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Radical change and deep transitions: Lessons from Europe's infrastructure transition 1815–2015

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ABSTRACT

Schot and Kanger (2016) argue that the shift from an unsustainable to a sustainable society requires radical historical change in the form of a Deep Transition: "a series of connected transitions in many socio-technical systems [e.g. energy, mobility, food] towards a similar direction [e.g. sustainability]." They call for more research. In response, this paper discusses a historical Deep Transition. It tracks the connected histories of Europe's mobility, food supply, warfare, and ecological systems, all of which experienced a transnational infrastructure transition in the 19th and 20th centuries. Studying these connected histories as a 'deep' infrastructure transition highlights important dynamics of radical historical change. This paper also adds to Schot and Kanger's research agenda, highlighting: (1) the importance of studying actors in Deep Transitions—particularly 'system entanglers' who interweave various sociotechnical systems and thereby connect transitions; (2) how such actors produced convergence, but also *divergence* across connected transitions; (3) the extreme unpredictability of Deep Transitions due to such divergences; and (4) the need for reflexivity regarding the analyst's role in delineating Deep Transitions, so as to avoid essentialism and the uncritical reproduction of contemporary preoccupations.

1. Introduction

Schot, Kanger and others argue that a structural solution to the world's many crises, and a shift from an unsustainable to a sustainable society, require radical historical change in the form of a Deep Transition: "a series of connected transitions in many socio-technical systems [energy, mobility, food, health and so on] towards a similar direction [i.e. sustainability]" (Schot and Kanger, 2016: 18. Also: Schot, 2016; Schot and Steinmueller, 2016). Deep Transitions involve many sociotechnical systems and may take centuries rather than decades; as such, they are even more difficult to understand, let alone govern, than individual system transitions. Deep Transitions research is timely and urgent; however, in sustainability transition studies, individual systems remain the dominant unit of analysis. Even so-called multi-regime analyses usually seek to understand individual system transitions, not overarching Deep Transitions (e.g. Raven and Verbong, 2007; Geels, 2007; Sutherland et al., 2015). That is why Schot et al. developed a Deep Transitions research agenda, calling for more research.

This essay answers that call. It discusses a historical Deep Transition. Over the course of two centuries, such very different systems as energy, mobility, industrial, financial, military, urban, knowledge, and even ecological systems changed in 'a similar direction': in a series of 'connected transitions', all were reorganized as *infrastructure*. Moreover, the perpetual interaction between these parallel system transitions was what produced an extremely dynamic and unpredictable process of radical historical change. For better or worse, the 'deep' infrastructure transition altered the social and physical world beyond recognition.

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A structured narrative of Europe's deep infrastructure transition based on historical evidence and literature was published recently (Högselius et al., 2016). This essay does not summarize that comprehensive narrative or present new evidence. Rather, it explores how this historical case and its research approach can contribute to the emerging Deep Transitions research agenda.

In particular, this essay explores the study of concrete actors in Deep Transitions. Schot and Kanger (2016: 5) observe an important research challenge: "a focus on big historical patterns [such as Deep Transitions] always creates a danger that choices made by different actors disappear from view." We could teasingly call this challenge the 'Deep Transition uncertainty principle': the larger the historical transition under study, the more challenging the study of its concrete actors, and vice versa. This is particularly problematic if we believe that "actors make transitions" (de Haan and Rotmans, 2016); that *methodologically* studying actors provides crucial insights into structural societal change; or simply that human experience is the research topic that matters. The question whether or not actors are sufficiently included in single-system sustainability transition theory has triggered heated debate in recent years (e.g. Farla et al., 2012; Avelino and Wittmayer, 2016; Fischer and Newig, 2016; de Haan and Rotmans, 2016). When studying still larger historical patterns such as Deep Transitions, the issue becomes even more pertinent.

Schot and Kanger (2016: 6) acknowledge that pertinence. However, their approach so far has focused on abstract—and admittedly speculative—theory rather than concrete actors and events. They synthesize such comprehensive theoretical frameworks as Techno-Economic Paradigms and the Multi-Level Perspective on transitions (MLP) to sketch the contours of Deep Transitions, and highlight changes in shared 'meta-rules' (e.g. working towards sustainability) across different systems as the key marker for such transitions. Meanwhile, concrete actors, as opposed to abstract actor categories and rules guiding actor behavior, fade from view. In my reading, Schot and Kanger's research agenda (ibid 25–26) reproduces rather than addresses the Deep Transitions uncertainty principle.

This essay seeks to open-up the matter of actors in Deep Transitions. For that purpose, it exploits the familiar historical research operation to methodologically study specific actors in order to identify and scrutinize structural historical change. In the context of this special issue on history and transitions, this research operation merits attention as a way to bypass the Deep Transitions uncertainty principle. This paper explores how studying selected historical actors can bring into view Europe's deep infrastructure transition. It develops its argument in two parts.

The first part discusses the issue conceptually. In order to identify and study historical actors relevant to Europe's deep infrastructure transition, it mobilizes four decades of work on the concept of 'system builders' in the history of technology and the Large Technical Systems literature. Of course other actor perspectives are possible; others must write about these. Applied to Deep Transitions, this concept inspires a follow-the-actor approach that identifies and investigates concrete historical actors who envisioned and actively worked on entangling various sociotechnical systems. These system entanglers operated at the actual 'connections' of the 'connected transitions' that we seek to understand. They were front-row witnesses to imaginings, contexts, conflicts, choices, and failures in the making of Deep Transitions.

The second part of this essay discusses Europe's deep infrastructure transition empirically. It sets the scene with an early 19th century vision of a societal transition towards a 'circulation society' that in boldness and scope compares to present-day visions of sustainable futures. Next it explores how studying concrete system entanglers helps spotlight and scrutinize the subsequent deep infrastructure transition that has produced today's network society. Examples demonstrate the connected histories of such very different (and usually separately studied) systems as mobility, food supply, warfare, and ecological systems, all of which have experienced an infrastructure transition in the past two centuries.

