find out which route is the fastest to the destination. Additionally, four of the interviewees assume that packets are being bundled or clustered together for transportation.

5. *Can we potentially learn from the DI to overcome barriers in developing the PI?*
   We have learned that there are barriers to reach to PI. One of the barriers named by our interviewees is the lack of collaboration between logistics service providers. Another barrier we encountered relates to the difficulty of collaborating for making new standards in logistics. In the discussion section, we argue that if we want to overcome barriers and further shape the PI, we should treat the PI as a concept that solely belongs to the SCM domain and not to the Internet domain. We concluded that the DI-PI analogy has been useful for inspiring the PI vision, but is not suitable to design specific solutions for the PI.

The strength of the analogy limits the value of the analogy. The DI-PI analogy lacks strength because, firstly, most of the similarities found by our experts are correct, but described on a very aggregated level. Secondly, the differences found in the DI-PI analogy outnumber the similarities. Thirdly, according to our findings, the level of understanding of the DI by PI experts is, in some cases, limited. We argue with our Analogy Functionality Model that when using the analogy to design, the source case's impact on the target case is very substantial, and wrongful transfer of information negatively impacts the target case. Given the lack of strength of the DI-PI analogy, we do not recommend to exploit the DI-PI analogy further for designing the PI. Based on the answers to the sub-questions, we argue that the value of the DI-PI analogy is limited to using the analogy for persuasive, explanatory, and inspirational purposes.

12.2. Recommendations

Firstly, we recommend that academics, policymakers, and the industry refrain from using the DI-PI analogy when further developing the PI and constructing road maps to move towards the PI. Instead, one should keep in mind that the PI belongs to the SCM domain and has little affiliations with the DI domain.

Secondly, caution is recommended when communicating about the PI. Our findings describe the risk of misunderstanding the PI, due the DI-PI analogy. As a result, a recommendation on communicating about the DI-PI analogy is made. This implies a four-step approach when communicating about the DI-PI analogy;

1. Remind the audience an analogy is being used and that all analogies break down at some point.
2. Identify the relevant similarities between the DI and the PI, so the audience understands why the analogy has initially been made.
3. Identify the relevant differences between the DI and the PI.
4. Inform the audience about the limitations that come with using analogies.

Thirdly, we recommend exploring the Analogy Functionality Model further. In this thesis, an Analogy Functionality Model was made, as there was no framework to evaluate the value of analogies for new concepts. An exciting avenue for further research is to extend and refine the Analogy Functionality Model and see if it can be used for different analogies, outside the SCM domain. In its current shape, the model shows the relation between the required strength of an analogy, the analogy's purpose, and the impact the analogy has on the target case. The model could be refined by giving more context to these relations. Also, the model is currently highly simplified by only including for proposes of analogies that can either be used or not depending on the analogy's strength. A more realistic model may contain subcategories of the purposes and more conditions to determine the analogy's breaking

point. Additionally, it is interesting to know for which new concepts and in which domains a more referenced version of the model could be used.

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A

Interview protocol

A.1. Interview protocol

Interview protocol for semi-structured interview with PI-experts

[Script prior to interview]: I would like to thank you once again for being willing to participate in this interview as part of my research. As I have mentioned to you before, my study seeks to understand the analogy between the digital internet and the physical internet and how the workings of the digital internet are perceived. I want to ask you about your knowledge and thoughts about the analogy between the physical internet and the digital internet. I will first ask you about what you think the analogy entails. After which, I will ask you about specific components from the physical internet and how you think the technology works in the digital internet. Please try to be as elaborate as possible and try to support your answers with graphic descriptions when you can. Our interview today will last approximately 40 minutes.

Do you have any questions? [if yes]: [Discuss questions]

Before we start off, have you been able to look at the consent form yet? [If yes]: Thank you, was everything clear or do you still have further questions? if yes: [Discuss questions]

[If the interviewee has not looked at the consent from yet]: [present the consent form again]

The consent form indicates that I ask your permission to audio record our conversation. Are you still ok with me recording (or not) our conversation today? Yes/No

[If yes]: Thank you, please let me know if at any point you want me to turn off the recorder [If no]: Thank you for letting me know. I will only take notes of our conversation. Before we begin the interview, do you have any questions? [Discuss questions]

[start the recorder and announce that the interview has started]

1. How are you connected to the physical internet?

2. How would you define the physical internet?

3. What does, according to your knowledge, the analogy between the physical internet and the digital internet entail?

[When the responded did not cover the technologies from question 2 till 6, ask the questions related to the technology the interviewee did not cover]

4a. Do you think there is an analogy on interconnectivity between networks? 4b. [If yes]: Can you describe how this technology works in the DI?

5a. Do you think there is an analogy on standardization? 5b. [If yes]: Can you describe how this technology works in the DI?

6a. Do you think there is an analogy on protocols? 6b. [if yes]: Can you describe how this technology works in the DI?

7a. Do you think there is an analogy on encapsulation or modularization? 7b. [if yes]: Can you describe how this technology works in the DI?

8. Besides the answers on these questions, would you like to add anything else to your answer at question one: What does, according to your knowledge, the analogy between the physical internet and the digital internet entail?

Thank you for your answers, we will now end with some general questions.

