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Under Construction: Material Integration of the Netherlands 1800–2000

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This article investigates the material integration in the Netherlands. Section 1 maps the proliferation of network technologies during the last two centuries. Sections 2 and 3 scrutinize the complex dynamics of network development for selected cases. The case of the electricity supply network reveals how institutional frameworks stabilized network development despite conflicts and contingencies, and how competing (gas supply) networks affected network development. The cases of the Rotterdam harbour, Amsterdam Airport Schiphol and the city address innovation and professonalization processes at the level of network nodes, which tie different networks together and heavily affect overall network morphologies and flows. Section 4 addresses the 'vulnerability paradox' as a specific characteristic of the networked nation.

Keywords: Infrastructure; Network Technology; Innovation Junction; Interface Technology; Electricity Supply System; Rotterdam Harbour

To understand how Dutch society and network technologies co-evolved during the last two centuries, we first have to analyse the remarkable proliferation of the latter. Most of the literature on infrastructures and large technical systems addresses a single network technology, the term we shall use, in one region or country. In some cases, similar network technologies in several countries are compared. Very few studies address multiple network technologies in one country.[1] However, juxtaposing the entire set of network technologies is essential to analyse the shaping of the 'material basis' of present-day network societies.

The first section of this article briefly maps the proliferation of network technologies in the Netherlands during the last two centuries. Network technologies expanded in

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scale, became increasingly dense and multiplied—as functions previously carried by transport networks gained their own separate infrastructures for energy supply and telecommunications. By 1970, this had resulted in a veritable 'material integration of the Netherlands': multiple, nationally integrated networks tied houses, farms, factories, fields and waters throughout the country together into one artificial, that is human-made, space.[2]

Such a mapping exercise may yield the unwarranted impression of a straightforward, uncontested, perhaps self-evident advance of the man-made geography at the expense of the 'natural' one. This was definitely not the case. The next sections of the article descend to the micro level to analyse how the design, construction and use of network technologies were the outcomes of complex dynamics involving different context factors, the efforts and ambitions of many actors, and possibly harsh negotiations or even open conflict. We will draw out some key features of the unpredictable dynamics of network technology building for a few selected cases at both the level of entire networks and at the level of crucial nodes where different networks were tied together.

At the network level, we shall examine the case of electricity supply, one of the major enabling and omnipresent technologies in present-day network societies. Analysing its dynamics we shall pay particular attention to the specific institutional setting that guided the behaviour of the actors involved. We will also emphasize the importance of the interaction between different networks for network dynamics, in this case the competition between electricity and gas supply networks. The rather unsuccessful introduction of electric cooking in the Netherlands reveals that the newer (electric) technology did not simply defeat its competitor; the outcome of this competition depended on many (f)actors.

Next, we shall address several processes playing out at the level of nodes that tie different networks together. Node dynamics both shape overall network morphologies and dynamics and may constitute important events in their own right. We will use the cases of the Rotterdam harbour, one of the world's largest, Amsterdam Airport Schiphol, one of Europe's primary air transport hubs, and Dutch cities to address a particular kind of technological development 'on location:' the shaping of interface technologies tying together different geographically expanded networks.

By way of conclusion, we will address the 'vulnerability paradox' as a specific characteristic of the networked nation. The implementation of a large number of new networks in society created a societal vulnerability on a scale previously unknown. This is caused by the increasing dependency on networks, despite continuous efforts to minimize the risks of mal-functioning.

Material Integration of the Netherlands

During the last two centuries, Dutch space was radically transformed. Around 1800, the Netherlands were comparatively empty: large parts of the country were poorly accessible and scarcely populated.[3] By 2000, however, the country had become a 'network society' as the Fifth National Policy Document on Spatial Planning proclaimed.[4] In the meantime, a number of nationally integrated, fine-meshed network technologies had been constructed that tied the entire country, every area and building, into one large human-made space.

