

# The Transmission Ticker: Exploring New Perspectives on Data Transmission Through Physicalization

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## ABSTRACT

The rise of the Internet and IoT has been resulting in an exponential global rise in data transmission and its associated environmental impact. The majority of people is ill-informed on the topic of data transmission, resulting in large confusion around the topic. This poses a problem in making people understand its ecological downsides. To address this issue, the Transmission Ticker project explores what new perspectives on data are developed through the physicalization of data. An (auto)ethnographic study was conducted in which the Transmission Ticker, a material speculation which physicalizes real time domestic data usage, was deployed in three households. Based on observations, photographs, journal entries and interviews, insights were gathered on the transformed perspectives concerning the research artifact and data transmission. Based on these insights, we propose six initial principles for the design of domestic data awareness systems.

## Author Keywords

Material Speculation, Domestic Behavior, Data Transmission Awareness, Physical Display

## INTRODUCTION

In recent decades, as the internet has enlarged its grip on society, the global transmission of data has grown exponentially [2, 6, 39]. Through continuously increasing data usage and the rise of data-intensive trends like Industry 4.0, IoT and Smart Cities, data centers are predicted to be responsible for 3 - 13% of the global electricity usage by 2030 [4, 6, 34]. To facilitate this enormous growth, Tech Giants like Google, Microsoft and Amazon have expanded their data transmission infrastructure through increasingly large and efficient data centers. In 2018, they were receiving, processing and transmitting information in quantities of 2.5 quintillion bytes (2.5 million terabytes) per day [30, 34]. The rampant technological advancement of the past decades has enabled high-speed and high-volume data transmission [31, 33, 48]. As a result, data transmission has become an irreplaceable part of human life. Yet, its implications, influence and impact are generally not well understood; the majority of people is ill-informed about the implications of internet data collection and data transmission is, generally and mistakenly, not seen as a threat to the environment [12, 16]. One of the main causes of current misunderstandings within

the subject of data transmission is its ungraspable character [51]. This lack in understanding of data transmission is evidenced by employed terminology such as ‘cloud computing’, a marketing term used to oversimplify complex background processes, concealing the sophisticated systems and technologies that realize the continuous transmission of data [52].



Figure 1. The Transmission Ticker

The general user’s lack of understanding considering data transmission makes it exceptionally hard for people to grasp the downside of this technology, such as the ecological consequences of uncontrolled, excessive data usage on a global scale [34, 48]. This ecological impact of data and the internet is similarly neglected by expert web developers [14]. One way the current excessive environmental impact of data could be tackled, is through a shift towards conscious domestic data consumption. Currently, data centers require significant overcapacity in order to handle data usage during peak hours; this causes the unnecessary deployment of extra computing equipment during non-peak hours, resulting in an increased electricity and resource usage [1, 34]. This study, therefore, explores how people’s understandings of and perspectives on data transmission can be enlarged, this to potentially generate more awareness of data transmission and its impact.

The underlying technologies facilitating data transmission have long been distanced from the user experience. Lately however, there has been a need to limit the excessive data usage of users. As a consequence of the global COVID-19

crisis, global data consumption increased drastically, exposing the limitations of data transmission more than ever before [28]. A number of the biggest e-entertainment companies like Netflix and YouTube have lowered their video quality for consumers to ensure that maximum network capacity is not exceeded by increased online streaming and video calls [5]. These circumstances, wherein humanity is directly confronted with the limitations of data transmission on a global scale, offers valuable opportunities to explore how perspectives on and relationships with data can be changed and enhanced.

To explore new perspectives on data transmission, the design research project of the Transmission Ticker was set up. Many, both broad and specific, definitions of data transmission exist in literature. In this study a definition adapted from Britannica is deployed, in which data transmission encompasses all digital information in the shape of electromagnetic signals that is transferred from one point to another, this transfer being either wired or wireless [38].

The approach for this study builds upon the work of Wakkary et al., wherein possible futures are initiated and observed through high-fidelity speculative research artifacts, referred to as material speculations [55]. This approach aims to initiate critical reflections about future design paradigms through triggering interest and curiosity, in this way facilitating a deeper understanding of potential future phenomena in design. With the Transmission Ticker (Figure 1), we adopt this form of speculative design. Using physicalization of the intangible phenomenon data transmission, we explore the use of domestic products as a means to generate understanding and initiate new perspectives on the topic. The contribution of this paper consists of an elaborate description of initiated data perspectives through physicalization, and presents six recommendations for data comprehension to be deployed in data-awareness products. Specifically, we underline possibilities that could present behavioral changes to the excessive domestic usage of data.

Emphasizing physicalization and materiality, influenced by material speculations, the Transmission Ticker is a high-fidelity prototype inspired by twentieth century mechanical design. Through peripheral feedback in the form of movement and sound, combined with visual tracing of the continuous data-usage, measured over the time span of ten minutes, the Transmission Ticker introduces a physical component to domestic data usage.

## RELATED WORKS

In this section, we will reflect on other research and design which aims to create new perspectives on energy and data usage. Furthermore, we position the taken approach of material speculations in the broader context of research through design and design fictions.