9. What is your profession?

10. What is your field of expertise?

11. How many years have you been active in this field?

Thank you for your participation in this research. [stop recording]

A.2. Development of the research questions

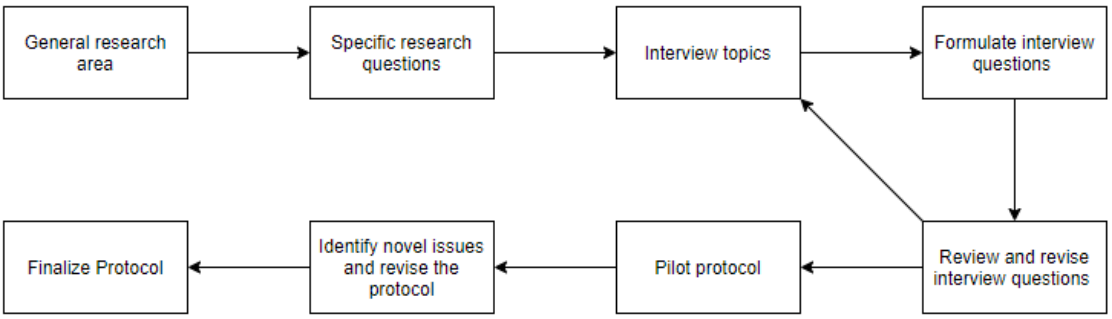


Figure A.1: Development method of the research questions based on Bryman (2012)

B

Digital Internet Assumptions

Table B.1: DI assumptions

Interviewee	Quotes
Interviewee I	So if you're small packages, you sent them. If you're going via this long distance lines or whatever, they are put together. But that's just copying and not really manipulating.
Interviewee II	If you send a packet from here to Spain there may be more than a 1000 service providers that can do that for you, I don't think that is the case in the DI.
Interviewee II	I know there are arrangement in the DI when it comes to standards of protocol but I do not know about any financial arrangements
Interviewee II	In the internet a message is duplicated and send via different channels to the receiver. It is undesirable in the PI to duplicate containers and see which route is the quickest
Interviewee III	When you send an e-mail it is split into packets, these packets enter the cable in a random order also different packets can be bundled on the internet, this is what they call multiplexing.
Interviewee IV	If you send a packet through the internet in theory the packet can be routed through any hub, which is not the case in the physical world
Interviewee V	If you look at them at the general level, you can really think about the analogy. Take the example of, if you send something on the Internet. We split the load in small packets. We do exactly the same thing in the logistic
Interviewee VI	I assume that in the DI parties put the competitive differences aside and develop standards just like the TCP/IP protocol
Interviewee VI	When a link is broken a data can find a different route through the DI network. This maybe interesting for goods in the PI as well if they find their own way through the network by their own intelligence
Interviewee VII	Messages are send via a standard TCP/IP protocol and then they are automatically routed with the use of algorithms

Continued on next page

Table B.1 – continued from previous page

First column	Second column
Interviewee IX	The reason why the internet works so well is because packets are standardized and so it doesn't matter which router you manage as log as you can manage all kind of packets you can fundamentally be a node
Interviewee IX	In the DI communication go up with the speed of light
Interviewee IX	In the DI data packets sometimes get lost, then all you need to do is to send a message that the packets needs to be reproduced
Interviewee IX	The internet protocol in particular introduced the concept of data packets so whatever the information is, it may be voice communication, maybe picture or detailed e-mails, they get broken up into single data packs and a single data packet can be routed in different ways over the internet over the path of least resistance then get assembled at the other side
Interviewee X	We all know that every data is starting form zero and ones. zero means no voltage, one means voltage. they can make up a byte, which is a binary number with eight digits and then based on that you get a data frame, data package and you can basically built everything upon that one so a byte is the smallest unit of digital data
Interviewee X	An e-mail is first broken down into these different frames and they can move via different routes through the internet individually. However in the digital internet for each standard unit of cargo there is a value, so if you lose that one, there is a loss.
Interviewee XII	The DI works in a similar matter as a American server is unable reject all internet traffic from China. According to my knowledge this is all very anonymous
Interviewee XII	The PI uses standardized packets just like the DI, this is why all routes are accessible for all packets
Interviewee XII	The is a phenomenon in logistics that may come awfully close to the DI, it is called switch in and in implies that a containers with the same goods switch to a different receiver during their travel

Continued on next page

Table B.1 – continued from previous page

First column	Second column
Interviewee XIII	The protocols for simple mail messages and things like this define a package. The size and the packet size has certain header requirements and tail requirements.These are all defined as far as how big they are, etc.. Now these things have changed over time and how they are managed in the original internet. Packets were of standardized size and they basically you had best effort shipment of these packets, every message was broken off, data was broken up into these packets and the Internet provided best effort. No guarantee for the simple reason that if it didn't arrive you could re transmitted. That was the thinking. Well, you can't do that today with streaming video and things like this. So there have been overlays that have been built on top of the original Internet protocols to try and handle all of these things, leading to lots of overhead, lots of management functions and some success. I mean, you would probably watch video on the Internet and you listen to music over the internet and you think that this is just natural.
Interviewee XIII	{explains the workings of a switch} Well, there's an ongoing communication to all of their peers in which they update their routing tables. Are you available? Are you? Who are you connected to? All of these things. And this goes on through the standard protocols of the Internet. They're not mapping the entire network. They're mapping the near environment within their service area. And that allows them then to understand which direction to send someone in they don't know the full destination pathway goes. That would require you to map the entire network, which would be too much for them to do. But they certainly know what the best next process is least congested. And there's also some quality of service elements that are attached to those least congested and pricing. If somebody puts a charge on a network link, they may avoid that because they don't want to pay in these types of things. But these are all going on in the background.
Interviewee XIII	{explains how consolidations works on the DI} Sure, the router can be looked at as a two sided input output mechanism on one side coming the inbound messages and they queue up. And depending on where they're going, they are switched to outgoing channels that will queue up the packets again and then send them out in a regular sequence based on how the router is setup. So this is very much like a cross-dock operation where trucks come in on one side, they picked up a bunch of stuff going to multiple different locations, then cross dock, then switches, then depending on which onward leg they need to go into, they're queued and pushed into a full van, a partial van and then proceed to the next leg of the journey.