The essay concludes by proposing several topics for the Deep Transition research agenda. These include the study of concrete actors—notably system entanglers—in Deep Transitions; how they produced convergence (Schot and Kanger's "connected transitions in a similar direction"), but also *divergence* across various sociotechnical systems; and the extreme unpredictability of Deep Transitions due to such divergences. Finally, this essay calls for reflexivity regarding the researcher's role in delineating and studying Deep Transitions.

2. System entanglers: actors who connect transitions

In order to identify and investigate historical actors relevant to the study of Deep Transitions, this essay mobilizes—and contributes to—four decades of work on the notion of 'system builders' in the history of technology and the Large Technical Systems literature. In doing so, and in engaging with Deep Transitions theorizing in the first place, this paper bridges between history and theory. Before proceeding, let me briefly specify what it does and does not do in terms of theory and conceptual work.

2.1. History, theory, concepts

The long and often heated debate on history and theory has never reached closure. If it shows anything, it is that many productive scholarly approaches co-exist. These approaches include a rich tradition of *empirical history* that methodologically eschews theory for 'distorting' historical reality; this tradition should be applauded when producing insights that social theory has failed to grasp (Davies 2003. In the history of technology: Buchanan 1991, 1997). However, this essay associates more with such fields as *social history* and *contemporary history*. Social history is known for its shift from 'elite' history to inclusive histories of everyday life; for engaging with present-day social issues that give history its relevance; and for engaging with social theory for that purpose—blurring the boundary between history and social science (MacRaild and Taylor 2004). Contemporary history too can engage with (draw on, contribute to, undermine, or read a source) contemporary social theories, especially if these theories address the same contemporary research topics (Graf and Priemel, 2011). Likewise, many historians of technology today address contemporary issues such as societal challenges,

global crises, and sustainability (e.g. Bijker, 2009; Kaijser, 2011; Högselius et al., 2013; Lundin, 2016; Van der Vleuten, 2017; Van der Vleuten et al., 2017), and do not hesitate to engage with theory if that serves their purposes.

As such, this essay speaks to the emerging Deep Transition debate, mostly a theoretical debate. Yet this essay does *not* use history to build a comprehensive and coherent theory, nor any 'alternative' to such comprehensive theories as Techno-Economic Paradigms or the Multi-Level Perspective on transitions currently in play (for MLP's epistemological status see e.g. Geels, 2010). To paraphrase historian James Cracraft (2015: 54): building a comprehensive theory is simply not its business. Still, this paper does urge Deep Transition theorists to take concrete actors (as opposed to 'abstract actor categories', see de Haan and Rotmans, 2016) more seriously—in particular those actors operating at the junctions of 'connected transitions.'

When this paper engages with conceptual work on the notion of 'system builder', it is not to build any comprehensive theory, but to re-craft the concept in order to identify and activate relevant historical sources, ask relevant questions, and build relevant narratives. This use of concepts perhaps resembles Actor-Network Theory (ANT)-inspired ethnographical work on sustainability transitions (even though such studies may select different actors and ask different questions, e.g. Padmadinata, 2016; de Hoop, 2016). Indeed, ANT spokespersons have persistently emphasized that rather than a 'theory' seeking consistency, ANT is a 'method' and conceptual 'toolkit' aiding scholars to "attune to the world, to see and hear and feel and taste it" and "tell relevant stories" (Mol, 2010: 262. Also: Latour, 1999; Law 2009, 2016). Such methodological use of concepts to access important yet overlooked phenomena in the empirical world has formed a strong current in historical and social technology studies since the 1980s.

2.2. Entangling systems, connecting transitions

Two approaches to the history of technology seem particularly relevant for the study of actors in Deep Transitions. Both became popular in the 1980s and have developed considerably since. Firstly, historical user studies conceptualized and researched user experience and agency in sociotechnical systems and the transformation of everyday life. Secondly, historical studies of large technological systems, which spawned Large Technical Systems or LTS studies, examined sociotechnical systems shaping 'the way we live, work, play and wage war' (e.g. Hughes 1991), conceptualizing and studying those actors who envisioned and built the systems, the 'system builders.' Both research traditions are well known in sustainability transition scholarship today, where they resonate with occasional tensions between systemic 'innovation-centered and 'user-centered' approaches. Though the two approaches have repeatedly conflicted, their complementarity has long been recognized (e.g. Nye, 2004; Van der Vleuten 2004a). More importantly for the Deep Transitions debate: both approaches present an actor perspective that can capture the connected histories of different sociotechnical systems. User-centered approaches can bring into view how connections between multiple sociotechnical systems are negotiated in daily user experience and practice. For example, the kitchen has been studied as a 'consumption junction' where users integrated water, gas, electricity, food supply, the cold chain, and waste disposal systems (Cowan, 1987; Oldenziel and Hård, 2013). Others must distill further lessons for Deep Transitions from this research line. I focus here on developing an LTS perspective on actors in Deep Transitions.

How can the LTS concept of 'system builders' be mobilized and adapted to help us identify and scrutinize concrete historical actors relevant to Deep Transitions? Schot and Kanger emphasize that Deep Transitions are sociotechnical, transnational, multi-system transitions. So the concept must detect and question actors involved in the making of such socio-technical, transnational, and cross-system entanglements.