### Physicalization in Energy and Data Transmission

Numerous forms of physicalization to represent data have been introduced throughout history, driven by digital innovations, many new forms of data physicalization have come into existence [11, 24, 25]. Through newly introduced technologies in the field of Human-computer interaction (HCI), data physicalization is increasingly used as a means to help

users communicate and explore data [41, 22, 25, 11]. This research topic has also been explored through the lens of educational psychology, which has presented clear evidence for the value of manipulable physical representations of data to facilitate learning and understanding [22, 23, 25, 41]. These works also indicate that digital forms of data physicalization are increasingly used in both education and design. To systematically use physicalization in design, Hornecker & Buur propose a framework that emphasizes four main themes: Tangible Manipulation, Spatial Interaction, Embodied Facilitation and Expressive Representation [23]. Adapting this framework for physicalization in design enables interesting new relationships between physical and digital representations.

This relatively new approach to communicate data in a physical manner can be identified in various works, most notably as a means to create awareness about energy consumption [7, 42, 47, 49, 50]. CairmFORM, for example, uses a tangible user interface to indicate green energy availability. Consisting of expandable, shape-changing ring lights, the artifact stimulates reflection on energy usage through physicalization [10]. Watt-light, similarly, uses lamps to indicate the current domestic energy usage [26]. Watt-I-see adapts a similar, abstract approach, using LED illuminated sockets to indicate whether the electricity has a sustainable source. Through a lava lamp-like interface with glass tubes, sources of power are indicated in an ambiguous, tangible way [46].

However, though more rarely, physicalization has also made its appearance in the area of data transmission. One of the most defining artifacts in this field was introduced as an inquiry into the design opportunities surrounding Calm Technology. The ‘Dangling String’ is an eight-foot piece of plastic that was placed in an office and hung from a small electric motor mounted in the ceiling. Electrically connected to an Ethernet cable, the string’s level of movement depended on the amount of ‘information’ that passed the string. The speed of the motor created different octaves and movements, depending on the intensity of network usage, creating peripheral information about the intensity of network usage within the company [59]. In another project by Hiroshi’s group, a small group worked on an origami spinning wheel which speed was dependent on the number of visitors on a website. As the number of visitors increased, the wheel started spinning faster, making this digital phenomenon tangible [9].

### Material Speculations

Building on prior research into the exploration of new perspectives on technology, a material speculations approach was adopted in this research. The approach by Wakkary et al. introduces a counterfactual artifact to an everyday setting which initiates speculations about possible futures by an observer to reason upon [55]. High-fidelity prototypes are used to explore and question possible, and preferable futures in emerging technologies. The approach of material speculations has proven its value in exploring new perspectives on ambiguous technological HCI subjects and in physicalizing questions to stimulate speculation about ‘possible worlds’ [53, 55]. Rather than following a design fiction approach, wherein the conceptual artifact itself is emphasized, material specula-

tions allows for a new form of explorative research within the field of design [53]. This approach invites for the exploration of designs which are not focused on usability. This follows the ethnographic, speculative approach by Hemmings et al. wherein experimental and extreme art and design methods are implemented in design studies [19].

Emphasizing the domestic component of material speculation enables an ethnographic exploration into people and their relationship with the home as described by Auger [3]. By introducing a counterfactual artifact, aesthetically opposing the existing landscape, in a domestic environment, new relationships between organism and environment are stimulated [3, 23, 55, 57]. The table-non-table by Odom & Wakkary adopts a similar approach, introducing an ambiguous object that opposes the existing landscape through shape and material, aimed to provoke speculations and initiated reflections about its purpose and functions [36]. Other projects including the Morse Things by Wakkary et al. and Rudiment #1 by Helmes et al., follow similar patterns as a means to create deeper understanding of the possible futures technology entails [18, 21, 29, 44, 55, 56, 57].

On the intersection of art and technology, a number of prior projects that use ink printing for aesthetic and communicative purposes exist. A notable project in this field is the Heart Calligraphy project by Artist Rogier Arents and PhD student Bin Yu. This project makes use of an installation that creates visual art using a heart rhythm sensor [43]. The installation creates brushstrokes, whose size is mapped to the measured heart rate [43]. This project applies concepts from aesthetics to communicate ambiguous data. It introduces a new form of data physicalization, which is focused on ambiguity as a means to generate interest and curiosity.

### Summary

Though various projects have been conducted using physicalization as a means to initiate understanding and explore potential perspectives in a HCI context, little research is done in the domestication of such approaches, specifically within the subject of data transmission. Following research into speculative design artifacts to observe possible futures on ambiguous technological HCI subjects, the gap between the physical and digital realm is bridged through an emphasis on materiality in the context of digital phenomena. Contradicting the restraints from the commercial sector, our artifact aesthetically and functionally opposes the domestic environment, in this way spiking the participants' interest and curiosity. In this research, the subjective interpretation is embraced as a driver of novelty and unexpectedness, magnifying the influence of physicalization in an increasingly digital era.

### PROTOTYPE

To explore how physicalization of data transmission might initiate new perspectives on data, a research probe was developed; the Transmission Ticker (Figure 1). The Transmission Ticker is a setup consisting of two pens and a roll of receipt paper which are individually driven by two motors. This setup is placed on a wooden base, inside which the supporting electronics are situated. The setup is enveloped by a bell jar.

The Transmission Ticker physicalizes the real time usage of data in the respective home where it is installed by printing dots on the roll of receipt paper (Figure 2 & 3). Every ten minutes, the two pens each print one dot. These dots visualize the amount of data used in this past time interval through their size, dots being bigger as more data has been consumed.