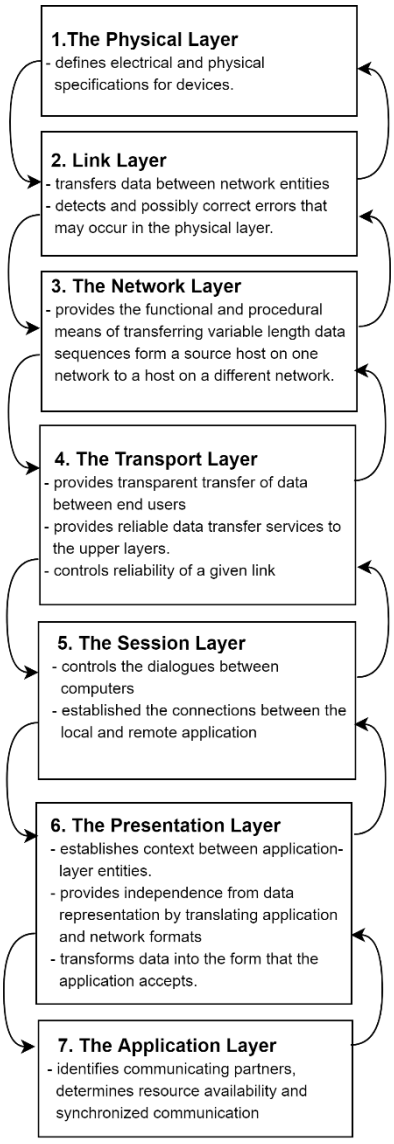
Continued on next page

Table B.1 – continued from previous page

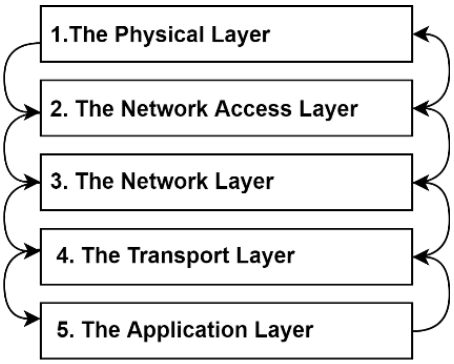
First column	Second column
Interviewee XIV	The basic idea is that for the for the e-mails or for any data package, in the IP protocol you have these standardised containers, which are data containers not physical containers. And the first part of the container, so the address label is standardized and everyone is going to understand what is written there and you have things like the source address and the destination address but you also have information like time-to-live so how long should this data package be available in the DI, so how long should we try to send in to the receiver. You have some information on check sums so that you cannot manipulate the data, which is the inside of the container. You have information on the size of the container. And then you just sent the data package and since you have this address sticker in the beginning of their message, which is which is understood by everyone. It's very easy to forward.
Interviewee XIV	Well the basic idea of the PI container is that you can have different modules that can be joined together to build one larger model, all standardized. This is not done in the DI. One large chuck of data may be split but these packages are not joined together. So here the PI goes further.
Interviewee XIV	I studied computer science and DI was one of the parts, but the routing part I was never so interested in I just there is this basic name space situation where you have to indication of which direction it should be forwarded. And you have the decentralise decision that each of the nodes is going to decide which is the next recipient. But I never got the details and write articles on the exact algorithms, so if you are really going to ask me how the real decision is made I have to say I do not know. I just know the basic concepts
Interviewee XIV	in the DI it is possible to duplicate the messages, possible duplicate the data and send it several ways. And the best one will fight through the internet and reach the target and if another one also reaches the target it will just be thrown away and you can't do this with physical stuff
Interviewee XV	[explains how routing is organized in the DI} I know how this is organized in DI. That is where it ends with the analogy. I would say, because we know that in the DI things are sent a couple of times. And if you have an e-mail, there are more or less clones of the e-mail that are sent through different streams, paths in the the digital Internet. And the first one wins more or less

C

The OSI and TCP/IP model



(a) The OSI Model



(b) The TCP/IP Model

D

Scientific Article

Exploring the Value of the Analogy between the Digital Internet and the Physical Internet

Sharon van Luik

***Abstract*—Since its literary introduction in 2010, many parties have shown their interest in the Physical Internet concept. Although the Physical Internet perks seem promising, academics still find it hard to give more context to the analogy between the Digital Internet (DI) and the Physical Internet (PI). This paper finds out what the value is of the DI-PI analogy to further develop the PI. Firstly, a literature study is conducted on analogical reasoning. It is found out that the strength of an analogy depends on the differences and similarities between the source and the target domain, and the knowledge one has of the source domain. Based on a literature study, an Analogy Functionality Model is proposed, which indicates different purposes of analogies require different strengths of the analogy. The different purposes described are the persuasion, the explanatory, the inspirational, and the design purpose. To determine the strength of the DI-PI analogy, data is gathered on the differences and similarities between the DI and the PI using semi-structured expert interviews. Fifteen PI experts were interviewed. The results of these interviews indicate a lack of strength in the DI-PI analogy. Additionally, it became apparent the level of understanding of the DI differs among PI experts. We argue that the value of the DI-PI analogy is therefore limited to persuasion, explanatory, and inspirational purposes. When using the DI-PI analogy for these purposes, one must be aware of the limitations of using analogies. It is recommended that academics, policymakers, and the industry refrain from using the DI-PI analogy when further developing the PI.**

Keywords: Physical Internet, Analogy, Logistics System, Analogical Reasoning

I. Introduction

Distribution networks, production networks, and supply networks are all part of a logistics network. Currently, logistics networks are often fragmented, meaning organizations have their own networks, and these networks lack interconnection [1]. This lack of interconnection, together with other inefficiencies, cause negative externalities. Montreuil, Meller, and Ballot [2] noted these inefficiencies and describe a vision in which supply chains are more economically, environmentally, and socially efficient. Consequently, they proposed a system where supply chains are worldwide interconnected, known as the Physical Internet.

