Building Digital Infrastructures: Towards an Evolutionary Theory of Contextual Triggers

Dina Koutsikouri
Swedish Center for Digital Innovation,
University of Gothenburg, Sweden
dina.koutsikouri@ait.gu.se

Ola Henfridsson
University of Warwick, UK
ola.henfridsson@wbs.co.uk

Rikard Lindgren
Swedish Center for Digital Innovation,
University of Gothenburg, Sweden;
University of Borås, Sweden
rikard.lindgren@ait.gu.se

Abstract

Past IS research suggests it is challenging to build digital infrastructures and then make sure they grow. While more users, innovative services, and new partners spur infrastructure evolution, we know little of the specific contextual triggers that set these generative mechanisms in motion. To this end, we conduct a case study of a digitalized public transport infrastructure to identify such triggers and explore their impact on its evolution. Our study contributes to the extant literature on digital infrastructure evolution in two distinct ways. First, we analyze, define, and propose three contextual triggers that improve our understanding of the generative mechanisms behind infrastructure development and growth. Second, we rely on this conceptual basis to sketch out the initial contours of a novel evolutionary theory of digital infrastructure triggers.

1. Introduction

Digital infrastructures have the power to restructure construction, healthcare, and transport. IS scholars have therefore paid recent attention to their role in societal development. Past research suggests that a well-functioning digital infrastructure constitutes a considerable resource for service innovation in any industry [1]. As such, it attracts more users and enrolls new partners, which create momentum that ultimately drives its further growth [2, 3]. At the same time, however, bringing such infrastructure to existence, making it work, and keeping it vibrant is fraught with challenges [4]. This means more knowledge on the building of these infrastructures is pivotal to IT professionals responsible for their management.

The notion of digital infrastructure in IS captures the emergence of increasingly complex assemblages of diverse actors and technologies. In particular, it seeks to zoom in on the complexity these assemblages render and related socio-technical dilemmas that surround them [4, 5, 6]. These dilemmas inevitably make deliberate managerial intervention difficult [7, 8]. Recent IS research conceptualizes therefore the building of digital infrastructures as an evolutionary process [9], which can be understood from a complexity, network, or relational perspective [3].

In this paper, we contribute to the received literature on digital infrastructure evolution. In particular, we zoom in on past studies of the generative mechanisms behind infrastructure development and growth [3]. They suggest mechanisms like adoption, innovation, and scaling are self-reinforcing and involve positive feedback loops [10]. Unfortunately, little is said about the nature and role of contextual triggers at play in making such mechanisms active. We define these triggers as transformational action-formation interventions that help to successfully evolve digital infrastructures. This notion of a trigger offers us a point of departure for advancing the current understanding of how to instigate infrastructure change. Our research question reads as follows: *How and why do contextual triggers activate generative mechanisms behind digital infrastructure evolution?*

We answer our research question by relying on an in-depth case study of the city of Stockholm's public transport infrastructure. It allows us to explore specific contextual triggers, scrutinize them vis-à-vis generative mechanisms, and analyze their impact on

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digital infrastructure development and growth. Specifically, we narrate an historical account of key events that unfolded during the initial design and subsequent implementation of the public transport infrastructure. Based on our empirical insights, we make two important contributions that extend received theory on digital infrastructure evolution. First, we analyze, define, and propose three contextual triggers that improve our understanding of the generative mechanisms behind infrastructure development and growth. Second, we rely on this conceptual basis to sketch out the contours of a novel evolutionary theory of contextual triggers. We believe our theoretical achievement may inspire IT professionals and policy makers alike to be mindful of the inherent power of such triggers in building and maintaining large-scale socio-technical systems.