Figure 2. Overview of the Transmission Ticker

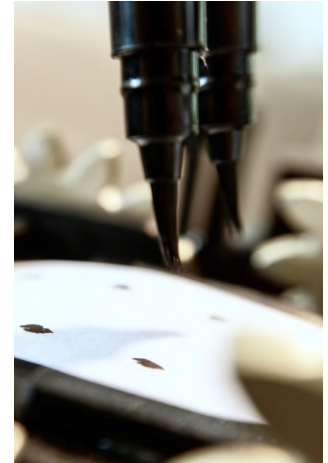


Figure 3. Close-up of the Transmission Ticker

Real-time data usage tracking of a household is enabled through the following setup: A network switch with port mirroring is placed between the internet access cable of the household and the router transmitting the household's WiFi signal. The network switch tunnels the data to a Raspberry Pi which uses the packet analyzer Tshark to convert this signal into quantitative values that express real time data usage. These values are communicated to an Arduino located inside the Transmission Ticker via a wired serial communication. The Arduino ultimately translates these values into corresponding commands for the motors which drive the receipt paper and pens.

### Inspirations

The final concept of the Transmission Ticker embodies the emerging and technologically advanced concept of high-volume data exchange. Iconic 20th century mechanical designs have, however, been a great inspiration for approaches of artistically physicalizing data. The most important inspirations being the stock ticker and the pen plotter.

The stock ticker is a device that prints the current price of several companies stocks on a thin roll of paper called Ticker Tape [37]. It was mainly used in the early 20th century in the US stock market. It has a characteristic look because of its clearly visible mechanically moving parts and the bell jar surrounding the machine. The stock ticker inspired the development of the Transmission Ticker, because it is an historic symbol of real time physicalization of information while being physically interesting both in its looks and movement.

Another historic mechanical device that inspired the development of the prototype is the pen plotter, a predecessor of the inkjet printer [35]. Pen plotters are printing machines, which use pens to draw vector-graphic images. Pen-plotters

reflect an aesthetic way of producing graphics, conveying the beauty of irregularity through the imperfection of the paper and pens [60]. Aesthetics through irregularity in printing has been reflected before in design in the already discussed project of Bio-Plotter [61]. This project has been a great inspiration in the development of the Transmission Ticker.

### **Reasoning**

The historic industrial look was purposefully chosen as one of the distinguishing characteristics of the Transmission Ticker. With its historic look, the Transmission Ticker goes against the concept of 'Form follows Familiarity' as proposed by Auger [3]. It looks alienated in the standard modern home interior, spiking the household members' curiosity, and making them reflect on the Transmission Ticker and its function.

For the study the choice was made to manufacture a high-fidelity prototype, making use of real manufacturing materials like wood, glass and polished plastics. In material speculation, high-fidelity prototypes are used because they enable long-term deployment, allowing them to become part of the home environment [55]. The Transmission Ticker as a high-fidelity prototype creates an opportunity to study the impact and roles it can have in a home, thus enabling a deeper understanding of how the artifact impacts participants' understandings of data transmission.

The tracking of data transmission brings about lots of quantitative information. Data visualization amplifies human cognition, thus enhances the recognition of patterns and prevents cognitive overload by reducing the search needed for finding information [27]. Dots are an elegant, nonjudgmental, yet ambiguous way to visualize data usage, allowing for quick meaning-making by the observer of the represented data. The decision for the method of data visualisation was also based on the importance of ambiguity that is pressed by material speculations [55].

The two nearly identical dots which are printed every ten minutes, make for a symmetrical aesthetic appearance. They highlight the Transmission Ticker's artistic qualities through proving that while both pens are moved in an identical way, irregularity and difference in expression is still present between the two dots that have been printed [60].

Incorporating the aspect of physicality from material speculations, people's data usage was physicalized as opposed to digitally represented [55]. Physically printing dots on paper creates a tangible track record of data usage and thus invites participants to examine their past patterns of data usage, making them reflect on it. Moreover, the technical and physical process of printing that the Transmission Ticker performs makes it seem alive through its movements and sounds. This enables participants to be reminded of their data usage through peripheral feedback in the form of both sound and movement.

## **METHOD**

### **Research Approach**

The aim of this study was to observe domestic behaviors and interactions, to explore occurring changes in the participants' perspectives on the Transmission Ticker, this to explore new perspectives on data transmission in a domestic setting. Therefore, a material speculations approach together with an ethnographic and autoethnographic research methodology was adopted. These approaches allow for the incorporation of both observations on perceived and described experience regarding the evolving perspectives and observations throughout the deployment.

Ethnography allows one to observe the everyday practices of people and interpret them to understand the underlying motivation and values attached to these practices [15]. This enabling rich insight into evolving perspectives of participants.

An autoethnographic approach was adopted since this enabled the involvement of the first-person perspective. Autoethnography accepts that the researcher is subjective in his interpretation of the world and values this reflective subjectivity as a valuable contribution to the conducted research. [32, 54] Moreover, only an individual himself is able to observe his deepest thoughts, drivers and desires and thus come to the fullest understanding of how his relationship with data is affected through the developed artifact.

For complex, yet unexplored, societal problems like increasing data consumption, speculative design is often used to explore possible futures [3]. In this study a possible future is explored where people would have understandings of data consumption which are comparable to current understandings of energy usage. A future in which there is an awareness and understanding of data consumption, of its environmental impact and of its limits. Speculative artifacts, like those designed as material speculations, have shown to provoke critical reflection in users of their current situation by bridging the actual and the possible world [55]. Due to the openness in interpretation of the speculative artifact, the meaning-making and understanding of the possible future is shifted to the user, allowing for a broad exploration of a topic like data transmission. The approach of material speculation was therefore taken in this research [55].