Comparing maps of the main network technologies in 1800 and 2000 shows just how massive this change was. In 1800 waterways were the most important integrating infrastructures in the Netherlands (see Figure 1).[5] In the wet 'Low-Netherlands,' they provided integration on a regional level and tied different regions into an international navigation system built in the times of the Dutch Republic. However, many communities on the higher, sandy grounds lived in comparative isolation. These were not reached by the inland navigation network. Their small rivers were hardly navigable. Road systems existed, including through-going roads, but their condition was poor. Communities in these sparsely populated, poorly accessible and cultivated areas had only very little relation to the outside world. An international economy thus co-existed with many isolated local economies. Accordingly the new centralized state, established with the French occupation (1795–1814), was far from realizing effective centralized government rule over the entire country. There was no national market and a Dutch identity—a sense of nationhood—remained limited to a few percent of the population.[6]

In 2000, all this had changed. In the meantime, the Netherlands had been materially integrated by an array of different network technologies connecting nearly every building, field and water into a large artificial space (see Figure 2). We will briefly survey these changes.[7]

Waterways and Transport Networks

The primary integrating infrastructures of the Dutch Republic, waterways, had always been multifunctional, hosting potentially conflicting functions as drainage, fresh water supply, navigation, fishing and even national defence.[8] Covering the swampy soils by drainage canal systems, and diking, damming and normalizing (later even canalizing) rivers, 'ecological networks' were increasingly brought under human control. In the 19th and 20th centuries this control was extended to a national level. The canal boom of the 19th century initially served the Dutch harbours and their connection to Germany, but by 1900 a national integrated system of waterways had been built.[9] In the 20th century, the focus shifted towards providing security against flooding and controlling the flow of fresh water, culminating in the ambitious construction of a national system for water management (ca. 1940–1971; Van der Vleuten and Disco, this issue) that could distribute fresh water over the country. In addition, the water network was branched on an enormous scale, including drainage canals for the cultivation of agricultural areas, sewage systems, and drinking water systems. All buildings and areas were linked together in a dense wet network.

Meanwhile local, regional and national governments and private companies constructed new transport networks and expanded existing ones.[10] Between 1839 and 1880 the state and private companies constructed a national railway network. From the 1880s, local railway and tramway building made the rail network increasingly dense; by

Figure 1 In 1815 Waterways Were the Most Important Integrating Infrastructures on Dutch Territory. Original source: Filarski, *Kanalen*, 91.

the early 1930s, it reached its maximum length of some 6500 km (including tramways), comparable to the size of the navigable waterways.

After the Second World War, railways and waterways subdued to the road network; the rail system was approximately halved. King William I (reign 1815–1840) had continued Napoleon's project to build imperial roads in the Dutch territory, and by 1850 a national network of main roads existed. Subsequent road building by provinces

Figure 2 Around 2000 the Dutch Networked Nation was Integrated by Multiple Network Technologies. The map includes maritime and inland waterways, railways, roads, air corridors, gas pipes, oil pipes, electric power lines, and digital ICT junctions. Source: Ministry of VROM, *Fifth national policy document*, supplement.

and, incidentally, private companies resulted in some 20,000 km of road by 1920, making roads by far the densest transport network. The spectacular success of automobilism and the introduction of a network of highways, only accessible to motorcars, gave a new impetus to road building in particular in the post-war era. By the end of the 20th century, some 115,000 km of road formed a multilayered, heavily used network that increasingly suffered from congestion. The density of the Dutch road network is only surpassed in Belgium and Japan.

Finally, a less visible, but increasingly crowded network of air corridors was delineated above the Dutch territory. The network is internationally oriented with Amsterdam airport as a major European node. Inland flights are still of marginal importance, despite 1930s' visions of private airplanes as successors of private cars and post-war policies to develop regional airports.

Functional Differentiation of Networks

While waterways and other transport networks were immensely expanded, the number of network technologies multiplied: functions that had previously been carried out through transport networks, such as energy supply and communication, increasingly received their own infrastructures independent of transport. Until the first half of the 19th century, communication had been based on messengers, mail or journals using the available transport networks. Electric telegraphy, introduced by private companies but quickly taken over by the state, sparked off an era of electromagnetic communication networks independent of transport networks. By 1855, the main Dutch cities were connected to Belgium, Prussia and Hanover. In 1900, some 600 telegraph offices were interconnected by over 20,000 km of telegraph wire. The development of radiotelegraphy increased the range of the network internationally.[11]

In addition, telephony was introduced in the late 19th century; the network rapidly gained national reach and soon interconnected most municipalities. Two more waves of increasing density followed. Individual houses were increasingly connected, in particular after 1970: a mere five connections per hundred inhabitants in 1950 had increased to 34 by 1980. Finally, the PTT offered public mobile telephony from 1949, but it was only in the 1990s that mobile telephony would interconnect individuals in the telephony network independent of houses or vehicles on a massive scale; today most individuals possess a mobile phone.