2. Theory

Building a digital infrastructure that delivers innovative services to users is primarily concerned with how to design, initially implement and adapt a socio-technical network [11]. Meanwhile, the way infrastructures are used typically changes over time in a process of evolution and adaptation. Thus, the concept of digital infrastructure evolution is 'a gradual process by which a digitally enabled infrastructure changes into a more complex form' [3, p. 2]. Bringing such a system into existence (Monteiro et al 2013), making it grow [10] and keeping it vibrant is a continuous challenge. Given the increasing digitalization in society and ensuing expectations of its significance to help improve, for example transportation and health care, a task worth pursuing is to deepen our awareness and understanding of how deliberate interventions can trigger successful building of digital infrastructures.

We next develop the conceptual basis for such investigation by first reviewing prior literature that deals with design and control of digital infrastructure evolution. We then develop our conceptual apparatus for building new theory on how to trigger the successful evolution (adaptation process) of digital infrastructure based on our empirical context of public transport services development.

2.1 Digital Infrastructures

Some fourteen years ago, [4] popularized the idea that the evolution of digital[1] infrastructure is a complex process beyond rational managerial control. At least three streams of infrastructure research have emerged (complexity, network, and relational) since then, each of them embodying a distinctive view of the very nature of this complexity [3].

For example, the network view [see e.g., 12, 7, 13], founded in Callon's [14] and Latour's [15] early actor-network thinking, defines digital infrastructure evolution as "the process by which multiple human actors translate and inscribe their interests into a technology, creating an evolving network of human and nonhuman actors" [3, p. 910]. Here, the designer or policy maker who makes interventions to build a city infrastructure that evolves successfully would seek to facilitate translation of interests and technology inscriptions. Similarly, the complexity view [see e.g., 16, 11] emphasizes the facilitation of adaptation processes of heterogeneous actors, while strengthening people's meaning-making within a community of practice is at the heart of the relational view [see e.g., 17, 6, 18].

The idea of effectively intervening into the evolution of digital infrastructures has generally been treated with skepticism in prior literature [see e.g., 4], but still there exist a few promising attempts to do so. Hanseth and Lyytinen [10] conceptualize digital infrastructure evolution as a bootstrapping process where infrastructure evolves step-by-step and additional steps feed on the momentum of previous ones, exhibiting the idea of positive self-reinforcement.

To this end, Hanseth and Lyytinen [10] offer design principles that generate early growth through simplicity and usefulness and thereby address the bootstrap problem. In short, their design principles include: design initially for usefulness; build upon existing installed bases; expand installed base by persuasive tactics to gain momentum; make the design of IT capability as simple as possible; and modularize the digital infrastructure. These principles are further divided into design rules. Overall, Hanseth and Lyytinen's work stimulates productive thinking about how to build and maintain digital city infrastructures.

[1] Notions such as digital infrastructure, information infrastructure, and IT infrastructure are used interchangeably in the IS literature. We adopt the term digital infrastructure inspired by Tilson et al's [8] recent call for research.

At the same time though, it is fair to say that their design theory does not provide any adequate explanation of the multiple causal paths that might trigger generative mechanisms of digital infrastructure evolution. Tilson et al. [8] have called for studies that develop new digital infrastructure theory, and clearly theorizing such causal paths represents a viable opportunity for knowledge-creation with a high degree of relevance for managing complex change efforts in societal settings [cf. 19].

2.2 Contextual Triggers

Prior work on digital infrastructure and bootstrapping [10] suggests that self-reinforcement is essential to grow an infrastructure [5]. Despite that the evolution of digital infrastructures is vulnerable to top-down control [4], we argue it can still be guided by pursuing actions that create such generative impulse. Using Hedström and Swedberg's [20] seminal work on social mechanisms we think of contextual triggers as transformational action-formation interventions. More specifically, we define these triggers as a series of events generated by human actors whose deliberate actions give impulses to initiate generative mechanisms that make digital infrastructures grow in terms of users, services, and partners. We believe that with the use of this type of triggers, we can better explain digital infrastructure development and growth over time.