### **Deployment**

The Transmission Ticker was deployed for a five-day period in three households. Prior to the deployment period, a two-day pilot test was conducted to review the developed research setup. The households varied in composition, each consisting of a researcher and his or her family or housemates. All researchers had academic experience in interaction design through their studies, whereas the other residents differed largely in background, education and pre-knowledge in the field of HCI. Below we discuss the various households and selected participants. All participants, except for the researchers, were given pseudonyms to protect their privacy.

The first household consists of four housemates, of

which two were researchers and two were participants. The researchers are Mike Roozenburg (20) and Lotte de Lint (19), while Marty (20) was a participant in the pilot and Lorraine (20) a participant in the final study. All members of the household are students who all currently study Industrial Design.

The second deployment was conducted in a three-member family, consisting of one researcher and two participants: The researcher, Wouter Meeuwis (20); Jennifer (21), the sister of Wouter and also a student, and Stella (54), the mother of Wouter and Jennifer.

The third household is a family of four, of which two parents and two sons. The researcher, Mats Erdkamp (20) is one of the sons of the family. The two participants in this household are father, Emmett (54) and mother, Clara (54). Emmett has a background in IT.

At the time of the study, a stay-at-home policy was in place due to the situation regarding COVID-19. All researchers and participants were therefore mainly working from home.



Figure 4. 1-3 The Transmission Ticker deployed in the different households

### Data Collection

To generate rich insights regarding the experiences, interactions and perceptions of the participants, different forms of data were gathered. The data collection methods were divided in two, consisting of ethnographic and autoethnographic methods. Ethnographic data collection was conducted through interviews, journal entries, observations and photographs. The autoethnographic data collection, meanwhile, consisted of journal entries and reflections, which were discussed and reflected upon by the researchers in a workshop.

Prior to the deployment, participants took part in an interview, providing the researchers with insights about their initial data perspectives and pre-knowledge of data transmission.

Participants were subsequently asked to journal during the deployment phase of the study. Together with the artifact came a physical diary, wherein participants were encouraged to write at least five minutes a day. This diary contained a number of inspirational questions and assignments to gain insights regarding their perception of the Transmission Ticker. In addition to keeping these journals, participants were asked to take photos of the artifact. Through these photographs, insights could be gained on the moment-to-moment perceptions of the participants and on what participants considered 'photo-worthy' or interesting.

Furthermore, observations were made by the researchers

regarding the participant-artifact interaction and interactions between participants. The AEIOU framework was employed as a tool to structure the observations that were made [17]. Within this framework, emphasis is placed on describing Activities, Environments, Interactions, Objects and Users.

Lastly, at the end of each day, the receipt paper was removed from the artifact, and timestamps were placed on both the beginning and end of the paper. These pieces of tape were then presented close to the artifact, inviting participants to write or draw on specific parts of the tape. This to open up a discussion about their behavior of the past days and to generate a tangible reference of their data usage over the past few days.

The ethnographical study was concluded by a semi-structured post-interview. The main purpose of this interview was to start a discussion about the meaning and functions of the Transmission Ticker, with the aim to examine a possible change in attitude which contrasted the pre-interview. Set questions and personal questions regarding the participant's data were combined in an effort to gain a deeper understanding of the reasoning behind certain journal entries and photos.

The autoethnographic part of the study consisted of the researchers keeping their own log of interesting observations and personal insights. Through daily journaling and reflecting on the presence of the Transmission Ticker, the researchers kept track of their personal insights and development of perspectives throughout the deployment. These insights would be discussed at a later stage in the form of a discussion, which will be presented in the data analysis.

### Data Analysis

After the finalization of the deployments, the collected ethnographic data was processed by a researcher who was unconnected to the researched household, this approach was taken to minimize biases. The interviews were selectively transcribed and analyzed together with the journal entries, photographs and observations made during deployment. All data points were analyzed through a thematic analysis, during which the data points were grouped into themes, these themes were subsequently clustered into overarching themes. This led to an understanding of the participant's experience, allowing for conclusions to be drawn about how participants perceived the artifact.

The autoethnographic data was processed through a workshop that was conducted by the team of researcher. During the workshop the researchers reflected on their journal entries and experiences during deployment. At the beginning of the workshop, the researchers presented their main feelings and experiences related to the deployment period through short individual presentations. Through this approach, a discussion about their experiences was initiated, while contrasts between the perceptions of the researchers were emphasized. The workshop was concluded by identifying a number of overarching themes that combined the insights gained by the various researchers.

As a finalization, the main themes from both the ethnographic and autoethnographic thematic analysis were combined and compared. Based on the overlap and contradictions in these themes, a final, overarching set of themes and sub-themes was composed to represent the main findings of both streams of data.

## FINDINGS

After thematic analysis of the collected data and the merging of the ethnographic and autoethnographic datasets, four main themes were identified: 1) the artifact becoming part of the family; 2) changes in data-awareness and behavior; 3) change in behavior due to habituation; and 4) development of critical data perspectives. The first theme mainly describes the role that the Transmission Ticker fulfilled in the households, causing the phenomenon described by theme two and three. The last theme represents what impact theme one to three had on the participants' wider perspectives on data.

### The artifact becoming part of the family

#### *Appreciation of its aesthetics*

In all households, the participants expressed appreciation of the aesthetic qualities of the Transmission Ticker, which resulted in them giving it a prominent place in their homes (Figure 4). Stella described it as being *'beautiful in her interior'*, while Emmett expressed appreciation for its nostalgic look. Marty underscored that the level of abstraction of the device emulated its beauty. This appreciation of the Transmission Ticker caused by its physicality, beauty and intricate mechanical shape hints at the importance of interesting aesthetics for a device in the home.