From the 1920s, also electromagnetic mass communication networks were set up on a national scale. National radio broadcasting dates from the mid 1920s, and by 1940 most households were able to listen to radio. The Philips company had supplied the first radio transmitters and thrived on the radio boom; it also set up experimental TV broadcasting in the Eindhoven region in the late 1940s, and provided the equipment for the first national TV broadcasting in 1951. A system of auxiliary transmitters soon guaranteed full national coverage. The rapid diffusion of TV sets (75% of all households were connected by 1970) tied the Dutch population into a very influential new virtual network.

Several energy supply networks differentiated from the transport networks.[12] Until the 19th century, energy had mainly been supplied by wind, water or horsepower, or through transport networks. In the 17th and 18th centuries, a well developed indigenous peat industry used waterways for transport; in the 19th and 20th centuries imported (and from the early 20th century indigenous) coal was distributed by rail or waterway. In the 20th century, however, separate networks for gas and electricity distribution would make seemingly abundant flows of energy cheaply available to every household by a simple pull of a switch or the turning on of a tap.

Pipeline networks for gas supply date from the first half of the 19th century but still had a local character by 1911, when some 200 gas factories supplied some 300 (out of 1121) municipalities though local networks. Despite the subsequent development of 'long distance gas' pipeline networks, it was only the discovery of large supplies of natural gas in Slochteren (1959) that spurred the construction of a national gas pipeline network, which was completed in 1968. Electricity supply dates from the 1880s, likewise in the form of local networks. In 1911, about 20% of the municipalities had access to electricity. In the next two decades the Netherlands were almost completely electrified—only six small municipalities out of 1050 did not have access to electricity in 1939—by a set of provincially organized, yet mutually hardly connected power grids. After the Second World War, the main players in the field agreed to construct a national grid, which was completed in 1954. We shall analyse this case in detail below.

By 1970, multiple networks tied together virtually all buildings and areas in the Netherlands into one and the same human-made space. Even apparently 'natural' water flows had been manipulated, appropriated and integrated into this space. Outside this artificial space remained only areas labelled 'natural territories,' comprising merely 5% of the territory (excluding 8% human-made forests).[13] Currently, even these areas are getting integrated into the Dutch network society (Van den Belt, this issue). To preserve and recreate 'real nature' of a sufficient size to maintain equilibrium, it has become national policy to interconnect isolated nature reserves by means of wet or green corridors, stretches of land of some 20–25 metres enabling the migration of species. The resulting man-made National Ecological Network was scheduled for 2018, but recent political changes have tempered both investments and expectations.

Still, with the multiplication and national integration of material networks—technological and 'natural'—a man-made Dutch space emerged, constituting without doubt the most significant change in Dutch geography in the last two centuries. The logic behind this development, however, is complex. Certainly it was not administered top down by central planners—national planning would not become a factor of importance in the Netherlands until the 1960s.[14] We will now discuss several aspects of network dynamics for selected cases.

Dynamics of the Electricity Supply Network

Electricity supply seems to be impervious for the fast pace and change of our time. In the first half of the 20th century, it had become an important symbol of modernity;

industrial progress was quite often expressed in terms of the degree of electrification of nations, factories or households. A closer look reveals that the development of this network technology, as of other network technologies, was not a linear, self-evident process. Many actors with different stakes negotiated about its shaping. Still, even if network technologies were socially shaped and contested, they acquired what Hughes—in his famous study that made electricity supply a scholarly exemplar of network technology development—called 'momentum': a certain mass, speed and a direction that proved hard to change.[15]

In this section, we shall emphasize two aspects of network development. First, we trace the origins of this momentum for the case of electricity supply to the emergence of a succesful institutional framework, which succeeded the initial disagreements and quarrels between stakeholders in the 1910s. We will also pay attention to the more recent destruction of this momentum, an aspect not often addressed in the LTS-literature. Second, another salient feature of the dynamics of electricity supply networks is their perpetual interaction with gas supply networks. These networks competed for markets but, as we will show, in some periods their relation was rather symbiotic than competitive.