Socio-technical entanglements: Thomas Hughes (1979, 1983) originally designed the concept of system builders to study how historical actors forged sociotechnical entanglements. Inspired by the sociotechnical system theories of his time, Hughes chose the sociotechnical system, instead of the technical artefact, as the unit of analysis to adequately study technical change. Yet he criticized the lack of human agency in existing sociotechnical systems theories, allegedly a science of structures unable to account for endogenous system change. Hughes, and soon many others, started to study human agency in the making and changing of sociotechnical systems. In the paradigmatic example, the concept of system builder spotlighted and helped inquire how Thomas Edison and his team built early electricity systems by developing, mutually aligning, and thereby entangling what we often call 'technical' elements (novel electricity generators, distribution systems, light bulbs etc.) and 'social' elements (financing structures, business models, a string of companies, concessions and other legislative artefacts etc.) into a robust and comparatively stable 'sociotechnical' system. Hughes' work inspired studies of actors entangling sociotechnical energy, mobility, communications, industrial, supply chain, health systems and so on. It became known for 'humanizing' systems theory (Galambos, 1991; also Mayntz and Hughes, 1988; Galambos, 1991; La Porte, 1991; Summerton, 1994).

The original system builder concept was soon criticized for over-exposing 'heroic' system builders at the cost of unruly and critical actors; foregrounding harmony at the expense of conflict; and teleologically assuming a system development direction (e.g. Law, 1991; Hård, 1993; Summerton, 1994). One response was to study system building as an open-ended and conflicted multi-actor process. Another response was to study actors as system builders for *heuristic* reasons—to get privileged access to interpretations, conflicts, and other dynamics of system building. The argument: actors involved in making or managing sociotechnical systems tend to identify and articulate problems, which include deviating viewpoints, critiques, opponents, alternatives, conflicts, and failures. By studying system builders, researchers should also find much conflict and failure (for recent discussion and references: Manders et al., 2016; Janáč and van der Vleuten, 2016).

Transnational entanglements: In the context of globalization and Europeanization, and the global and transnational turn in history, a rich body of transnational infrastructure history emerged (e.g. Van der Vleuten and Kaijser, 2005; Van der Vleuten and Kaijser, 2006; Badenoch and Fickers, 2010a, 2010b; Schipper and Schot 2011; Högselius et al., 2013; Ambrosius and Henrich-Franke, 2013; Schiefelbusch and Dienel, 2016; Marklund and Rüdiger, 2017). In that literature, the concept of system building was

repurposed for transnational analysis. Note the distinction between two forms of transnational analysis, which sometimes blend despite different intellectual origins (Van der Vleuten, 2008). In the 1970s 'transnational analysis' primarily referred to including non-governmental actors in the study of International Relations. In globalization studies of the 1990s and 2000s, the same term indicated scrutinizing entanglements of the local, national, and international. Both meanings are still with us today, and historians of technology have studied 'transnational system builders' in both meanings. They studied how international expert networks and organizations built international energy, communication, and transport systems (e.g. Van der Vleuten et al., 2007; Lagendijk, 2008; Schipper, 2008; Laborie, 2010; Van der Vleuten, 2010; Anastasiadou, 2011; Lommers, 2012). They also studied how system builders entangled local, regional, national and international sociotechnical systems in order to build the European electric power system (e.g. Lagendijk and van der Vleuten, 2013), or seemingly 'domestic' nuclear power plants, canals, or rail tunnels (Hristov, 2014; Janáč and van der Vleuten, 2016). These studies investigated—through the lens of selected system builders—not only successful system building, but also critiques, conflicts, alternatives, and failures; indeed, they set out to symmetrically study transnational integration and fragmentation (Van der Vleuten and Kaijser, 2005). In sum, the notion of transnational system building trained investigative attention on actors forging transnational as well as sociotechnical entanglements and how they proceeded, succeeded, or failed.

Incidentally, the field of sustainability transition studies has made its spatial turn more recently (Coenen et al., 2011; Van der Vleuten and Högselius, 2012; Shove et al., 2014; Truffer 2015; Hansen and Coenen 2015; Wieczorek et al., 2015). Schot & Kanger (2016: 16) observe that this development seems to be increasingly dominated by an economic geography of transitions where specific actors and agency tend to fade from view—perhaps another instance of the uncertainty principle in transition studies at work?

Cross-system entanglements: Can the system builder concept be repurposed once more to also help us capture how actors forge entanglements between *different* transnational sociotechnical systems, and spotlight the role of such actors in Deep Transitions? Three debates within LTS scholarship are particularly helpful in that effort.

First, several authors have adapted the concept of system builders to study the *current and future* making of *heterogeneous*, though still predominantly individual, Large Technical Systems. For example, Braun (1994) and Braun and Joerges (1994) introduced the notion of '2nd order system building': Past ('1st order') system builders, such as Edison or power or railway companies, had manipulated and aligned technical and social elements into comparatively homogeneous sociotechnical systems, such as electricity or railway systems. Most system elements were somehow under system builder control. However, Braun argued, in a world full of 1st order systems, future system building would increasingly take the form of combining elements from *different* systems into new *heterogeneous* ('2nd order') systems. His examples included organ transplant and waste recycling systems. For example, 2nd order system builder *Eurotransplant* combined new elements (a central computer and patient database) with those in existing systems that it did not control (hospital facilities and surgeons in the medical system; dedicated telephone and data lines, beeper services, taxies, and chartered flights in telecom and transport systems; and so on) into a heterogeneous super-system for the circulation of organs. A related conceptualization is Edwards' (1998, 2007) understanding of cyberinfrastructure as a novel, heterogeneous 'network of networks', 'internetwork', or 'web'—forged by 'gateway builders' rather than system builders. Note that for Braun as well as Edwards the unit of analysis remained the individual (and heterogeneous) system, not the broader entanglements of sociotechnical function systems that the Deep Transitions debate addresses.