#### *Anthropomorphism*

During the study, multiple participants attributed human characteristics to the Transmission Ticker. This could be an indication that a deeper emotional attachment that had been developed with the artifact. Both researchers and participants described checking up on the device to ensure that 'he was alright'. Wouter described: *'I felt compassionate towards the Transmission Ticker when it had to work hard when data consumption was high.'* Anthropomorphism was displayed most clearly by Clara, she described that the device had felt like a living being to her and that she had therefore named it Wally. The emotional attachment resulting from the anthropomorphism of the Transmission Ticker was also reflected in the participants' actions. There was a constant checking up on the artifact and messages were sent to the researchers by the participants when the device seemed to be acting out.

#### *Feeling tracked*

Throughout the study participants expressed feelings of discomfort regarding their data privacy, they felt tracked by the artifact, even with the artifact's high level of abstraction of data tracking and visualization. Marty expressed that he felt *'like somebody's watching me, like Big Brother'*, while Lorraine described him as a quiet observer. The importance of physicality in enticing a feeling of being tracked becomes clear through Clara and Emmett expressing that they had online data tracking tools, but did not use them or felt observed by them. The participants and researchers became aware of how their

domestic behavior can be extracted from their data consumption patterns, even from the low-detail abstract visualisations provided by the Transmission Ticker. This functioned as a trigger for reflection on the unparalleled amount of information that could be derived from the big data sets multinational technology companies already have of every individual.

#### *A trigger for reflection and discussion*

Through curiosity about the Transmission Ticker, active reflection and discussion arose about its functionality and the broader concept of data. Clara indicated it being a topic of discussion with guests. Stella and Jennifer started to actively 'test' the artifact by purposefully using a lot of data and watching its 'reaction'. In the post-deployment interview Lorraine, Stella and Jennifer all indicated that they would like to know more about data and its origin. Both in their actions and answers participants exhibited an increase in curiosity about data over the deployment period.

### Changes in data awareness and behavior

#### *Awareness of personal data consumption and dependency*

A clear increase in awareness of the moments of data consumption and personal dependence on data consumption was present in both the researchers and participants. Stella, for example, learned about the concept of background data, through the dots that were printed when everybody was offline. Multiple participants also actively attempted to pinpoint what activity had been conducted when specific dots had been printed. Moreover, Lotte experienced an increased awareness of data dependency through noticing a constant continuity of dots, indicating the ever-present transmission of data.

#### *Little change in behavior*

While there was enlarged data awareness present, little change in data consumption behavior was exhibited. Lorraine, Stella and Jennifer all indicated that they had not lowered their data consumption behavior over the course of the study. This matched the observations made by the researchers that data consumption behavior was consistent over the course of the study. Stella did indicate changing her behavior, but with the purpose of testing the device. Lotte changed her behavior by spending more time offline, wanting to decrease her constant online presence. Participants thus experienced little stimuli from the Transmission Ticker to lower their data consumption.

### Change in behavior due to habituation

#### *Decline in active revision*

Over time, the active revision of the physical printed dots decreased in frequency and its purpose shifted towards serving as a long-term behavior tracker and reflection tool (Figure 6). Participants gradually became less reactive to the Transmission Ticker's activity, likely due to its fading novelty. Lorraine describing it as being able to *'track daily habits, both online and offline by inspection of the printed pattern of dots.'* Furthermore, Lotte used it to revise and reflect on her data usage over the period of an entire day (Figure 5). In multiple instances, participants discussed previously printed dot-patterns, justifying these based on their actions within the household. Lorraine writing: *'Small-sized dots today; must have been because Lotte was painting, and I was making clothes.'*



Figure 5. Inspection of receipt paper for long-term reflection

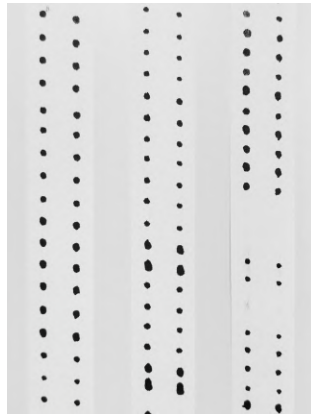


Figure 6. Examples of dot patterns created during deployment

### The changing role of sound

As habituation of the artifact occurred, the auditory stimuli of the Transmission Ticker became increasingly important in prompting reflections on data consumption. A clear mechanical sound was present when the pens were pressed on and lifted off the paper. Lorraine and Jennifer both indicated that the sound acted as a reminder of the artifact its presence. Emmett, contrarily, indicated that after some time he stopped reacting to the sounds coming from the artifact. For Clara, hearing the sound was a trigger to roll back her chair and take a look at the Transmission Ticker. The audible duration of the dot printing was an indicator for the quantity of data that had been consumed and was therefore used by Lotte and Mike to reflect on their data usages while working. Mats started to guess the size of the dots before looking at the receipt paper, based on a revision of his behavior over the past time interval. Lastly, the Transmission Ticker took on the role of a timer in Mats his household, as the family adopted it as a reminder of time. A great variety of functions was derived from a low information auditory cue, proving the power of a non-intrusive peripheral cue in triggering awareness and reflection.