Institutional Frameworks

The notion of institutional framework, originating in institutional economics, has been adapted to analyse the development of network technologies by Thue and Kaijser.[16] For Kaijser the concept denotes the formal and informal laws and regulations, organizational structure, and ownership patterns of network technologies. In Sweden, he argues, the institutional frameworks of 'paradigmatic' network technologies like railways in the 19th century and electricity supply in the 20th century were copied for other network technologies, resulting in successive 'national institutional frameworks' for network technologies in different eras in Swedish infrastructural history.

In the Netherlands, the shaping of an institutional framework for electricity supply took an unexpected turn. In the early 20th century, electricity was provided by a variety of actors and systems. Entrepreneurs offered electricity both in large cities and in small communities. In larger cities, the municipal authorities increasingly founded their own public utilities. In rural villages in the North, electricity supply networks were also organized as co-operative societies, proving very successful in Denmark, a major competitor to Dutch agriculture.[17] Finally, by far the largest generating capacity was located in industrial firms, using the available steam power for generating electricity. This heterogeneity was reflected in the variety of systems. Most smaller networks were direct current (DC) systems, comparable to the system of Edison. Some larger networks featured alternating current (AC), but here too various systems were available.

Already in the first decade a pattern emerged that would characterize the Dutch electricity sector for most of the 20th century: demand and production pushed each other incessantly, resulting in an ever-increasing scale of production, transmission and consumption. Expectations of continuous expansion played an important role in this process and often became self-fulfilling prophecies. This applied especially to the larger municipal and private companies, using AC systems because this technology offered better transport possibilities. The position of the smaller rural utilities gradually deteriorated, although some of them would survive for decades.

Network expansion posed new problems: crossing municipal borders implied acquiring licenses from several municipalities. In want of a clear institutional framework, matters were solved on an *ad hoc* basis. However, it also touched the interests of a new actor that soon and quite unexpectedly entered the scene: the provincial authorities, the intermediate level in the Dutch political system. Inspired by German examples, several entrepreneurs approached provincial authorities with plans for regional power plants. Although hesitant at first, the provinces entered the electricity supply business with the argument of developing the countryside and countering urbanization. 'Greedy' private companies, according to the provincial authorities, would never be interested in unprofitable projects. Small rural communities, on the other hand, did not have sufficient financial and organizational capacity. The provinces introduced a provincial concession system and founded their own provincial utilities. Despite some fierce resistance and allegations of abuse of public power, they frustrated the development of competing public and private companies with all means available. In the province of North-Brabant for example, they pushed the municipal authorities in Eindhoven to break with a private supplier; they also changed the rules for being able to refuse two cities of expanding local electricity networks.[18] A few exceptions to this 'provincial model' were accepted, but more important was that new actors were deliberately and successfully excluded.

Another option would have been an intervention of the state. In 1914, a state committee strongly recommended to push for a national electricity network, fearing that provincial boundaries might produce electric ones as well, but the suggested measures proved politically unviable. The Dutch government too accepted the new order. Only a few years later, in the final years of the First World War when state intervention had become accepted practice, the debate was resumed. A new committee proposed a state company to construct a national power grid, as soon would happen in France and Great Britain. However, a corresponding Bill did not survive Parliament. The first Electricity Act would be accepted only in 1938, and did not arrange for state interference; rather, the government reserved the opportunity to interfere in case that the utilities would not succeed in integrating their networks by themselves.