Organizational control and technical architecture represent key dimensions in making infrastructures evolve [12, 21, 3], which implies that the series of events that make up triggers consists of both dimensions, yet oftentimes tilted towards either one of them. We propose that control-focused triggers are attempts to positively influence an infrastructure's evolution by changing its control mode. Actions taken to centralize the control may, for example, involve efforts to promote adoption among a particular type of users rather than a diversity of users. Similarly, we propose that architecture-focused triggers are attempts to positively influence an infrastructure by transforming its architecture. Actions taken to offer a flexible, open-ended architecture can include, for example, attempts to trigger the creation of new innovations through third-party development. In sum, for any evolution process of digital infrastructure, there may exist a number of triggers, where each one, or in combination, influence the potential for user adoption, service innovation, or scaling of the infrastructure.

We argue that triggers do not exist in a vacuum, but reside rather in the context of contextual conditions and outcomes [cf. 22]. First, the triggers exist in the context of appropriate combinations of contextual conditions such as cognitive beliefs, artifacts, and legitimation [cf. 23, 24]. Cognitive beliefs refer to the actors' cognitive representations of the infrastructure and its role in the larger social and economic system it belongs to [25]. Artifacts refer to the tangible embodiments of the infrastructure [26], while legitimation refers to the practices and systems that define how the infrastructure should be evaluated [25]. Second, the ultimate outcomes of triggers are the inception of generative mechanisms of digital infrastructure evolution including adoption, innovation, and scaling [3]. These are self-reinforcing mechanisms that essentially generate user adoption, new services, and stakeholder growth.

The causal powers of adoption, innovation, and scaling of digital infrastructure evolution have been carefully treated in prior literature [3], but so far little has been done to further understand the actions that set them in motion. This means that the extant literature tends to treat context largely as a quite static entity related to control and architecture [e.g., 4]. Both these entities have traditionally been seen as causes with quite singular causal paths, and merely recent observations indicate that centralized control may not necessarily create negative effects on infrastructure evolution [3].

The recognition of equifinality, i.e., the notion that a particular outcome may have different causal paths [29], calls for more research that illuminates triggers to successful digital infrastructure evolution. Such knowledge is valuable for people responsible for governing digital infrastructures in ways that help to expand their use and reach. We conducted an in-depth case study of the public transport infrastructure in the city of Stockholm to inductively trace the contextual triggers leading to successful digital infrastructure evolution.

3. Research Method

We selected the public transport infrastructure in Stockholm as our in-depth case for two reasons. First, Stockholm has a leading position in public transport in general, and has launched a number of initiatives to develop their public transportation through the use of digital technology. For instance, Stockholm was early on releasing open data and APIs related to public transportation. At the point some of these initiatives took off, we gradually appreciated the case as a suitable venue for our research. After all, when generating theory, it is useful to examine “a case that is considered to be prototypical or paradigmatic of some phenomenon of interest” [28, p. 101]. We reasoned that selecting the Stockholm case would help us to generate a first view into public transport infrastructures by theorizing through idealization [29].

Second, we had useful access to a significant amount of respondents and data related to the evolution of this infrastructure. Rich and longitudinal data is important when wishing to trace underlying causal structures that may explain the occurrence of particular series of events. Given our use of critical realism as an under-laborer for our empirical study [30], data collection conditions in which “retroduction” [31] can be put into practice are important. This would involve enough material for enabling the development of new angles of the phenomenon studied, or repeatedly hypothesize mechanisms from empirical observations [32].

Data collection: We relied on several data sources including semi-structured interviews, participant observation, and archival studies. First, we conducted 20 semi-structured interviews with 19 respondents. The interviews were tape-recorded and transcribed verbatim. All respondents had been involved in the development of Stockholm’s public transport infrastructure in one capacity or another. We interviewed three senior managers at the Swedish Road Administration, two research institute directors, an innovation manager at a vehicle manufacturer, a manager at the transport office of the City of Stockholm, an IT project manager at a Stockholm Transportation Company, two technical project managers at a Gothenburg Transport Company, one innovation manager from the Swedish Transport Association, an ITS-manager, one public transport analyst, an administrator of transport related projects at the Swedish Innovation Agency, a third-party developer of travel applications, and four public transportation researchers.