### Development of critical data perspectives

#### Speculative visual representations

In the post-interviews, participants were able to give high-definition, speculative, visual representations of their understanding of data. This contrasted their mostly flat answers given when the same question was posed during the pre-interview, demonstrating a remarkable development in the participants' understanding and awareness of data. Marty, for instance, envisioned data transmission as a 'stream or river, the web pages being represented by little fish and tv-shows by sharks.' showing significant change in his perception of data compared to his pre-interview description, in which he stated that '[Data transmission is] activities I do that are saved on the internet.' When Stella was asked to draw her vision on data, she drew presents and boxes floating in the air, each one representing a packet of data (Figure 7). The vivid descriptions given by participants in the post-interviews likely represent the occurrence of critical reflection into the meaning of data during the study.

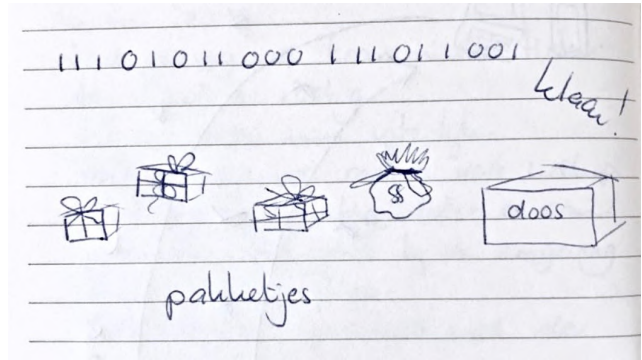


Figure 7. Stella's drawing of her understanding of data

#### Power and privacy implications of data

Both participants and researchers had the experience of being watched and tracked by the Transmission Ticker, provoking reflections on the power of and privacy concerns regarding data transmission. Lorraine described that 'In the future, we will be tracked like currently done in China.' Whilst, Marty speculated that the power obtained through data might cause a revolution. Lastly, Clara described that we will come to live as 'robots' where self-driving cars and automatic kitchens provide us with any comfort. These mostly critical and future-oriented perspectives demonstrate an increase in awareness of big data's power.

#### Presence and importance of data in the world

Comparing pre- and post-interviews, several participants and researchers articulated more elaborate and powerful visions on the importance and presence of data in the world. Lorraine, for example, described data as being her 'gateway to the bigger world, the way to transcend the 'bubble' of home.' Clara emphasized the widespread use of data: 'Everybody is using data, even unconsciously, from babies to the elderly.' On the other hand, Stella expressed that without data, we would end up in prehistory again.

#### Addressing high-volume data consumption

In the household of Wouter, curiosity was expressed by participants about the influence of high-volume data consumption. This led to speculation about personal drivers for change in the participants' behaviours. Jennifer described that data will become 'healthier and more sustainable in the future', while indicating that money would be a driver for her to lower her consumption. Stella contradicts this by indicating a lack of monetary drive, predominantly displaying sustainability-driven motives.

### DISCUSSION

The following discussion presents the main insights drawn from our speculative design research, reflecting on the goal we posed at the beginning of this paper; explore the use of physical, domestic products as a means to generate understanding of and initiate new perspectives on data transmission in the home. Expected and unexpected findings are discussed to present the opportunities derived from the usage of abstract human-object communication to generate possible futures regarding data consumption. We reflect critically on the biases and limitation

of this study, reviewing the influence of our methodological combination of material speculations, ethnography and autoethnography on the study and on the results. Additionally, we propose six design recommendations for data comprehension to be deployed in future data-awareness products as a driver of behavioural change to the excessive usage of data. In the end, suggestions are made regarding interesting areas for future works that were uncovered during this study.

### Reflection on findings

In this study, one of the main components was the initiation of reflection through the physicalization of data transmission. This phenomenon was clearly represented in the behaviors during and answers given after the study. Most participants showed remarkable growth in their understanding of data and were able to provide a more elaborate description of their perspectives of domestic data transmission at the end of the study. Most participants mentioned to have clearly experienced motivation to explore the subject of data transmission by the behavior of the artifact.

As designed for, the artifact's ambiguous character invited for reflection and speculation about its purpose and function, resulting directly in similar reflections and speculations about data transmission as concept. Nevertheless, although the participants clearly stated the value of long-term reflections through the artifact, this was not reflected in their behavior. Throughout the entire study, no more than one participant actively reflected on its data consumption using the receipt paper of earlier days. All in all, the provided physical tool for long-term reflection was generally underused by participants, indicating that it was likely not regarded as useful or inspirational enough.

The little observed change in behavior can be likely explained through the participants' perception of multiple attributes of the Transmission Ticker. Firstly, there was a high level of perceived ambiguity of the information provided by the artifact. Moreover, Emmett was not convinced that dot size increased due to higher data consumption. This indicates that participants were not able to easily distinguish the differing size of dots and thus compare their usage of data throughout the day. Thirdly, the Transmission Ticker was perceived as non-judgmental; multiple participants expressing that its behavior felt neutral. Jennifer also expressed that she still did not *'know whether data is bad or not'*. Lastly, no limits on data consumption were imposed on participants. Multiple participants, however, indicated that they do regularly change their data consumption due to a limitation imposed by their phone subscription.

Secondly, the artifact was designed to invite for experimentation as a means to create deeper understanding of data consumption through interest and curiosity. This was confirmed through their actions; actively turning devices on and off as a test, their interview answers and their inquisitive journal entries. These behaviors are in line with earlier studies which employed material speculations, wherein ambiguity and abstraction form a clear basis for active participant interaction [55].