All this not only shows that organizing electricity supply was contested, but also how negotiation and reconfiguration produced an institutional framework dominated by provincial utilities that proved remarkably stable—its main elements stayed intact until the 1989 Electricity Act. The institutional setting also had far reaching consequences for the morphology of the Dutch electricity supply network. The provincial companies constructed provincial networks fed by new provincial central power stations. Furthermore, design characteristics converged because all companies used only two advisors, both professors at the Delft Technische Hogeschool (Technical University); one, Clarence Feldmann, pleaded for 10 kV cables, and today no other country has a higher percentage of underground cables. The other, Gerard van Swaay, introduced a (50 kV) ring structure in the province of North Brabant that would serve as an exemplar for grid design for most of the century. Finally, the main electricity companies (including also a few municipal and private players) increasingly co-operated through their organization the Vereniging van Directeuren van Elektriciteitsbedrijven in Nederland (the Dutch society of electricity company managers). This organization facilitated knowledge sharing and spurred standardization, though on a voluntary basis respecting principal regional autonomy. Thus emerged an electricity supply infrastructure of rather similar electricity supply networks serving provincial territories that jointly electrified urban and rural municipalities throughout the country by the 1930s. In general, the provincial utilities supplied local distribution companies, but there was a tendency to take over local distribution as well as large auto producers.

On the other hand, these provincially organized networks were rarely connected, and existing connections were sparsely used. The main players did not reach consensus upon constructing a national power grid, and a nationally integrated system did not emerge. The electric boundaries that the pre-First World War State Commission had feared became reality.

After the Second World War, a national power grid integrating electricity supply on a national scale was constructed, but again its shaping bore the stamp of the institutional setting.[19] In the 1930s, proponents of national integration had claimed that a national grid would greatly reduce the need for back-up capacity and improve the network's reliability, but others deemed it not worth the additional costs of grid building. A breakthrough occurred during the German Occupation (1940–1945). Clever manoeuvring by national grid proponents, wartime pressures from the German authorities, and post-war pressures from the Dutch government inspired an institutional set-up that would facilitate grid building while maintaining the position of the existing players. The existing utilities founded an organization, the Samenwerkende Electriciteits-Productiebedrijven (Sep, Co-operating Electricity Production Companies), to co-ordinate grid building, manage electricity exchanges with foreign partners and prepare the introduction of nuclear power. Regarding grid building, each partner was responsible for constructing the grid in its own territory; each owned its own power stations, its part of the national grid and its distribution networks. Furthermore, after construction each remained responsible for balancing supply and demand in its own region. The central organization could only in case of emergency command cross-provincial electricity supply. In fact, in the first decades of its existence the national grid was used only incidentally. Electricity flows remained predominantly on the provincial level.

In addition, the shape of the grid, completed in 1953, reflected its projected use as a back-up device. Design followed the same principles developed during the electrification of the provinces: it consisted of two connected rings, a 150 kV ring in the Western and Southern part of the country, and a 110 kV ring in the Northern part, reflecting its less developed character. Every connection consisted of multiple line connections in parallel. Moreover, in case of emergency, each line could carry twice the regular load. In short, the grid was designed to ensure maximum reliability. In order to reduce costs, the number of transformer stations connecting the high voltage grid to the provincial grids was limited.

In the meantime, electricity consumption increased enormously. Dutch engineers started to work on a new, higher capacity national grid almost immediately after the completion of the first one. The first drawings show the Dutch grid as a part of a Trans-European 380 kV network, but soon the engineers returned to their own design philosophy: the second national grid also consisted of two rings, a 380 kV ring covering the West and South and a 220 kV ring for the Northern parts. The new grid was superimposed on the existing layers of the electricity network with only a limited number of connections. Its construction proceeded slowly; it would take more than 20 years before the main lines were put into place.[20]

In sum, we may observe how every major change in the expansion of electricity supply networks was the outcome of contingencies, negotiations and sometimes open conflict. Still, these changes took place within a very stable institutional framework that had emerged in the 1910s. Only major external pressures and internal problems produced a radical change during the last two decades of the 20th century, when the process of scale increase halted. A combination of factors, including environmental concerns, industrial policy and European integration, provoked an institutional restructuring of the electricity sector (and the gas sector) culminating in the liberalization of energy markets.[21] For the material networks this did not change much yet, although international electrical connections are now used much more heavily. However, the management of the electricity network has changed dramatically. Centralized control and co-ordination are replaced by market mechanisms. These changes shatter the image of a linear network growth. Momentum proved not an absolute feature of mature systems, but a relative one, within the boundaries of the prevailing institutional framework.