Second, we also engaged in participant observation. The leading author of this paper spent 24 hours observing meetings and workshops related to projects in sustainable everyday traveling, including workshops on the future of public transport. Finally, our study included a significant volume of archival data, such as reports, press clippings, and online data resources. One significant type of archival data was reports written by consultancy firms and research institutes that participated in some of the projects focused on building Stockholm’s digital layer of the infrastructure. It helped us verify key events and review visions behind, and sometimes outcomes of, particular initiatives.

Data Analysis: The data was analyzed in three steps. The first step involved careful exploration of the research situation [35]. Our coding of the transcribed interview material helped us generate an initial understanding of Stockholm’s public transport infrastructure and its evolution and stakeholders. In particular, we generated a series of key events through open coding of the data material. We then, similar to Henfridsson and Bygstad’s research [3], identified the main objects [e.g., 34] associated with each event. This procedure helped us creating a data display providing a powerful overview of the infrastructure evolution process.

In the second step, we then used a procedure, which broadly maps the idea of retroduction, [33], in which we hypothesized possible triggers capable of generating the events observed in the data material. This process started from observations that indicated that the adoption, innovation, and/or scaling mechanisms were triggered. Using such an observation, we backtracked the process by which the observation was generated, paying specific attention to the elements we knew from Hedström and Swedberg’s analysis of action-formation mechanisms [22]. An important part of this process involved abstracting and analyzing objects (e.g. data portals, developed apps) in terms of their constitutive structures and causal powers.

Once faced with intermediate versions of the three triggers (adding service value, creating design attractors, and lowering infrastructure barriers) we challenged our emergent understanding vis-à-vis other plausible triggers. This process involved critical reflection on the social and historical background to account for how the event under investigation unfolded. Finally, drawing on Garud and Rappa’s [25] views of technology, we examined the contextual conditions of the triggers by distinguishing elements of cognitive beliefs, artifacts, and legitimation practices. We also examined the extent to which the events generated in our in-depth inquiry showed signs of significant user adoption, increased number of partners, and/or service growth. This was important to determine whether the outcomes, that is, the mechanisms of adoption, innovation, and scaling were actually triggered.

4. Case Study

Stockholm is a growing city that was recently ranked fifth when it comes to most congested cities in Western Europe. The population is estimated to increase by 25% in the next 15 years, and therefore its officials have taken action to leverage the public transport infrastructure by exploiting newfound digital opportunities. This is manifested through, for example, the introduction of travel planning systems and services, real-time traffic information, and open data and application programming interfaces (API). Indeed, changing contextual conditions have contributed to the digitalization process. For example, while broadband access has been widely established for long, rapid adoption of smartphones among citizens has recently created new ways to connect to the digital infrastructure. In addition, the Swedish public transport market was deregulated in early 2012, which paved the way for operators to engage in boundary-spanning design projects (e.g., innovation competitions) that explored digital options related to open data use. Against this backdrop, we here trace a series of events that spurred the evolution of Stockholm's digital transport infrastructure.

An internet-based system for informing travelers on multimodal travel planning was implemented in October 2000. The system called "Trafiken.nu" sought to improve traffic flow in and around the city by providing travelers with real-time information about the current traffic situation. It enabled travelers therefore to dynamically revise their travel plans including choice of transport mode. This information portal was developed collaboratively by City of Stockholm, Stockholm Public Transport, the Traffic Administration and the Swedish Road Administration, and represented Stockholm's first significant attempt to use digital technology for tackling transport-related problems such as congestion and air pollution. Indeed, technological advances including the Internet, cell phones, and infrastructure-based sensors created a viable opportunity to collect and integrate traffic information and make it available for travelers. One transport researcher highlighted:

"It was a product of political confidence display regarding new technology and Internet's capabilities to influence transport demand as well as fulfilling a need for a smooth traffic information channel."