The sound of the artifact formed an unexpectedly important component of the short-term reflection of data consumption by participants. The sound of the Transmission Ticker was a direct consequence of the mechanical experience. Interestingly, however, the sound served as one of the main components in the initiation of reflection for both the participants and researchers, enabling them to reflect on their consumption over the past 10 minutes. Sound acted as a trigger to observe the artifact and caused reflection through the sound itself. The information, communicated through the sound by two parameters, caused passive reflection. Sonification, a field known as a subtype of auditory displays, using non-speech audio to communicate information, was unintentionally deployed in the artifact [58, 20]. This finding aligns with the earlier described 'dangling string project', where sound was a key driver for developing and understanding of data transmission [59].

Furthermore, the anthropomorphic interpretation of the artifact by the participants created interesting, unanticipated human-object relations. This finding reflects similar patterns to various speculative design studies, whereunder Morse Things, Table-non-table and Rudiment #1, wherein participants assign human emotions to non-living objects in an attempt to attach purpose to ambiguous, unfamiliar object behavior [55, 57]. The implementation of anthropomorphism is increasingly used in design as a tool to enlarge the users feeling of connection with an artifact [13, 40].

Lastly, the physicalization of domestic data transmission resulted in an increase in awareness of data privacy. As a combination of the anthropomorphic interpretations, making participants feel 'watched', and the visualization of the participants data usage over time, users become more aware of the information that could be derived from even such ambiguous data tracking. This is in line with the privacy paradox, which describes that the state of awareness fades away vastly when a stimulus is no longer present [45]. Continuous emphasis on the presence of an artifact and thus on the privacy issues is therefore caused by the physical characteristics, movements and sounds of the artifact.

### Reflection on the study and its limitations

#### *Relationships*

The nature of the relationships between researchers and participants can be of great influence on the participants' behavior and thus on the outcomes of the research. In this study, all researchers were living with the study participants and were either related to or close friends with the participants. The close relationships researchers had with the participants might have caused subconscious steering of participants by the researchers. Steering might have occurred through the reactions researchers gave to answers in interviews or through the researchers' actions in the home, causing the participants to exhibit the desired behavior.

The positive effect of these close participant-researcher relationships however, was that researchers were presumably better able to interpret behaviors of the developments in perspective of the participants [8]. As a result of this, the researchers might have come to better conclusions regarding the participants' underlying drivers and values.



Stay-at-home measures were in place because of the situations regarding COVID-19, at the time the study was being prepared and set up. Meetings on the study were therefore conducted in rooms where the future participants were present, as was the building of the prototype. Because the participants had observed the study preparations, the possibility exists that they had gained pre-knowledge on the study and had already had reflections on the subject prior to the study. This might have caused the baseline interview to be less representative and might have provided participants with pre-knowledge on the artifact and the concept of data transmission.

Nonetheless, the fact that the researchers were already living with the participants likely weakened the participants' feeling of being in a study and of being observed by a researcher. This likely resulted in the participants behaving as little out of the ordinary as possible, providing a better opportunity to study actual reactions and behavior. Ethnographic studies often take such an approach of integration into a group, as it enables them to better study participants in a natural setting [8].

#### *Influence of the artifact*

All researchers have a background in Industrial Design. This might have primed them to overestimate the value and influence of design, and thus, in turn, the effect the artifact had on the participants' actions and reflections.

Besides, participation in a study about data likely had a positive effect on the participants' interest in, and reflection on data transmission. Without the presence of the artifact, the mere participation in the study and the task of journalling would have likely affected the participants' perspectives on data. The involvement of data perspectives is thus not self-evident prove of the ability of the artifact to initiate reflection by itself.

#### *Participants*

The group of participants in this study was rather unrepresentative of Dutch society, negatively influencing the generalizability of insights. Five out of six participants were highly educated. Moreover, all research participants were from western culture and part of the upper-middle class. Lastly, three participants had an above-average level of pre-existing knowledge on the topic; two having a background in design and one in IT. This rather homogeneous group of participants, with above-average expertise, might have created a skewed view of how people react to the research artifact.

#### *Study duration*

Finally, this study is limited in its ability to study the long-term effects of the research artifact on the participants' perspectives on data transmission. The time allowed for three deployments of five days, during which habituation of the artifact occurred. No conclusions can, however, be drawn regarding the additional habituation that could occur and how this would influence behavior.

#### *Material speculations*

When reflecting on the approach of material speculations in this study, we conclude the approach was highly effective for the subject of interest. Material speculation enabled habituation and incorporation of an artifact into the home to be studied. Factors that are of great importance when designing for the domestic environment.

#### *Autoethnography and ethnography*

The combination of ethnography and autoethnography, that was taken in this study, proved to be a generator of valuable and rich data. In the gathered data, both the first- and third-person perspective were well-represented through the different deployed techniques for data collection. This allowed for diverse exploration from different angles of the generated perspectives. Moreover, different meanings of identical data were extracted through different levels of interpretation. This, for example, through the group discussions held about the autoethnographic research and the interview which were interpreted by a researcher who was unrelated to the particular interviewed research participant. The different kinds of data, perspectives and interpretations gathered, allowed for the formulation of a refined picture regarding the generated perspectives on data transmission.

Moreover, the different streams of data gathered in the ethnographic approach allowed for triangulation of insights. This increased the credibility of identified results. The combined methods approached was furthermore valuable as it allowed the researchers to better empathize with the study participants through their autoethnographic experiences. The researchers had critically examined their behavior, their interpretations of these behaviors and their underlying values. Through this, they were better equipped at asking questions and interpreting behaviors to identify the true drivers and values of the participants.