Electricity and Gas

Another factor affecting network dynamics that we want to emphasize is the interaction between several networks, which may take the form of competition or co-operation.[22] In the 19th century private companies like the Imperial Gas Company, and later municipal governments, established local gas networks. Urban gas networks became the first public utilities, serving as exemplars for the creation of, for example, drinking water or electricity supply networks. The existence and further development of gas supply networks has affected the development of electricity supply in several ways.

First, the introduction of electricity supply initially posed severe problems for municipal authorities as they competed directly with the municipal gas factories, whose revenues had become crucial to municipal economies. Municipal authorities had several options, like postponing the construction of an electric power plant, leaving it to private companies, or starting a new public utility. In the Netherlands, all alternatives were tried. However, when electricity supply was taken over by provincial authorities this immediate problem disappeared. Competition continued as electric lighting gradually supplanted gas lighting, but gas companies survived and successfully entered new markets. Most important were cooking on gas stoves and, to a lesser extent, providing appliances for heating and heating water.

In the 1920s, and in particular during the economic crisis of the 1930s, the electric utilities also attempted to enter the stove market. They copied gas companies tactics: introducing coin meters and differentiated tariffs for attracting lower income classes; opening shops for selling electric appliances; introducing electric cooking in home economics school programmes; and training women in their homes. The competition was also fought in the media, including the production of movies for educational and propaganda purposes. The message of gas and electricity supply companies was almost identical: both stressed the modernity of gas or electric cooking compared to traditional ways of cooking. In addition, the promoters of electricity emphasized the safety risks of transporting and using gas. They also spread the gospel of the all-electric society, promising a leisure society in which electric appliances would take care of (almost) everything.

In the debate, both competitors used price calculations to demonstrate the superi–ority of the technology they supported, but the differences were marginal. A disadvantage of electric cooking was that users had to buy a whole new set of pans and pots. Use played an important role in other aspects as well; women had to adapt their way of cooking if they opted for an electric stove. They usually stuck to the ways that they had learned in school or at home; they did not change their habits easily.[23]

Despite all their efforts, electric utilities gained only about 10% of the stove market. Regional differences can be attributed to the activities of local or regional utilities, but gas cooking maintained the upper hand and electric cooking remained limited to a market niche. Still, the successful introduction of a whole range of 'modern' electrically driven appliances like washing machines, refrigerators, freezers, and TV and audio-sets boosted the sales of, and societal dependency on, electric utilities and their electricity supply networks.

The gas sector, on their part, expanded only in the markets for cooking and heating. This sector was much less organized than the rather homogeneous electricity sector. Local gas companies co-existed with large regional suppliers producing gas in cokes ovens, and after the Second World War new players offered refinery gas, natural gas and bottled gas. The gas sector also lacked standardization. Still, success in these markets meant that gas companies were able to survive and expand. In the 1950s, the number of connections to the gas networks in the Netherlands was second only to the UK.

The discovery of large supplies of natural gas in the Northern part of the Netherlands (later also in the North Sea) and the rapid introduction of natural gas in Dutch society settled the competition in cooking and heating. Within a few years a national high pressure gas transport grid was constructed. The existing networks were upgraded and integrated in this network. Furthermore, the Netherlands became a major gas exporter through a correspondingly developing international pipeline network. Crucial for this expansion was a political agreement on a new institutional framework in gas supply, characterized by a public–private co-operation between the Dutch state and two oil companies, and by a national monopoly. A 'revolutionary' market strategy enabled the rapid transition to natural gas financially. The main target was to conquer the market for space heating first. The ensuing introduction and diffusion of central heating systems made electric cooking and heating unattractive with the exception of small boilers and heaters, only to be used as a complementary option.[24]

In the early 1970s, two major national energy systems had been constructed, providing energy—electricity and gas—to (almost) every corner in the Netherlands. Moreover, these systems had become increasingly intertwined. Electricity and gas had competed for markets for decades; until the 1960s, electricity companies were the 'aggressors,' trying to penetrate markets occupied by gas companies. The introduction of natural gas changed this, and their relation became more symbiotic as natural gas became the main fuel for electric power plants. However, we shall not pursue this issue here.