When looking at the level of interconnection, digital networks have reached an exceptionally high level of interconnection. The Internet, as we know it, is an efficient network of networks where data packages move relatively cheap, efficient, and secure. This was the motivation for proposing a metaphor in which the Digital Internet is compared to the potential future of logistics [2]. The metaphor is known as the Physical Internet (PI). To make a clear distinction between the PI and the 'regular' Internet this article refers to the Digital Internet (DI) for what otherwise may be known as the Internet. The formal definition that Montreuil [3] gave to the PI is "an open global logistics system founded on physical, digital, and operational interconnectivity through encapsulation, interfaces, and protocols." PI aims to enable an efficient, sustainable, adaptable, and resilient logistics network.

Since its literary introduction in 2010, the PI has gained much traction. Many parties have shown their interest in the concept, and many publications followed. Although the perks of the PI seem promising, academics still find it hard to give more context to this analogy between the DI and the PI, as can be seen in the next section.

Finding out what the value is of the analogy is highly relevant from a scientific and societal perspective. From a scientific point of view, this is relevant for further developing the PI. The findings can contribute to a shared understanding of the DI-PI analogy. If there is indeed value in the analogy, there is a pertinent research avenue for theory-building. If there is only limited value, one may suggest taking research interest in the PI elsewhere. A third scenario is one where thinking in terms of the analogy may not have any value at all and even slow the development of the PI down.

From a societal point of view, this research is also helpful regarding the development of the PI. The PI is very promising in terms of creating a more efficient and sustainable supply chain network, and this research contributes to future endeavors in moving towards the PI. Additionally, this research may be helpful to create a clearer picture of what the PI with regards to the analogy implies, which may foster the adoption of the PI in the industry.

A. Research context & literature review

The next sections present an overview of prior work on the analogy between the DI and the PI. For this purpose, a literature review is performed using the aforementioned publications of two key publications found using a search string. As a starting point, academic databases were used, such as the TU Delft Repository and the academic search engine Scopus, searching for the terms 'Physical Internet' AND 'Digital Internet.' As a result, two articles were found, of which one a literature review [4]. From here, references of these publications are used to find new relevant publications. All books, articles, and conference proceedings published prior to May 2020 are considered. All results were screened according to their applicability, which is a useful comparison to the DI. Underneath, the publications on the comparison between the DI and the PI are discussed.

In 2010 a conference proceeding was written, which proposes the PI as a paradigm change, enabling us to rethink current logistics networks and to move to a system that works like the DI [2]. According to the authors, this is a system where networks are interconnected by a common operating framework, making it easier to transport and handle loads. Additionally, they elaborate on the PI container, a container to carry physical goods, and explicitly designed for the PI. The authors describe a PI container that also carries information that can be compared to the MAC address in the DI, which functions as a unique identifier.

One year later, Montreuil [3] published a paper in which he suggests to exploit the DI-PI metaphor to develop the PI vision. He explains how the DI has exploited the physical world before and that now is time to use the metaphor in the opposite direction. Additionally, the author points out the advantages of standardization in the DI and compares it to the standardization in the physical world by means of 20- and 40- feet containers. Other comparisons the author makes between the DI and the PI regard how the DI offers secure solutions to transport information flows and how the DI relies on certifications of protocols to enable many actors to use the system. The author states that the PI does not aim to copy the DI, but instead means to inspire the PI vision that provides sustainable solutions to logistics problems. The paper does not elaborate on how and to what extent the analogy can be exploited.

In 2012, Montreuil and Ballot introduced the Open Logistics Interconnection (OLI) model, which is a framework based on the Open System Interconnection (OSI) framework that is commonly used to analyze ICT systems [5]. The authors state that the OSI framework has been instrumental in shaping the DI, which is their motivation for creating the OLI framework. The paper emphasizes the layered framework's advantages and expresses the need for a more detailed version of an OLI framework.

In 2013 several foundations of the PI were described as being inspired by the DI [6]. The authors wrote about the foundations of the PI and described concepts such as encapsulation, interconnectivity, and standard coordination protocols from the DI. The information on how the foundations are derived from the DI is given on an aggregated level. It remains unclear if one should further exploit the DI to develop these foundations further.

Later an attempt has been made to dive deeper into the DI-PI analogy [1]. The authors state strong similarities between DI and logistics, despite the differences in the type of objects transported in the network. They focus on the interconnection potential of logistics networks, using a model. Their analogy is based on the interconnection of networks, the structure of networks, and the routing of objects in these networks. As a limitation of their findings, they state their research is exploitative, and details are left out, such as the containerization of the merchandise and the routing protocols used.

In 2017 a conference proceeding was written that studied the analogies between routers and logistics hubs [7]. More specifically, the authors analyzed the types of routers and the hierarchy of these routers. Additionally, they use this analogy to make an operation model for hubs that aims to ease the creation of routing algorithms for these hubs.

Dong and Franklin studied the PI based on the DI [8]. They propose a conceptual framework for PI network routing with the DI as a foundation. They translated eleven elements from the DI to the logistics web, including actors such as users, carriers and service providers, and actions such as collaboration. Additionally, they found differences in the DI and the PI related to cost and time metrics. The comparison suits the research objective of the authors and is, therefore, still general.

An application of the DI-PI analogy found in literature is the conceptualization of a Border Gateway Protocol (BGP) [9]. The authors analyzed the DI and recognized that both the DI and the PI have Autonomous Systems (ASes). The ASes in the DI are connected with a BGP. The authors have copied and adapted this protocol to fit the PI.

Lastly, in 2020 a new literature review has been conducted [10]. The results lead to a significant question regarding the right approach to realize the vision of the PI. The authors state the DI might be helpful due to its 'layered nature,' which, according to the authors, makes it possible to improve specific aspects of the DI without disruption other layers in the system. They suggest a similar structure could be beneficial for the PI so researchers can improve specific aspects of the PI without disrupting the whole system.

B. Filling in the research gap

Prior research has highlighted several main components of the DI and compared these with their respective counterparts from the logistics system on a general level. Although some publications state it is worthwhile to further exploit the analogy between the DI and the PI, the number of publications is still limited, and it remains unclear to what extent and for which aspects the analogy is useful. To fill this research gap, the following research question is formulated:

"What is the value of the analogy between the DI and the PI, to further develop the PI?"