The number of visitors to the information portal exceeded 7.2 million in 2008. However, at this point there were signs that users wanted to receive real-time information in a mobile format, and it was soon realized that a new approach to service development was needed. A first such approach involved a new multimodal travel planner launched in February 2009, which allowed its users to compare journey times, cost and environmental impact across both private and public travel mode, and thereby advance the service. It failed to attract those users who preferred smart phone-based access of travel information though. In 2011, the owners responded by providing a mobile version of the service called the "Travel Planner". The immediate effect was that user searches increased four times compared to the web service. Its success was still limited largely because of competition from other user-oriented travel applications in, e.g., Apple's app store. City of Stockholm representatives realized they had not responded swiftly enough to shifting user behaviors caused by rapid smartphone diffusion.

Yet another sign of this fact indeed had a disruptive effect on service development by almost entirely changing the future game plan. Using scraping technology to tap real-time data from the Stockholm Transport Company (SL), a student had created an unsanctioned travel application called "Res i Stockholm". For Stockholm's biggest public transport company, this caused serious problems in the form of server overload. One of the staff involved in resolving the issue recalled:

"We noticed that developers were screen scraping our sites to gather information and timetables for building new mobile apps. This was something very new to public transport organizations that traditionally owned this information and kept it as part of their service. These third-party apps turned out to be quite popular with the public. From this point, it became clear that sharing your data and information with third-party actors who could deliver good services and innovative apps was the obvious thing to do."

Despite considerable hesitation, however, SL eventually decided to change its data access policy and by offering a public API reach out to third-party developers. This decision to embrace externally driven co-creation activities for developing user-centered service digital applications was the first concrete step towards building an infrastructure for releasing and generating a more constructive control over travel-related data. From the developer's point of view, the project was driven entirely by a motivation to develop 'a useful app'. The student commented:

"It started as a hobby project… and because I had the technology and wanted to learn app development I simply created a service that I wanted to have, but did not exist out there."

After some initial resistance, industry professionals learned to think differently about meeting service needs, which was materialized into a novel strategy for digital service development. "Res i Stockholm" soon became one of the most downloaded applications for facilitating public transport travel, despite the initial shake-up in 2008 when it was launched in AppStore.

Making traffic data available to the public in this way promoted a culture of 'openness' within Stockholm's public transport sector. Data owners began to work cooperatively as to learn more about digital innovation and appropriate strategies for open data sharing. An innovation platform for open transport data called "Trafiklab" was formed in September 2011 to capitalize on the new mindset to release traffic data in a more organized fashion for third-party development. It assembled actors such as Swedish association for Public Transport companies (Samtrafiken) and Stockholm Public Transport Company (SL) so as to provide a structure for cultivating an ecosystem of actors that could secure the development of new services adapted to traveler needs. Trafiklab's innovation manager commented:

"*It was an opportunity for the industry to start to work with open data and open APIs. We wanted to make it simple to access this data and make it fun for our industry and third-party developers to discuss these issues. It was important to keep this industry initiative all together on one site instead of each public transport entity creating its own channel, data sources, set of agreements, and different types of APIs."*

Indeed, the developer platform, which hosted 26 different APIs from 12 different suppliers including data owners from both public and private sector, turned out to be a success. The service was spreading among developers and some 1100 of them were registered on the Trafiklab site in early 2013. To expand the network of information providers beyond conventional transport data, it was deemed important to build awareness among its members of how to work with third-party developers and offer them free use of APIs with limited restriction. Indeed, Trafiklab received a number of rewards during 2011-2012, which further boosted its generative capability to trigger digital service development in the public transport sector.