Second, some LTS authors transcended the domain of infrastructure studies to study precisely these broader entanglements. For example, Mayntz (1988, 1993) incorporated Large Technical Systems in sociological systems theory. She argued that LTS had become fully differentiated social function systems on a par with healthcare, education, religion, politics, industry, the military, etc. Moreover, she claimed that this novel system was increasingly and asymmetrically shaping other social function systems—all became increasingly dependent on LTS infrastructure services. This insight compares to Castells' (1996–1999) study of the reproduction of a network morphology through the 'network society'—in production, work, leisure, crime and even nature. Note that these works, unlike the above-mentioned studies of heterogeneous system builders, have little to say about concrete actors. Once again, the Deep Transitions uncertainty principle seems to prevail.

Third, combining these two debates, Van der Vleuten (2003, 2004a, 2004b) raised the question *who* historically entangled different social function systems, thereby historically shaping the network society. A pilot case study in the Netherlands found that a vast range of system builders (1st order, 2nd order, gateway builders, and others) *simultaneously* (that is to say not sequentially) and *interactively* built various systems—energy, mobility, communication, food, industrial, financial, and even ecological systems (ibid. and De la Bruèze and Van Otterloo, 2004; Hermans and De Wit, 2004; Davids 2004; Van den Belt 2004). In this interactive process most if not all social function systems were reorganized according to an infrastructure logic and morphology: connected transitions indeed. This approach informed the recent study of Europe's infrastructure transition in terms of transnational infrastructure, food supply, industrial, financial, military, urban, ecological, and knowledge system builders, who interactively infrastructured a wide variety of societal and environmental systems, and jointly brought about radical historical change (Högselius et al., 2016). Again, this perspective included system building conflicts and failures, and studied transnational system integration as well as fragmentation.

This leads us back to the task in hand: to mobilize the concept of system builders for an empirical actor-perspective on Deep Transitions. Four decades of work on the system builder concept suggest a follow-the-actor approach that identifies and investigates specific historical actors: those who simultaneously entangled social and technical elements into sociotechnical systems; local, national, and international scales into transnational sociotechnical systems; and various sociotechnical systems into 'connected systems'. Studying such system entanglers implies questioning how they combined these three-fold entanglements, and also identifying the problems, critiques, conflicts, and failures they encountered. It is to such specific system entanglers, who worked on the actual 'connections' of 'connected transitions', that we now turn.

3. System entanglers at work

As noted, a structured narrative of Europe's deep infrastructure transition ca. 1815–2015 was recently published (Högselius et al., 2016). This section presents snapshots from that narrative to illustrate and further explore how a system builder or entangler approach can help "tell relevant stories" about connected transitions. All the historical data is taken from Högselius et al. (2016) unless otherwise noted.

3.1. Envisioning a deep infrastructure transition

System builders, according to Tom Hughes, often base their work on an encompassing vision. To set the stage for our investigation of actors who entangled transitions, let us look back on the early 19th century vision of an encompassing societal transition towards a 'circulation society' that is just as daring as present-day visions of sustainable futures.

Historians have traced visions of today's network society to the early 19th century Saint Simonian movement (Mattelart, 1996; Williams, 1997; Giessmann, 2006). At the occasion of the Vienna Congress after the Napoleonic Wars in 1814-15, Count Claude Henry de Saint Simon, whom the movement is named after, and the young historian Augustin Thierry urged for pan-European *cooperation* instead of the competition that had led to war; they proposed joint canals and road works for the common good. The next generation of so-called Saint Simonians fully articulated a network vision (I use the contemporary term 'network' and the later term 'infrastructure' interchangeably) and started putting it into practice. With de Haan and Rotmans (2016) we could call these actors 'topplers'—actors who envision a systemic societal transition, see themselves as operating at a tipping point in history, and work on radical change by building networks, changing institutions, and innovating.

These early topplers envisioned a societal transition that was not about infrastructure as such. Instead, the aim was to liberate humanity from the millennia-old plagues of conflict (between nations, between classes, and between the sexes), poverty, and the bonds of nature. They envisioned a 'universal association' in which liberated peoples collaborated equally for joint prosperity and peace. This transition would change the human condition forever, they argued.

In this context, historians interpret the writings of the young French engineer Michel Chevalier in 1831–32 as a 'manifesto' for our current network age. Chevalier joined the pacifist Saint Simonian movement in the late 1820s, was editor of its main journal, and quickly became a movement leader. In his writings Chevalier (1832a, 1832b) argued that "material networks" such as railway and steamship lines, and "intangible networks" such as credit facilities, would enable a continuous exchange of ideas and goods across continental, national, and class boundaries. His railway plan was as influential as it was naïve: divert military spending to a transcontinental railroad network connecting the Atlantic to the Pacific, and the Baltic Sea to Northern Africa. Through it, people would engage in economic and industrial cooperation, creating prosperity for all countries, classes, and individuals. There would be no more cause for war, and besides, why attack those with whom one has a prosperous cooperation? Chevalier called this envisioned society "the circulation society." Translated into many languages, his vision caught on. Just one concrete example: soon after Belgium declared independence from the Netherlands in 1830, Chevalier was cited by the new Ministry for Public Works and young state engineers as inspiration to construct the world's first national railway network.

As for concrete action, Chevalier and his fellow topplers had experience with what we would now call social action. De Haan and Rotmans argue that social movements form around topplers, as today in the case of sustainability. Around 1830 Saint Simonianism too was a social movement. Its protagonists founded a 'religion of humanity' and staged public happenings, for example advocating the liberation of female sexuality from the exclusivity dictated by Church marriage laws. Imagine parades in colorful dress and a crowd of thousands of participants, mostly women, chanting in the streets of Paris. Movement leaders such as Prosper Enfantin, Charles Duveyrier, and Chevalier even made their 1832 trial a colorful happening, but were sentenced to jail nevertheless, for undermining morality and social order. Whether because the movement was disbanded by the authorities, or because it imploded: as a social movement, Saint Simonianism never recovered (Drolet, 2008; Pilbeam, 2014).