To answer this central research question, five sub-questions are created:

1) *What is the value of analogical reasoning for new concepts?*
2) *What are the similarities between the DI and the PI, according to experts?*
3) *What are the differences between the DI and the PI, according to experts?*
4) *How do PI experts perceive the DI?*
5) *Can one potentially learn from the DI to overcome barriers in developing the PI?*

Answering the first research question aims to determine if reasoning using an analogy is useful for developing new concepts or ideas. The answers to questions two and three

create a better understanding of the strength of the DI-PI analogy. Question four aims to find out what perception PI experts have on the DI and if there are any misconceptions about the workings the DI. Our last question aims to find out what barriers there currently are to reach the PI. In the discussion, we will reflect on whether the DI-PI analogy could help us overcome these barriers.

II. Methodology

In this research, a qualitative research approach is used that fits the exploitative character of this study. A literature study was conducted on analogical reasoning to answer the first research question. The following search strings were used: 'Analogical Reasoning,' 'Analogical Reasoning Pitfalls,' 'Metaphor Pitfalls,' 'Analogical Reasoning Limitations,' 'Metaphor limitations,' 'Analogical Reasoning Innovation,' 'Design by Analogy' and 'Analogy Scientific Discovery.' In the results of these search strings, the ten publications with the highest number of citations were selected for further inspection. The search strings were used in the *Web of Science* and in the *TU Delft Repository*. Additionally, all references in the Analogical Reasoning section of the *Standford Encyclopedia of Philosophy* were used to get a general overview of the field and the history of analogical reasoning.

The remaining research questions were answered using fifteen interviews with PI experts following a semi-structured interview protocol. The interviewees were recruited based on their scientific publications and affiliation with the PI (Table I). They were asked to elaborate on the differences and similarities they see between the DI and the PI. The interviews were manually coded in ATLAS.ti using a thematic coding process. After the coding, the perceptions of the interviewees on the DI were validated, and the results are used to reflect on the value of the analogy.

Table I
An overview of the interviewee roles and background

Participant	Role
Interviewee I	Non-academic researcher
Interviewee II	Non-academic researcher
Interviewee III	Non-academic researcher
Interviewee IV	Professor of Industrial engineering
Interviewee V	Professor in supply chain and production systems
Interviewee VI	Entrepreneur supply chain
Interviewee VII	Professor in supply chain and production
Interviewee VIII	Professor in supply chain and operations develop the PI
Interviewee IX	Research Fellow at a FMCG conglomerate
Interviewee X	Assistant professor operations management
Interviewee XI	University lecturer
Interviewee XII	Professor in sustainable global supply chains
Interviewee XIII	Adjunct professor in logistics
Interviewee XIV	Non-academic researcher
Interviewee XV	Professor in operations management

III. The value of analogical reasoning for new concepts

In our literature review, it became apparent that analogies are used for many purposes, and they can be recognized in many different fields. The type of thinking that relies on analogies is called analogical reasoning. In an analogy, two objects or systems of objects are compared according to their similarities. In this comparison, there is a source case from which information can be transferred to a target case. This comparison is also referred to as mapping. After an analogy has been mapped, new inferences can be made, which is also known as an analogical argument. An analogical argument cites similarities between two systems of objects to support the conclusion that further similarities exist between the systems. In an analogical argument, ones states that *X* is like *Y*, because they share properties *a,b,etc.* Therefore, *X* probably has property *c* since *Y* also has property *c*. Its context can only determine the relevance of similarity (or a dissimilarity). Various logicians and philosophers have identified commonsense guidelines for evaluating and interpretation analogies [11]–[15]. The most dominant criteria are:

1) More relevant similarities result in a stronger analogy
2) More relevant differences result in a weaker analogy
3) Limited knowledge of the target or the source domain results in a weaker analogy

A. Purposes and Pitfalls

While analogies are often used to enhance comprehension and stimulate learning, they can also cause misconceptions. Many authors have described the risk of developing misconceptions about the target domain [16]–[19]. Misunderstandings arise when one transfers irrelevant concepts from the source domain to the target domain. Another risk of using analogies is the risk of fixation. As discussed previously, analogies may foster the generation of new and creative designs. However, using analogies also comes with the risk of design fixation. Design fixation inhibits creativity as it is triggered by focusing on existing paths and solutions [20]. Additionally, when transferring knowledge from the source to the target domain, there is a risk that the wrong knowledge is transferred, which negatively affects the target domain [21]. This is the point where an analogy becomes dysfunctional.

Despite these limitations, analogical reasoning has been described as crucial for recognition, learning, and creativity

[22]. In the literature, four different purposes of analogical reasoning are found. Firstly, analogies can be used to persuade an audience to come to action [23], [24]. They have to power to make ideas more colorful and convincing and to make new concepts more understandable. Secondly, analogies can be used to explain something and educate an audience [16], [22], [23], [25]. As a result, analogies are often used to give more context to new concepts and explain unfamiliar terrain. Thirdly, analogies can be used for inspiration [26]. When using an analogy for inspirational purposes, the source domain has a certain quality that the target domains aspires to have. As such, it can be used to inspire new concepts or change exciting target cases. Lastly, analogies can be used to design a target case, which is also often referred to as design-by-analogy [20], [27]. In this case, elements or entire systems of elements are transferred from the source case to the target case.

B. Analogy Functionality Model

An Analogy Functionality Model (Figure 1) is made that combines results on analogy valuation and on the different purposes analogies. This model gives an overview of the different purposes of analogies in relation to the required strength of the analogy and the influence the analogy has on the target case. This model shows that different purposes have different influences on the target domain.