Fueled by this open platform success, prize-centric innovation competitions were arranged to develop new digital services for public transport users. The first transport-related digital contest "West-Coast Travel Hack" took place in October 2011. This event sought to facilitate a shift to more sustainable ways of travelling (e.g., from car to public transport), and the team that developed the most innovative, best implemented, and impactful digital service prototype was rewarded. The participating teams competed for awards exceeding the total amount of 100000 SEK (approx. 10000 €) together with wide exposure of their achievements. In total, the travel hack event yielded 20 prototypes, of which 15 were smartphone applications.

A contributing factor to the success of Travelhack was that it attracted new partners to embrace the idea of opening up their previously protected data. The research institute director responsible for 'smart' city initiatives in the Stockholm area noted:

"*Travelhack made all the actors within the public transport sector more aware of how to leverage open data. I think it has been a key element in kick-starting service innovation within transport in general."*

In total, nine data providers featured about 20 APIs with different types of data including public transport data, environmental data as well as data about commuting, disruptions, and ridesharing. The event was repeated in 2012 and 2013 and different new API owners took part to present their APIs.

The evolution of Stockholm's digital infrastructure for public transport services was evidently triggered by both staged and improvised actions ultimately designed to resolve the city's major congestion problems. Early on heterogeneous actors teamed up to provide public travelers directly with a novel service to handle pre and en route trips through a unified single information channel. Following the exponential growth of smart phones, however, users increasingly called for travel information to be delivered through various apps. Public transport actors were 'caught by surprise' and suddenly they found themselves in a situation requiring them to re-think their service development to absorb external input that could spawn new innovative practices. Overall, the whole trajectory of events constitutes several instantiations of an evolving digital infrastructure that gradually enabled distributed development of transport services to travelers in Stockholm and beyond.

5. Results

Stockholm is increasingly viewed as an IT-intense city situated at the forefront of developing sustainable public transport services. It relies on a cohesive and open digitalized public transport infrastructure, which provides the basic foundation for developing citizen-oriented applications (e.g., integrated travel planners). We here establish three contextual triggers as key to incepting the generative mechanisms that lead to its successful evolution. Consistent with our initial theorizing, these triggers suggest that such infrastructure evolution is always contingent upon existing beliefs and expectations to scale up the development of digital services as well as the context where interventions take place.

Adding service value: The introduction of the traffic data web portal (Trafiken.nu) was the first initiative to address the demand for travel information in Stockholm. As an early and relatively unsophisticated web-based infrastructure, it was easy to use and provided travelers with a service that was previously unavailable. Indeed, it opened up novel opportunities for travelers, especially car owners, to receive real-time information about their journeys. The fact that trips could be optimized at both individual and collective levels helped to facilitate sustainable travel behaviors in terms of reduced congestion and emissions.

The increasing use of mobile technology, however, meant that users wanted to have traffic information in their mobile phones. Concurrent digitalization of transport information spawned re-thinking among data owners to start releasing traffic data so as to facilitate the development of better mobile traffic services. Apple's release of iPhone in Sweden during the summer of 2008 was instrumental to intensify such service innovation by third-party developers. Travelers quickly embraced the first travel app (Res i Stockholm) because it satisfied user needs. Between October 2009 and October 2013 the number of visits to the service successively rose to over 14 million per month. In the end of 2013, the amount of new devices downloading the service was recorded to be 1000-1500 each month. Consequently, the process involved not only opportunistic exploitation of emerging mobile technology, but also mindful exploration between collaborating parties to use open data to spur service development. It was far-reaching in terms of attracting new users to the digital infrastructure and setting the stage for new innovation practices within public transport.

Based on our in-depth case study, we refer to this trigger as *adding service value*, which depicts a process by which actors attempt to meet user expectations by exploiting opportunities offered by new technologies and thereby ignite user excitement.

Creating Design Attractors: The initial actions to erect a digital transport infrastructure were successful not only in terms of attracting new users, but also for enabling collaboration between public transport operators and third-party developers. It helped to leverage the altruistic motivations of the developer community to engage in collaborative service innovation, which led to a legitimate way to create useful digital travel planners. Indeed, the previously experienced tensions caused by screen scraping of web sites to build mobile apps further spurred the development of a common strategy to promote such cooperation across boundaries. An important aspect of this new strategy was to re-orient development efforts by modifying existing work practices to attract the application developer community and thereby accelerate service innovation. In particular, the decision made by the public transport authorities to provide user friendly APIs was crucial to establish a new innovation trajectory within the public transport system.