Dynamic Nodes

Closer scrutiny of the case of electricity supply thus reveals that the dynamics of this rapidly expanding network were socially conditioned, contested, complex, yet structured. Such dynamics also play out in the complimentary element of geographically expanded functional networks, the network nodes, hubs or junctions. Some authors distinguish between these terms, but we will use them synonymously for locations where different networks meet.[25]

Nodes interconnecting multiple network technologies, such as harbours, airports or cities, have been identified as crucial drivers of overall network dynamics.[26] But they are also important in their own right, constituting gravity points of functional activity, power and decision making in present day network societies and linking up localities with the 'space of flows.'[27]

In this section, we shall focus upon a particular kind of innovation crucial to overall node development and the collocation of multiple networks in particular: the shaping of interface technologies that interconnect different types of material networks. Nodes can be studied as 'innovation junctions'.[28] We shall illustrate this for the cases of grain elevators in the Rotterdam harbour, aviobridges on Amsterdam Airport and the urban plan in Dutch city development.

Grain Elevators in the Rotterdam Harbour

In the second half of the 19th century, the Rotterdam harbour rapidly developed into a major European transit site for bulk cargo. Sea going vessels brought in British coal, ores and grain, which were then transferred to riverboats or railway wagons. In the opposite direction, German coal was transferred to sea ships. The harbour became a major node connecting various networks.

Scale increase in the flows of goods and in the size of ships necessitated continuous infrastructural adaptation in and outside the harbour. First, the entry to the harbour had to be enlarged and deepened. A new connection to the sea, the Nieuwe Waterweg (New Waterway) was constructed from 1862 onwards. In addition, the harbour was repeatedly expanded and enlarged. The municipal government played an active role in this process. Despite occasional opposition by local parties, it persisted to seize the opportunities that increasing flows of goods seemed to offer. In the same period the railway network was expanded and river transport improved, providing Rotterdam with excellent connections to the German hinterland. The Rhine became the most important transport route to the industrializing Rhineland.[29]

An important aspect of the development of the Rotterdam transit trade was the mechanization of the on-site transfer of bulk goods. Transfer was necessary because large sea going vessels could not go further inland than Rotterdam. Loading and unloading was hand work executed by day labourers. In the last decade of the 19th century, options to mechanize loading and unloading were investigated and the first grain elevators were introduced, but only on a limited scale and without changing the existing labour relations.

The introduction of pneumatic driving grain elevators from 1905, by contrast, stirred quite an uproar. This type of elevator used vacuum pumps to transport the grain from the ship to a reservoir, from which the grain was dropped on the scales for weighing before it was stored or transferred to other means of transport. From a network perspective, this local innovation is interesting because it constituted a new interface technology greatly speeding up the trans-shipment process.

This innovation on location displayed many aspects of sociotechnical system building,[30] a useful concept for analysing the dynamics of geographically expanded networks as well as nodes. For instance, while elevator technology had originally been developed in England and Germany, the design had to be adapted to the specific circumstances of the Rotterdam harbour. The elevator height had to be increased and the transport mechanism altered. Another problem was that automatic weighing of the moving grain was not considered sufficiently accurate, leading to a new version with manual weighing equipment.

The eventually successful innovation did not merely involve adapting the design, but also required changes in the local infrastructure and the organization of labour. The latter factor proved a major hurdle. The original elevator design with automatic weighing devices had already provoked a strike by the well-organized weighers, fearing to lose their jobs. This opposition initially seemed to block the implementation of grain elevators. The German grain importers, dependent on the Rotterdam weighers as long as elevators only handled a minor share of the grain, responded by promising not to buy elevator-handled grain and in effect installed an elevator-boycott.