#### **Recommendations**

Observing the behaviors, perceptions and reflections of the participants in the context of the Transmission Ticker, a number of design recommendations are proposed to form a basis in creating meaningful, effective data-awareness systems to be deployed in a domestic setting. These recommendations represent an interpretation of the behaviors and reflections of the participants that initiated new valuable perspectives on and insights in data transmission. It subsequently forms a basis for a deeper understanding and interest in the field of data transmission, providing six initial principles for the design of domestic data awareness systems.

#### *Design for reflection*

Facilitation of both short- and long term reflection was perceived in this study as a crucial component to initiate understanding and create critical insights in data usage. Based on the perceived effectiveness of sonification as a stimulus to initiate short term reflection in our research, the usage of peripheral stimuli to promote short term reflection is recommended. This resonates with the emerging field of sonic interaction design [20]. To motivate for long-term revision of data consumption, visualization with clear timestamps has shown to generate value for users, as it allows for overview of activities.

#### *Design for frame of reference*

Creating a frame of reference has shown to be one of the main drivers of behavioral change. This study indicates three criteria to create this frame: limitation, judgement and comparison. Through these three criteria, deeper understanding in the quantity of data transmission can be generated, enabling users to make more educated decisions about their data usage,

while introducing a measurer to impose more critical decision making.

#### *Design for personal involvement*

To stimulate conscious behavioral change, an important facet described during this study is the creation of personal involvement. We propose to connect data consumption to more graspable subjects, to enhance understanding as a means of stimulation. In this study, participants became involved with the artifact, and the connected data consumption, by connecting with the artifact on an emotional level and through connecting its functionality with topics in their world of experience. Linking familiar subjects like privacy and sustainability to the largely unknown field of data transmission has shown to increase interest and understanding.

#### *Physicalize*

Users seem to be used to digital confrontation with the negative trade-offs of their digital behavior like privacy infringement. Based on repeated remarks about digital data consumption measurement software by the participants, it became clear that participants feel only minimally confronted by digital warnings. This showed a clear contrast with their interpretation of the Transmission Ticker, which physical behaviour was perceived as both intrusive and confrontational by the participants. Through a physicalized feedback system, the user will likely experience an increased feeling of the 'realness' of their data consumption and an elevated level of confrontation.

#### *Design for safety*

The mapping of data consumption over a period of time has shown to increase the user's awareness of behavioural tracking through data. We propose to design for a feeling of data safety, distancing the design from the debate of privacy infringement to emphasize trust. Participants described a feeling of 'being watched', caused by the anthropomorphic characteristics assigned to the artifact. This resulted in a feeling of unsafety regarding data usage, while triggering an understanding into the consequences of cookies and big data. To emphasize usability embrace the importance of privacy in design, this phenomenon should be taken into consideration.

#### *Consider ambiguity*

Finding a balance between ambiguous and concrete visualisation seems to form an important influence on the interaction with and meaning assigned to an artifact. Whereas ambiguity allows for curiosity, and thus invites the user to speculate and create its own understandings and perspectives on the communicated data, it simultaneously decreases the possibility to serve as a behavioral check. During the study, the ambiguity of the artifact resulted in a critical reflection by the participants on its actual functionality. We emphasize the importance of carefully considering the level of employed ambiguity in data-awareness design, this to align it with the broader aim set for a particular design.

#### **Future Work**

The Transmission Ticker study aimed to explore initial insights in potential features of future awareness systems. Our findings show promising possibilities for valuable human-object interactions to be deployed domestically. Yet, more research

is proposed to further explore specifications, elaborations and development of a framework in the design of data awareness systems to be for commercial use.

Firstly, further research is advised in the enhancement of awareness and behavioral change through the connection of the subjects of data transmission and sustainability. This study has shown that this connection is not automatically made by participants, even as awareness of data transmission increased, while this would potentially be a motivator to change data consumption behavior.

Furthermore, the recommendation *Design for frame of reference* is a valuable subject for further research. The three currently proposed criteria are broad in nature because of the explorative aim of this study. Examining the possibilities for creating such a frame of reference and researching differing levels of effectiveness would enable the development of clearer guiding principles for data awareness design.

Lastly, this study has presented a number of unexpected findings for which was not specifically designed. Future work on these subjects would enable the exploration of their potential. Specifically, considerations of the implementation of anthropomorphism and privacy as motivators for data-conscious behavior are regarded as interesting future fields of research.

#### **CONCLUSION**

In this paper, we explored what new perspectives on data are initiated through the physicalization of data. The gap between the physical and digital realm is bridged through the Transmission Ticker; a counterfactual artifact that physicalizes domestic data usage and thus emphasizes its materiality. This artifact was deployed within the researchers' households for five consecutive days during which an (auto)ethnographic study was conducted. The ethnographic data gathered from this deployment was thematically analyzed, and a workshop was conducted to, reflect upon, and interpret the autoethnographic data. The main findings include incorporation of the artifact into the family, changes in data awareness and behavior, changes in behavior due to habituation, and the development of critical data perspectives.

Subsequently, we presented a series of design recommendations for future data awareness systems based on the insights gained during the study. These recommendations mainly focus on promising factors that pose opportunities for behavioral changes to the excessive domestic usage of data. Lastly, we propose suggestions for future research to further explore the opportunities and phenomena presented in this study.

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