When one uses an analogy to persuade an audience about a particular idea, the use of the analogy has a minimal effect on the target case. Using an analogy to explain something can affect the target domain indirectly. When an analogy either contains incorrect inferences or is misinterpreted by the audience, misconceptions about the target domain can develop or even spread. When an incorrect analogy spreads, there is a possibility that others build on that analogy for further research, theory-building, or design. The magnitude of the effect depends on the audience of the analogy. When the audience is active in the field of the target domain, the consequences can be more substantial than when the audience has a minor affiliation with the target domain. When using an analogy for inspiration purposes, one derives certain qualities or design requirements from the source domain to the target domain. An example is nature-inspired algorithms. These algorithms are inspired by phenomena in nature and later adapted to better fit a certain application, e.g., optimization algorithms based on ant colonies [28]. In this example, ant colonies inspired and improved optimization algorithms, which affected the target domain of optimization algorithms. When using an analogy to design, the source case has a substantial influence on the target domain. When one designs using an analogy, one copies elements from the source domain. In this case, the source case directly affects the target case. This is why the design purpose has the most significant influence on the target case and bears the biggest risk, as shown in our model in Figure 1.

This model aims to identify the relation between the magnitude of the analogy effects on the target case and the required level of analogy strength for different analogy purposes. The bigger the consequences of a dysfunctional analogy are on the target case, the more careful one should be when applying the analogy. We argue that different analogy purposes require different levels of strength. For instance, when one uses an analogy for persuasion, the analogy can still be functional when the analogy is of moderate strength, meaning, the source domain and the target domain are similar to a minor extent. When one uses an analogy to design, the analogy is only functional when the analogy is strong, meaning there are many relevant similarities and limited relevant differences. A takeaway from this model is that at some point, the analogy becomes dysfunctional. This point is different for each analogy and depends on the number of relevant similarities and differences. The less relevant similarities between the source and the target case, the sooner the breaking point will come.

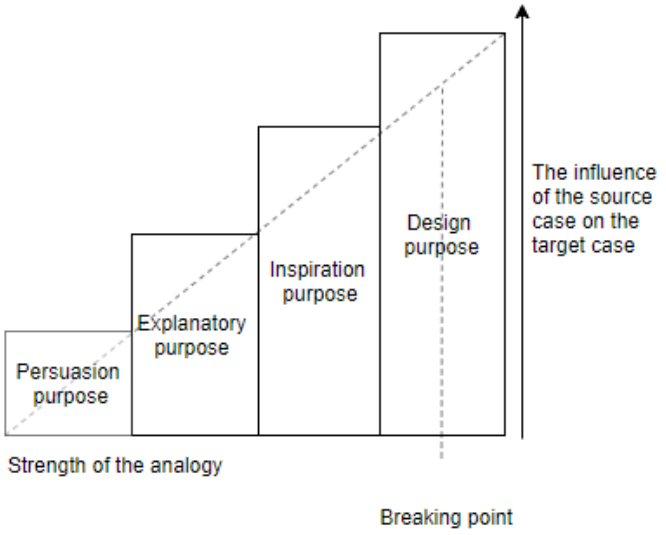


Figure 1. Analogy Functionality Model

IV. Similarities and Differences According to Experts

The interviewees described various similarities and differences between the DI and the PI. Eight interviewees drew similarities between the standardization of transportation units (packets, frames, packages, containers), interfaces, and protocols. Many described the advantages of using standard protocols in the DI and the PI. Other frequently mentioned similarities regard the bundling and splitting of transportation units. Interviewees described how cargo can be split into smaller units or bundled in a bigger unit to foster efficient cargo combinations. The majority of the interviewees describe how in the DI data can be split into smaller data units. The interviewees differ in opinion as to if, why, when, and how data in the DI is split or bundled. Five interviewees mentioned a similarity about is the high level of convenience and security the DI offers, interviewees describe how the PI provides a similar user experience. Two interviewees also identified the sharing of assets in the DI and the PI. They describe how in the DI data packets from a single sender move via different

networks, and in the PI, cargo could do the same. Other similarities regard the flexibility of rerouting a transportation unit when necessary, and the openness both DI and PI offer in terms of the ease of joining the network.

The difference that is most frequently mentioned by our interviewees is the replication of a data packet, which is done in the DI but impossible or unfeasible in the PI. Interviewees often describe how packets in the DI can easily be destroyed and replicated to be sent again, as opposed to the PI, where instead of data, there are physical goods. Five interviewees mentioned the differences in the cost structures. In this case, the DI is described as a network with relatively high investment costs as opposed to operational costs. Whereas in the PI, every movement requires a modality making marginal costs higher. Four interviewees mentioned the difference in transmission speed. They explain how data moves over the DI with almost the speed of light, and shipments in the PI can take hours or even weeks. Additionally, interviewees mention how the relatively low speed in the PI requires the PI to have some sort of capacity planning, which is different from the DI. Also, three interviewees talked about the differences in the evolution and the history of both networks, which, according to them, accounts for the collaborative nature of the DI as opposed to the PI.

V. The perception of the Digital Internet

During the interviews, the interviewees made assumptions about the PI. In some instances, they acknowledged that they could not elaborate on specific technologies of the Internet they mentioned when talking about the analogy. Four interviewees mentioned from the beginning of the interview, they are not familiar with the Internet domain. Six interviewees found it hard to elaborate on specific analogy elements they described on an aggregated level. The most challenging part for the interviewees was to elaborate on elements related to routing data over the DI. That being said, there were interviewees with a computer science background who thoroughly elaborated on DI technologies.

The assumption PI experts made about the DI were validated. In our validations, we found out that some interviewees had a perception of the DI that deviated from reality. Several interviewees gave an accurate explanation of the working of the DI, while others experienced difficulties when explaining specific technologies. Most interviewees were able to explain DI technologies on an aggregated level. When it comes to common perceptions that deviate from the truth, we noticed that four of our interviewees assume in the packets are split, and multiple packets follow different routes to find out which route is the fastest to the destination. Additionally, four of our interviewees assume that packets are being bundled or clustered together for transportation. It is correct that data can be split into packets on the DI; however, packets following different routes seem to be the exception rather than the rule.