Instead, our topplers invented the technocratic approach they are known for in technology studies today. An inner circle of people worked behind the scene to win governments, financiers, and industrialists for the universal association. After his jail time, Chevalier himself investigated the role of infrastructure in the United States economy for the French State, taught as a professor of political economy, and became senator under Napoleon III, always promoting domestic railways and cross-national connections such as transalpine tunnels and the Panama and Suez canals. He was the French signatory of the first Anglo-French free trade treaty of 1860, the take-off moment of trade liberalization and globalization. Other Saint Simonians similarly worked for infrastructure projects, credit institutions, and other exchanges—often from visions of global community and equality.

The Saint Simonian vision of an infrastructure-based societal transition persisted: The transformative power of infrastructure as harbringer of liberty, prosperity, and peace was reused for transnational electricity, telephone, broadcasting, road, waterway, and aviation schemes in the 1920s and 30s, and again in the 1950s and 60s; in electronic superhighway programs and the European Union's Trans European Network program in the 1990s; and in social media today. Facebook's classic mission statement to "give people the power to share and make the world more open and connected" can thus be interpreted as a current expression of a centuries-old theme.

3.2. Transport system builders

The study of specific system builders and entanglers helps us examine the deep infrastructure transition beyond Chevalier's 'ideology of circulation' (Mattelart, 2000) or 'myth of infrastructure' (Badenoch and Fickers, 2010b) and its negative, a cynical

'critique of ideology' exposing infrastructure exclusively as a tool of power and exploitation (Mattelart, 1996, 2000). In the next sections I zoom in on selected transitions of quite diverse systems relating to the transport networks that Chevalier had highlighted. Before addressing relevant system entanglers, however, two comments about the mobility transition are relevant.

First, the mobility transition of the 19th and 20th centuries has been comparatively well studied. Historical studies of domestic transport system builders have now been complemented with studies of transnational system builders (e.g. Schipper 2008; Anastasiadou, 2011; Janác, 2013. For mobility history: Mom 2003, 2015). This literature shows that a wide and diverse array of actors jointly built a transnational, multi-layered, multi-modal sociotechnical transport network that eventually spanned the globe, connecting about every structure in the human-built world (Radkau, 1994). It is also clear that especially the transition to car-centered mobility (for a historical state-of-the-art see Mom 2014) raised severe sustainability concerns that have inspired research on sustainable mobility transitions (e.g. Geels et al., 2011; Sengers, 2016; Oldenziel et al., 2016). Clearly, Chevalier's earlier vision on global transport connectivity has been realized many times over, for better or worse.

Secondly, it is worth repeating that the system builder concept spotlights not only how actors built systems, but also how they encountered conflict and failure. One telling example to underscore that crucial point: Henri Duveyrier, son of Charles Duveyrier who had been on trial in 1832, joined the trans-Sahara railway project in the 1870s. Like other Saint Simonians he believed in forging a universal association of complementary European and non-European societies—in this case between France and North-Africa's nomadic Tuareg society. Instead of a militarized colonial railway building style, Duveyrier proposed a collaborative approach, in which French railway builders acquainted themselves with the Tuareg language and dress. The military command only went along with reduced military presence. However, that 'weak military approach' only made project expeditions attractive targets for Tuareg rebels. After a massacre on one expedition in 1880, Duveyrier was publicly blamed, withdrew, and finally committed suicide. Military system builders took charge of the railway project. An expedition trail of burned-out villages and killings caused public outrage; later, competing interests within the railway lobby and the First World War further delayed the project. After that war the priority of North-African transport arteries made the transSahara railway less urgent; decolonization buried it (Heffernan 1989). Tracking specific system builders thus reveals how the railway's civilizing mission became indistinguishable from aggressive high imperialism (Diogo and Van Laak, 2016), as well as system builder failure. Indeed, the relative disconnection of sub-Saharan Africa persists in today's global network society.

3.3. Food system transitions

Of all the social function system transitions relating to the transport transition, Europe's modern food transition is perhaps most worthy of Chevalier's dream. Food historians tell us that the two major food transitions of the last two centuries—from structural want to plenty, and from monotonous to varied diets—count among the most impressive accomplishments of humankind, vastly increasing the health and longevity of large populations. Transport systems were crucial to these food transitions, for they ended the vulnerable dependencies on local food supply.

A system entangler perspective helps research the connection between Europe's transport and food transitions. First, it informs the search for relevant actors who entangled transport and food systems. Consider the example of the scarcely known Working Group on Transport of Perishable Foodstuffs under the United Nations Economic Commission for Europe (UN ECE, 1947), the organization that championed European Integration until it was bypassed by the OEEC/OECD in funding and the EEC/EU in authority. This Working Group, largely unstudied by either transport or food historians, was a front-row witness to the role of transport in Europe's post-war food transition from monotonous to varied diets (Van der Vleuten 2010).

Second, the system entangler perspective asks how such actors envisioned and built transnational, sociotechnical, cross-system entanglements. The UN ECE and its Working Party developed a vision that included several of these entanglements: With the exception of its richest countries, Europe's greatest post-war enemy was malnutrition—caused by monotonous diets of starchy staples such as potatoes and grains etc.. The remedy was to build transport facilities for nutritious, but highly perishable foods such as meat, fish, dairy products, fruits and vegetables. And (reusing Chevalier's "networks against war" argument) these food chains should form an interdependent pan-European food economy to combat the other great dangers—nationalism and the Cold War's East-West divide triggering a nuclear Third World War.