Based on our in-depth case study, we refer to this trigger as *creating design attractors*, which depicts a process by which infrastructure stakeholders modify innovation practices as they offer design resources to stimulate service development while also maintaining some control over the outcomes. The outcome of this trigger sets off the innovation mechanism loop in terms of more services offered and ultimately increased user satisfaction.

Lowering infrastructure barriers: The establishment of a new innovation trajectory was conditioned by the open architecture strategy that public transport authorities commonly enacted to allow outside actors to add new resources to the digital infrastructure. Looking back at the infrastructure evolution, this structure supportive of distributed development generated confidence and assurance among heterogeneous actors to cooperate and build trustful relationships. It attracted new partners who promoted the platform by adding their APIs related to bike hiring and repair, ride sharing, parking availability, $C0_2$ emission levels, and commuting pattern. The main trigger for activating the scaling mechanism was the institutional support created to shift outmoded ways of working. This highlights the importance of lowering socio-technical barriers for new stakeholders to enter the stage as a means to propel distributed service innovation. In other words, it showcases the that sustainability of open data ecosystems is dependent on shifting norms that supports new ways of working.

Based on our in-depth case study, we refer to this trigger as *lowering infrastructure barriers*, which depicts a process by which actors unite to lower entry barriers for new partners as they establish a new pathway for distributed service innovation.

6. Discussion

Hanseth and Lyytinen [10] suggest that it is challenging to erect digital infrastructures and spur their successful evolution. To tackle this bootstrap problem, they argue, designers should seek to invent attractive solutions for users while the user community is small or non-existent (i.e., designers must prioritize early users' needs over completeness of their designs). In the same vein, Henfridsson and Bygstad [3] identify several generative mechanisms that underpin digital infrastructure evolution. Such mechanisms act as self-reinforcing processes with positive feedback loops through which new products/services become invented due to constant re-combinations of resources [10]. An illustrative example is a situation where users adopt a novel infrastructure service because of prior investments in resources that led to increased usefulness of that service. Likewise scaling mechanisms may allow an infrastructure to expand its reach, which permits enrolling new partners with their own capabilities and processes.

Apparently digital infrastructure change can be depicted as a gradual process by which a digitally enabled infrastructure evolves into a more complex form [3]. Recent IS research, adopting a complexity, network, or relational perspective of infrastructure evolution, suggests that this evolutionary process entails both social and technical elements [17, 20]. This inherent complexity makes direct managerial intervention tricky, and received theory tells us that it is difficult to control the design and evolution of digital infrastructures [13, 20]. It is therefore important to explore how such infrastructures evolve to understand how formal, planned structure can meld or pave the way for informal, locally emergent structure [6].

Indeed, there are several strategically important issues that surround building and managing of a new digital infrastructure that deserve full managerial attention [34]. One such issue is simply how to motivate contributions (of data and effort) to the project. Another issue concerns how to align the end goals of a diverse collection of developers, funders, and potential users. Alongside these issues, the objective of these infrastructure projects must be to achieve persistent institutional arrangements. Ribes and Finholt [34, p. 379] characterize such institutionalization of infrastructure as "the work of generating sustainable goods and services linked to social or collective purposes, with connotations of permanence, transcending individual lives, interests, or intentions"

A worthwhile research task is thus to explore into the contextual triggers that unleash the causal powers of generative mechanisms of infrastructure evolution including adoption, innovation, and scaling [3]. While no previous IS research has exploited this research opportunity, we have sought to investigate which triggers can incept successful evolution of digitalized public transport infrastructures. Our study builds on an in-depth case study of Stockholm's public transport infrastructure to inductively explore contextual triggers and their generative impact on successful digital infrastructure development and growth.