VI. Assessing the Physical Internet analogy

A. The value according to experts

Interviewees value the analogy differently, ranging from highly dysfunctional to highly fruitful. During the interviews, some interviewees explained the analogy could be used to develop the PI further, but also acknowledge there is too many difference to copy attributes or relations one on one. Interviewee XIV stated that she thinks there is still a lot we can learn for the DI, but copying certain principles would not be beneficial for the logistics. Interviewee XIV shares this opinion and compares the PI to a lighthouse. He explains, "The PI is like a lighthouse showing us the way, but as soon as you reach the lighthouse, you have a problem because it means that the ship has stranded."
Interviewee XIII explains how the DI-PI analogy has the potential to change the way we think about transportation systems. He describes how the current thinking paradigms bottleneck innovation in the logistics system and PI had been able to change people's perspective. "It provides a way for people to see in another spectrum the kinds of transformation that we are aiming for. It makes people say 'Wait that's been done somewhere else?'" he explains. He assumes that so far, we have only exploited about two or three percent of what we should be exploiting from the DI-PI analogy. Interviewee XV also shares this perspective and adds that there is a lot to learn from the DI in terms of sharing revenues, building protocols, and managing flows.

Interviewee V explains how, according to him, the analogy works well if you look at the structure; however, when you look for a practical solution, the analogy becomes dysfunctional because the characteristics are different. Interviewee IX also explains we should be careful when using analogies. As an example, he refers to a city distribution center project, in which they tried to design distribution centers similar to a Port Authority. The project failed due to differences between the two cases. Interviewee XI has a less positive opinion and states that for him, the analogy has reached its breaking point, and it could even be dangerous and misleading as audiences do not understand the PI because they do not understand the DI. He advises: "Forget about the metaphor. Think about pragmatics. What do you want to achieve now?" As an example, he explains how neuroscience has computational models that are inspired by biology. And one of the analogies that people frequently use is the analogy of the human mind as a computer. The interviewee explains that neuroscientists think we should drop the analogy as there are too many differences. "Analogies can be useful to start to understand something, but later become a hindrance to deeper understand of a phenomenon," he states.

B. The different analogy purposes in the PI

The interviewees have described the purposes of analogies. For instance, there is a clear **persuasion purpose** in the DI-PI analogy. One of our interviewees explains how the analogy helps audiences to open up their minds and think about a

whole new paradigm of logistics. He explains there are many inefficiencies in our current logistics operations, due to various bottlenecks. According to him, the analogy makes people realize that logistics can be a lot more efficient. He states that the DI has developed to a state that we could not even have dreamed of 30 years ago and. "With the DI-PI analogy, people can see that it is possible to change a paradigm completely," he reasons. The analogy has proved to be persuasive as the concept of PI has gained a lot of traction throughout the years. The number of publications about the PI has grown over the year, and different events have been organized [10]. The 7th International Physical Internet Conference is organized this year, and many universities and research institutes are involved in the topic.

We can also see an **explanatory purpose** of the DI-PI analogy. One of our interviewees explained that in his opinion, the PI is a future and advanced state of the logistics network and that he uses the DI to explain what this advanced state of logistics looks like. Two of our interviewees mention they lecture students regularly and that the analogy can help people to start understanding a different logistics paradigm. The **inspirational purpose** is most visible in literature as many foundations of the PI are inspired by the DI, such as the connection and synchronization of networks, developing standards, and heterogeneous equipment that is respecting a certain protocol [3]. Likewise, our interviewees describe particular traits of the DI they aspire the PI to have, such as high convenience for the user. As we a **design purpose** goes further than an inspirational purpose. Where an inspirational purpose allows us to develop design requirements based on the source case, a design purpose copies aspects from the source case to the target case. Limited publications demonstrate the design purpose of the analogy. The most pertinent example is a conference proceeding where a Border Gateway Protocol for the PI was developed [9].

C. The value according to the Analogy Functionality Model

As discussed, one should be careful when applying analogies due to its limitations. The breaking point of an analogy is the moment where the analogy becomes dysfunctional. An analogy becomes stronger when there is a high amount of relevant similarities compared to differences. The results deriving from the interviews indicate there are many differences between the DI and the PI that cannot be overlooked and interviewees described close to an equal amount of similarities as differences. As can be seen in our model, an analogy that is less strong results in an earlier breaking point of the analogy. Because the DI-PI analogy lacks strength, we argue the analogy is not suitable for design purposes. As became clear in this model, one can use the analogy to persuade, educate, and inspire; however, one should stop when one wants to use the analogy with the purpose to design.

VII. Discussion

It became apparent that there are many differences between the DI and the PI, and the similarities are only present on an aggregated level. We also found out that different experts have different levels of understanding of the DI, and in some cases, the knowledge was limited. This is why we argue that the DI-PI analogy is not a strong analogy, and this influences the value of the analogy.

We presented an Analogy Functionality Model and argued that different purposes require different levels of strength of the analogy. Due to the lack of strength of the DI-PI analogy, there is no value when it comes to a design purpose. By not using the analogy to design, one avoids the risks of transferring elements from the DI to the PI that are not suitable for the PI. What also became apparent is that the analogy is used for other purposes, as interviewees pointed out to use the analogy to persuade, educate, and inspire. All in all, the analogy has value, but not for design.

Our results imply that academics, policymakers, and the industry should refrain from using the DI-PI analogy when further developing the PI and constructing road maps to move towards the PI. Whereas, the PI in itself may be very promising as a future logistics concept, according to our research, using the DI to develop the PI further is less promising.

The applicability of our results is limited to the current state of the PI. We concluded that we can not copy elements from the DI to the PI at this moment. However, when the PI is further developed, we do not exclude the possibility that there may be specific problems where the DI-PI analogy can be of value when it comes to digital solutions in the PI. Also, throughout this thesis, it is insinuated that the PI can be designed. This is a top-down approach that relies on the assumption that the PI is something that can be designed. This, in itself, is an assumption that can be questioned.