From that vision, the Working Party distilled an action plan that entangled socio-technical, transnational, and cross-system elements into a European food-transport system. To start with, a dietary transition required updated global nutrition standards and national communication, as well as changes in national food production and consumption; these tasks were handed to the World Health Organization and the Food and Agriculture Organization. The Working Party then set out to appropriate and innovate transport systems for perishable food. It worked with stakeholders to improve refrigerated train wagons, trucks, and containers—equipped with steel walls withstanding chemical cleaning, insulation, temperature measurement, cushioning, and so on. Speed was essential, so the Working Party asked relevant organizations to align train timetables on a panEuropean scale, arrange border priority for perishable food transports, and exempt perishable food trucks from occasional national bans on Sunday driving. To protect perishable foods *en route*, it defined European standards for food refrigeration, fruit and vegetable sizes, packaging and handling. It also worked on supply chain operators, for example asking the International Road Union to establish a cool chain transporter association (*Transfrigoroute*) to organize the sector. By the late 1950s Europe's trans-national, socio-technical perishable food-transport systems were operational.

Third, the system entangler perspective investigates conflicts and failures. The UN ECE closely monitored Europe's food production, trade, and consumption statistics, and noted by the 1960s that Europe's malnutrition had been conquered. Monotonous diets had given way to varied diets. Although the UN ECE had done some ground-work, food statistics showed that domestic, not

international, food chains were responsible: most countries (except the UK) had become largely self-sufficient in perishable foods. Food nationalism reigned supreme. East-West food trade, a prominent UN ECE target, lingered at 3% of all foreign trade still in the 1980s. Western European countries still had significant imports from (former) colonies, and intra-European Communities trade was rising—a Community, which from a UN ECE perspective built a 'Europe' for the happy few (its 6 and later 12 original members) rather than the entire continent. A transport-based food transition had materialized, but an interdependent Pan-European food economy clearly had not.

Similar system entangler analyses have been made for Europe's food transitions from want and structural hunger to plenty since the mid-19th Century, and from nation-centered to EU-centered food systems from the 1960s. Here, too, we see tremendous success as well as miserable failure (Högselius et al., 2016).

For example, from the 19th century onwards, British, French, Dutch and other (colonial) trade companies increasingly set up plantations and cattle ranches in Africa, South America, and Australia. They mobilized or built river boat, rail, or road transport systems to get produce to harbor city facilities; transcontinental shipping (e.g. the British Vestey company's Blue Star Line) to their homelands; and domestic distribution systems to markets and consumers. Starting in Britain, Western and later Northern and Southern European food intakes rose steeply. Improved health and life expectancies followed suit. On the downside, native peoples in the Argentina Pampas and Patagonia were killed or expelled to make way for European ranchers. Australian Aborigines were incorporated as forced labor. Note that the Aboriginal rights movement started with a walk-out from a Vestey farm in 1966. These examples reiterate that studying system entanglers is *not* about studying the heroes of history (Summerton 2003); it spotlights success and failure, winners and losers, of Europe's connected transport and food transitions.

Even when established, the functioning or failure of food chains occasionally had disastrous effects. During the Soviet Famine of 1932–33 (3 to 4 *million* casualties), well-functioning supply lines carried off foods and left farmers to die. In the 1943 Bengali Famine (2 million casualties), supply lines were cut after the Japanese invasion of rice-supplier Burma and the subsequent British 'scorched earth policy.'

The European Economic Community's agricultural Common Market is also a tale of food system building and dismantling, of winners and losers. Thanks to common food chains and support measures, the Community's food production, trade, and consumption spiked (and produced wine lakes and butter mountains). Conversely, Community protectionism cut off former colonial plantations from Community supply lines. Community dumping policies further destroyed postcolonial monoculture economies, where many returned to subsistence farming (Rempe, 2009). "What did we do?" asked a regretful 86-year old Sicco Mansholt, EC Agricultural Commissioner from 1958 to 1972: "we drove third world framers into despair … we got stuck with intensive pig farming and manure mountains … dramatic" (as cited in Westerman 1999: 228). The disruption of colonial supply chains in turn became an important trigger of illegal migration culminating in Europe's current migration crisis, another example of 'connected transitions.'

This section discussed the entanglement of food and transport systems in some detail. The next sections extract two important additional insights for the Deep Transitions research agenda.

3.4. The wheels of war

We have seen that transport and food system entangling produced winners as well as losers, the latter having been absent in the Saint Simonians' circulation society visions. The main insight gained from another connected transition, the infrastructure transition of the military system, is that historical actors can take original objectives in an entirely opposite direction. In this case the consequences were particularly grave: Chevalier's "networks against war" morphed into tools of war that greatly amplified the scale of destruction and suffering.

In 1870 Chevalier, a pacifist, was the only member of the French Imperial Senate to vote against war with Prussia. What followed was a shock: Within two months, the French army had been overrun and the emperor captured. The reason for the humiliating defeat: The Prussian army had successfully deployed railroad and telegraph infrastructure to coordinate troop movements and rapidly concentrate troops where they were most needed, outnumbering the French in every battle.

It turned out that the Prussian military had been working on this strategy for some time. Military strategists such as Helmut Von Moltke the elder, Chief of the Prussian General Staff from 1857, were quick to recognize the military significance of railroads to gain tactical advantages during mobilization and on the battlefield. They entangled the ongoing transport transition into a transition of the military system in several ways. For example, they developed elaborate Military Travel Plans: fusing military and mobility systems they revamped military tactics according to an infrastructure logic, while at the same time changing mobility systems; private and state railways had to design their capacity and routes for the peak load and spatial demands of mobilization and war. In the 1866 war with Austria, Prussia's rail-based military had its first great success. Von Moltke then introduced a military railroad corps for support and quick repairs, and a joint civilian-military management plan for railways in wartime. Single-track railways to borders were upgraded to double-track. Prussia's subsequent victory over France sent shockwaves throughout Europe.