Our study extends received theory on digital infrastructures in two distinct ways. First, we analyze, define, and propose three contextual triggers that improve our understanding of the generative mechanisms behind infrastructure development and growth. Complementing extant work on bootstrapping [35, 10], we propose adding service value, creating design attractors, and lowering infrastructure barriers as such contextual triggers. Adding service value that entails the transformational action-formation by which actors exploit opportunities offered by new technologies to meet user expectations and thereby ignite user excitement. Essentially, such opportunity exploitation may involve adding timely services that the infrastructure users realize that they need once they encounter them. This builds, oftentimes quickly, a user base, which is typically seen as a critical aspect of infrastructure evolution [5, 10].

Creating design attractors, which is another trigger, denotes the process by which infrastructure stakeholders modify innovation practices as they create design attractors to stimulate service development. As showed in recent platform as infrastructure research [36, 8], transferring design capability to users, or end-user service providers, can be essential for triggering involvement of multiple actors in service development. Creating design attractors manifests an attempt to capture processes by which to trigger such development in the evolution of digital infrastructure. Lowering infrastructure barriers captures the trigger by which infrastructure actors unite to lower the barriers to entry for new partners as they establish the new pathway for distributed service innovation. Platform ecosystems [37] typically seek lower such barriers, not least as a way to expand the network of actors around which the ecosystem is formed.

We also offer a step towards an evolutionary theory of contextual triggers. As outlined above, the extant digital infrastructure literature underlines the difficulties to control or manage the evolution of digital infrastructures. Accepting this idea as a starting-point, we have developed an initial version of a theory that examines the early stage processes that contribute to the inception of the generative mechanisms.

In addition to the theoretical implications, the insights gained in this study may also serve as a basis for practical implications in terms of guidelines that we believe will help business managers, IT professionals, and policy makers in their efforts to build and maintain digital infrastructures. In building the public transport infrastructures of the future, much effort should be invested in paving the way for self-reinforcement. For instance, it is not sustainable for transport authorities in the long run to develop all services on the top of an infrastructure. Rather, in our study, we observed how the City of Stockholm lowered barriers to contribute to the infrastructure, for instance. We also observed how creating design attractors in the form of open data and application programming interfaces were important, yet not sufficient to successfully build the digital layer of public transport infrastructures. Dealing with digital infrastructures, stakeholders need to develop a comprehensive take on public transport infrastructure that includes enabling service value added, design attractors created, and infrastructure barriers lowered. As a result, professionals engaged in efforts to create digital infrastructures must be cognizant of the circumstances that pave the way for deliberate action to instigate infrastructure evolution. However, such capability is important not only for building these infrastructures, but also for keeping them vibrant over time.

The limitations of the study help pave the way for future work. With regard to our case study, the selection of Stockholm as the main case affected which contextual triggers emerged as relevant. Despite the fact that the identified triggers explain how infrastructure growth is initiated the extent to which we can generalize them and their generative impact from the Stockholm case requires additional research. R&D investments and industry-academia collaboration funding for digital infrastructure initiatives are relatively high in the Stockholm setting, which raises the risk that the conditions under which the three triggers identified are different compared to conditions characterizing other public transport infrastructures located in other cities in which the same triggers may be observed.

While we offer an understanding of three contextual triggers, we admit that the granularity of our analysis of these triggers is at a relatively high level, which suggests that we might not have discovered all of the triggers relevant for igniting the generative mechanisms of infrastructure evolution. It would therefore be worthwhile to pursue more research that more carefully scrutinizes the nature of these triggers and thereby specifies their respective characteristics.

On a final note, we hope that our research will be received as an attempt to adopt and develop a lens that may be useful for addressing infrastructural challenges of the future. In fact, we appreciate digital infrastructures as a promising angle on digital technologies in this regard, since infrastructures are shared across organizational boundaries and traditional communities.

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