Furthermore, the similarities and differences in the DI-PI analogy may not be fully be exploited. We found out different experts interpret analogies differently. And due to the structure of the semi-structured interviews, the interviewees got a lot of freedom to provide the information they wanted to provide. As a result, not all areas of the analogy were covered by all interviewees. Likewise, some interviewees described a particular element as a similarity, while others described the same element as a difference. To gather a more reliable list of similarities and differences, one could validate the list generated in the research by means of a focus group or a Delphi-method. This gives experts the opportunity to iterate on each-others opinions. However, we question the necessity for this as most experts agree on differences, and different opinions can also be a result of the overall understanding and interpretation of the DI and the PI.

VIII. Conclusions

The findings on the sub-questions are summarized, after which the main research question: *"What is the value of the analogy between the DI and the PI, to further develop the PI?"* is answered.

1. What is the value of analogical reasoning for new concepts?

Four different purposes of analogies are described: a persuasion purpose, an explanatory purpose, an inspiration purpose, and a design purpose. The findings indicate there are limitations to using analogies, and there are risks for the target case. Firstly, if the wrong information is transferred from the source case to the target case, it could negatively impact the target case. Secondly, analogies can cause misunderstandings about a target case. Thirdly, a designer of a target case can become too fixated on the source case, which is known as design fixation. To determine the strength of an analogy, three criteria are defined. Firstly, more relevant similarities result in a stronger analogy. Secondly, more relevant differences result in a weaker analogy. Thirdly, limited knowledge of the source domain results in a weaker analogy. We conclude by proposing an Analogy Functionality Model, which shows a relation between the required strength of the analogy and the magnitude of the impact on the target case for different analogy purposes. It is concluded that an analogy has value until it reaches a certain breaking point. Where this breaking point is, depends on the strength of the analogy.

2. What are the similarities between the DI and the PI, according to experts?
We learned about the various similarities between the DI and the PI, according to experts. Most interviewees drew similarities between the standardization of transportation units (packets, frames, packages, containers), interfaces, and protocols. Other frequently mentioned similarities relate to the bundling and splitting of transportation units, the high level of automation in a network, and a decentralized organization. Another frequently mentioned similarity is the carefree feeling and security users experience when they use the network. Some interviewees also identified assets sharing, routing flexibility, and the openness of the networks as similarities.

3. What are the differences between the DI and the PI, according to experts?
The most frequently mentioned difference concerns the replication of the packets, which is done in the DI but is impossible or unfeasible in the PI. Other differences that were frequently mentioned are the differences in the cost structures and the differences in transmission speed. Also, three interviewees talked about the differences in the evolution of the networks, which according to them, account for the collaborative nature of the DI as opposed to the PI. Differences in planning and decision making were also mentioned, as were differences in the splitting and bundling of shipments in the PI and data packets in the DI.

4. How is the DI perceived by the PI experts?
We validated various assumptions PI experts made on the workings of the DI. In our validations, we found out that some interviewees had a perception of the DI that deviated from reality. Few interviewees gave an accurate explanation of the working of the DI, while others experienced difficulties when explaining certain technologies. Most interviewees were able to explain DI technologies on a very aggregated level. When it comes to common perceptions that may deviate from the truth, we noticed that four of the interviewees assume that packets are split, after which multiple packets follow different routes to find out which route is the fastest to the destination. Additionally, four of the interviewees assume that packets are being bundled or clustered together for transportation.

5. Can we potentially learn from the DI to overcome barriers in developing the PI? We have learned that there are barriers to reach to PI. One of the barriers named by our interviewees is the lack of collaboration between logistics service providers. Another barrier we encountered relates to the difficulty of collaborating for making new standards in logistics. In the discussion section, we argue that if we want to overcome barriers and further shape the PI, we should treat the PI as a concept that solely belongs to the SCM domain and not to the Internet domain. We concluded that the DI-PI analogy has been useful for inspiring the PI vision, but is not suitable to design specific solutions for the PI.

All in all, the strength of the analogy limits the value of the analogy. The DI-PI analogy lacks strength because, firstly, most of the similarities found by our experts are correct, but described on a very aggregated level. Secondly, the differences found in the DI-PI analogy outnumber the similarities. Thirdly, according to our findings, the level of understanding of the DI by PI experts is, in some cases, limited. We argue with our Analogy Functionality Model that when using the analogy to design, the source case's impact on the target case is very substantial, and wrongful transfer of information negatively impacts the target case. Given the lack of strength of the DI-PI analogy, we do not recommend to exploit the DI-PI analogy further for designing the PI. Based on the answers to the sub-questions, we argue that the value of the DI-PI analogy is limited to using the analogy for persuasive, explanatory, and inspirational purposes.

IX. Recommendations

Firstly, we recommend that academics, policymakers, and the industry refrain from using the DI-PI analogy when further developing the PI and constructing road maps to move towards the PI. Instead, one should keep in mind that the PI belongs to the SCM domain and has little affiliations with the DI domain.

Secondly, we recommend exploring the Analogy Functionality Model further. In this thesis, an Analogy Functionality Model was made, as there was no framework to evaluate the value of analogies for new concepts. An exciting avenue for further research is to extend and refine the Analogy Functionality Model and see if it can be used for different analogies, outside the SCM domain. In its current shape, the model shows the relation between the required strength of an analogy, the analogy's purpose, and the impact the analogy has on the target case. The model could be refined by giving more context to these relations. Also, the model is currently

highly simplified by only including for proposes of analogies that can either be used or not depending on the analogy's strength. A more realistic model may contain subcategories of the purposes and more conditions to determine the analogy's breaking point. Additionally, it is interesting to know for which new concepts and in which domains a more referenced version of the model could be used.

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