After 1870, every major military command in Europe copied the Prussian approach and redefined military strategy, at home as well as in their colonies. All made military travel plans that anticipated the offensive and defensive movements of their allies and potential enemies. Thus emerged a complex, tightly coupled, systemic interdependence between multiple national military travel plans. In 1914 those plans were executed in a sequence whereby armies reacted to each other according to pre-set schemes. This mechanism has been mentioned as one of the immediate reasons (there were of course many background reasons) why the war broke out so fast and so wide (Bucholz 1994).

Military system entanglers had connected with the deep infrastructure transition; at the same time, they had removed the infrastructure transition from Chevalier's war-abolishing aims. To stick to the railroad example: military planners had not foreseen that

their railway-based movements would get stuck—as they did on the First World War's Western Front. On either side of the front, main railway arteries and improvised narrow gauge rail lines in the front zones continued to feed soldiers, supplies, and ammunitions into the trap, like two huge conveyor belts. The number of casualties was unprecedented—some of these Western Front battles still rank today among the deadliest ever. Meanwhile, infrastructure warfare also erupted on the seas.

The destructive capacity of infrastructured warfare only increased when militaries appropriated aviation and advanced radar and communication infrastructure for aerial warfare. The carpet bombings of the Second World War are a case in point; later followed elaborate transnational (NATO and Warsaw Pact) ballistic missile systems. The story of infrastructure warfare continues today with electronic soldiers and drone warfare. I shall not follow up on that story here. The purpose of this short military history excursion is simply to take the notion of simultaneous convergence (in form) and divergence (in purpose and effect) of connected transitions to the Deep Transitions research agenda.

3.5. Nature's infrastructure transition

Europe's deep infrastructure transition did not merely transform the social function systems that social scientists usually study. As humans appropriated and modified nature to fulfill specific functions in the human-built world, nature, too, morphed into a social function system. Moreover, this appropriation would similarly take the form of an infrastructure transition. The construction of 'ecological networks', or 'green infrastructure' as these were called from the 1970s, is a particularly instructive example.

This was a different sort of system entanglement process. The historical actors who brought the infrastructure transition to the food and military systems, and to most other social function systems, worked as heterogeneous system builders (Braun, 1994) blending transport, food, and military systems. Ecological system builders brought Chevalier's infrastructure vision to nature, thereby drawing nature into the deep infrastructure transition. However, instead of blending transport and ecological systems, they tried to separate them. The massive introduction of badger tunnels and ecoducts—viaducts enabling animals to cross motorways—illustrates this effort. The ecological networks case thus reminds Deep Transitions researchers that system entangling and system separation need to be studied symmetrically, as was done with transnational system integration and fragmentation.

The ground work for nature's networks had been done by conservationists and urban planners from the late 19th century. Conservationists had bought and preserved cultural and natural heritage sites. On the initiative of the Swiss, the International Consultative Commission for the Protection of Nature was established in 1913 to promote the national park idea; in 1948 followed the International Union for the Conservation of Nature that still exists today. By then, over 5,000 nature reserves existed world-wide; by the 1980s that number had increased to over 30,000 (Chape et al., 2003). While conservationists established what ecological network builders would later call 'network nodes', urban planners had established numerous 'network links': the late 19th century Garden City movement had introduced the concept of green belts around cities to contain urban sprawl and preserve rural space for recreation. From the mid-20th century, the construction of green belts in or around cities also accelerated.

The idea to connect ecological nodes and links into networks was pioneered in the Soviet republics of Estonia and Lithuania in the 1970s. Their concept was anthropocentric: following the Russian geographer Boris Rodoman's ideas for "functional zoning", national territories should be divided into urban, industrial, cultivated, and natural zones. The natural zones served to purify air, clean water, and protect habitats in order to compensate and secure resources for the other polluted zones. In Estonia, large natural zones were interconnected via forest belts and river valleys in a "network of compensative areas"; by 2000 that network covered half of the country's territory. Meanwhile, in the 1980s the Dutch had developed a second, nature-centric concept of national ecological networks (Van den Belt, 2004). Here the reference was ecological: according to systems ecology, biodiversity correlates with the size of nature areas. Nature was severely fragmented in the Netherlands; biologists found that the way to create larger habitats and increase biodiversity was to interconnect these zones via ecological corridors. They prepared a policy plan to build a national ecological network for circulating plants and animals, just like transport networks circulate people and goods. By 2011, 30% of that network was completed. Moreover, 1990s ecological system builders managed to win political support for a Pan-European Ecological Network with their "nature has no borders" argument. Ecological system building had become a transnational endeavor—and one that, much to the frustration of conservationists, could not keep up with road building, especially in Central Eastern Europe.

As noted, from a system entanglement perspective, this case adds to our understanding of Deep Transitions because ecological system builders tried to separate—not entangle—ecological networks from the built environment. That proved tremendously difficult. For example, the pioneers of the Dutch ecological network became more than a little frustrated when the political parties in power chose to include military training grounds, cultivated areas, and plantation forests, and turned the ecological network program into an agricultural subsidy scheme. Later followed debates about nature tourism, and several ecological corridors were adapted for kayaking and hiking. These conflicts illustrate the particular challenge that ecological system builders faced and face.

4. Beyond the deep transitions uncertainty principle

In the context of this special issue on history and transitions, this paper set out to explore the historical study of specific actors in Deep Transitions. It brought to the table a follow-the-actor approach developed in the history of technology and the Large Technical Systems literature. That literature was once a source of inspiration for the so-called Multi-Level Perspective (MLP) on sustainability transitions. But while the MLP opted to focus on rules and routines structuring actor behavior as the marker for transition dynamics, the history of technology and Large Technical Systems literatures continued to study how specific actors shaped sociotechnical systems. This approach has been considerably refined since the 1980s. Applied to the Deep Transition debate, it suggests identifying and studying system entanglers who connected transitions in various social function systems. In illustrating such an approach

regarding Europe's deep infrastructure transition, this paper suggests several lessons for the emerging debate and research agenda.

First, the follow-the-entangler approach seems to work in actual research practice: spotlighting key actors working on the connection of various sociotechnical systems helps the researcher to trace sociotechnical, transnational, and cross-system entanglements. Regarding the deep infrastructure transition, studying of system entanglers reveals the connected transitions of such very different social function systems as transport, food supply, warfare, and even ecological systems. It spotlights successes as well as failures, winners as well as losers, and even that some connected transitions—notably the networking of nature—require disentangling rather than entangling practices. It will not do for Deep Transition studies to reduce the study of actors to abstract categories or *meta*-rules that guide actor behavior, for as Mol (2010: 261) has pointedly noted, "what actors do is always again, in one way or another, surprising", and these surprising actions are key to the shaping of unpredictable Deep Transitions.

It would seem both worthwhile and doable to study Deep Transitions from an actor perspective. Approaches from other actor perspectives than explored here are of course possible; the study of users, governance actors, and media actors seems especially promising. Further research questions could include how actors define and experience deep transitions; what role system entanglers play in deep transitions vis-à-vis other actors and structural dynamics; and—a particularly thorny issue—whether these actor processes can and should be governed, and if so, by whom.

Secondly, this approach uncovered how system entanglers created *divergence* in Europe's deep infrastructure transition as well as the convergence that defines Deep Transitions. Taking as our point of departure Chevalier's bold 1830s vision of a future circulation society, we saw that other actors mimicked infrastructure thinking, producing convergence, while at the same time taking the infrastructure transition in different directions, producing divergence. Some of these divergences were of the utmost historical significance: Chevalier and his followers (who included many national governments and international organizations—and still do today) believed that new transport and communication networks would eradicate structural problems of the past, such as endemic poverty, war, and vulnerability to the whims of nature. However, military system builders captured and appropriated the same mobility transition that ought to bring peace, progress, and liberty, only to develop unprecedented warfare capabilities and scales of violence. Also, while the mobility transition aimed to free people from the cruel bonds of nature, the successful expansion of the infrastructured human-built world connected peoples in a series of shared environmental crises. The relevant Deep Transitions research question is how different actors appropriate (and possibly pervert) key sustainability transition technologies today, and in what direction they are taking this transition. It should be interesting and doable to track such appropriations.

This leads us to a related third point: such divergence makes Deep Transitions extremely unpredictable. As Schot and Kanger noted, Deep Transitions are even more difficult to understand and govern than transitions in individual sociotechnical systems. The deep infrastructure transition is a case in point: initiated with the very best intentions, it brought great progress in wealth and health for many, but also unprecedented socioeconomic inequality, military and environmental destruction, and new risks: Even the successful food transition, from want and monotony to plenty and variety, led to progress as well as inequality and occasional suffering. Can we imagine and anticipate the unintended, harmful consequences of a deep sustainability transition? Perhaps, as part of the Deep Transitions research agenda, we need to evaluate the toolbox that decades of Technology Assessment have developed. Either way, I would suggest that transition scholarship needs its Collingridge 2.0 for Deep Transitions.

Fourthly, this paper suggests the need for reflexivity on the analyst's role in delineating Deep Transitions, in order to avoid essentialism and the uncritical reproduction of contemporary preoccupations. For example, when arguing that a sustainable future requires a deep sustainability transition, Schot (2016) and Schot and Kanger (2016) identify (but do not historically qualify) a First and a Second Deep Transition. The First Deep Transition to industrial modernity was 200 to 250 years in the making, and, so they argue, produced today's unsustainable society. It was characterized by *meta*-rules and routines guiding actor behavior in various sociotechnical systems toward intensive resource and fossil fuel use, waste production, mass production and consumption, mechanization and labor productivity (Schot 2016: 3). The upcoming Second Deep Transition must somehow deal with the negative externalities of the First Deep Transition; supposedly it has been in the making since the 1970s, and its future is still unclear—Schot & Kanger (2016: 3) repeatedly state their "non-teleological and non-deterministic credentials", underscoring the open-ended character of the upcoming sustainability transition.

This paper, however, suggests caution when taking the First Deep Transitions for granted in any essentialist manner. Based on historical evidence, one may just as well identify a deep infrastructure transition in the past 200 years. Moreover, the deep infrastructure transition does not fit with Schot and Kanger's First and Second Deep Transtions, for infrastructure connectivity seems pivotal to both (consider present-day visions of smart grids, smart mobility, and smart cities as sustainable innovations). Apparently, delineations of Deep Transitions are in the eye of the beholder; they are contingent upon the researcher's questions, guiding concepts, and sources.

Moreover, Schot and Kanger define their First Deep Transition from the perspective of the Second Deep Transition to sustainability: they tend to sweep processes and events that we find unsustainable today under the First Deep Transition, despite very different and asynchronous histories. Thereby they produce a tremendous oversimplification of the historical record. In sum, the notions of the First and Second Deep Transitions should be subject to scrutiny and reflection; at the very least, Deep Transition research needs to clarify its role in defining such transitions, validate such transitions empirically, and submit its choices to the intersubjectivity of scholarly debate.

Social history, as noted, engages with present-day social issues and social theory, including Deep Transitions theorizing. Without aiming to do any boundary work between history and transition studies, my concluding observation is that engagement goes two ways. For example, Deep Transition thinking *avant la lettre* helped develop the historical thesis of Europe's Infrastructure Transition as a contribution to the historical literature on technology and the making of modern Europe. Conversely, this essay feeds back lessons from that historical research experience to the emergent Deep Transitions debate. In my view, it is such mutual benefits—and the

explicit rejection of a stereotyped division of labor—that makes such disciplinary exchanges both relevant and exciting.

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