However, an analysis by Van Driel and Schot shows that after the conflict was resumed worker opposition had the opposite effect of stimulating innovation.[31] The elevator company proceeded to introduce grain elevators and dockworker protests escalated into sheer violence. The Dutch army was brought in to intervene. The conflict now had major local implications. In addition it spurred a national debate on innovation, affecting the thinking of political and union leaders who hitherto had regarded strikes against machinery as reactionary.[32] Labour relations polarized and the parties now perceived the hierarchy in the port as the stake of the conflict, not merely the position of one professional group. In this context, the grain elevator company managed to mobilize the support from other entrepreneurs that they had lacked previously, including the German grain traders. The new alliance of entrepreneurs rendered worker strikes rather powerless. The grain elevator was implemented surprisingly rapidly; by 1913, pneumatic elevators handled 96% of the grain.

Post-Second World War containerization had similar speed and efficiency effects on the trans-shipment of general cargo as grain elevators had had on bulk cargo.[33] In these cases, interface innovation processes not only intertwined with major local developments (such the battle for power in the harbour), but also contributed to the success and continuous expansion of the harbour to one of the world's largest.[34] In this process, harbour entrepreneurs and Dutch politicians incessantly pushed for improvement of the harbour's connections to its (especially German) hinterland by motor-, rail- and waterway. The Rotterdam harbour developed into a major network node with major effects on the routing of Dutch and European transport arteries.

This process continues today. National planners have branded the port as a 'mainport' and driver of the Dutch economy (see below). Accordingly, heavy investments are allocated to its infrastructural connections. For instance, the first Dutch branch of Trans European Network for freight trains, a so-called freight freeway, is scheduled to connect the Rotterdam harbour non-stop to the German border by 2006. Notably, also this project has been strongly contested, opposing a powerful lobby of direct beneficiaries and politicians with amongst others ecological and NIMBY groups. The negotiated changes towards a more environmental-friendly design constitute a moderate success for environmentalists, but also imply that even more national resources are allocated to projects serving to maintain the Rotterdam harbour's leading position.[35]

Amsterdam Airport's Aviobridges

Another major node in the Dutch network society is Amsterdam Airport Schiphol, located near Amsterdam. The airport started in 1919 and was primarily the basis of KLM, the Royal Dutch Airlines. After the Second World War, air transport expanded greatly and new plans for a larger airport were designed and implemented. Accessibility by road and railway were repeatedly improved. Like the Rotterdam Harbour the Amsterdam airport has been designated as a mainport of the Dutch economy. Accordingly and comparable with the harbour's connection to the European freight freeway network, the first Dutch branch of the Trans European Network for High Speed Trains is scheduled to connect the airport's indoor train station with Rotterdam, Antwerp, Brussels, Paris and London by 2007.

The airport also formed a location for producing interface technologies. One example we briefly want to mention is the transfer of passengers between airplane and terminal.[36] The roots of this innovation date back to the introduction of jet aircrafts. The number of planes and passengers increased exponentially after the Second World War, but the new planes also created new problems because of increased noise levels and health risks due to exhaust gases and the use of a new fuel, kerosene. In the USA, airports experimented with constructions to protect passengers when boarding and leaving the plane. A prototype of the steel 'Lockheed-bridge,' constructed by Lockheed and United Airlines, was introduced in Chicago's O'Hare airport in 1958.

In Amsterdam Airport, the building of a new terminal and KLM's desire to park its new DC-8 jet aircrafts as close as possible for visibility and promotion reasons, inspired a search for technologies to connect terminal and airplane. In addition, airport logistics suggested separating passenger flows completely from the handling and fuelling of the plane. A local firm was contracted and developed the Aviobridge, an aluminium telescopic passenger bridge. This movable bridge could be connected to most airplanes by an ingenious turning and moving mechanism. Contrary to the grain elevator, this innovation did not lead to social conflict, although the airport considered the first bridge to be too 'clumsy' and expensive and some simplifications were necessary. Yet, the aviobridge became a success and an export product; over 300 aviobridges were sold to other airports worldwide.

Urban Plans

Cities are also major nodes in present day network societies. They are internally networked, comprising a multitude of network technologies enabling urban flows of people, goods, foods, energy, information, water and waste.[37] Simultaneously they interconnect (trans)nationally integrated network technologies. A local innovation with major implications for city as well as overall network dynamics was the urban plan.

In the second half of the 19th century, the rapid growth of city population was accompanied by deteriorating hygienic conditions.[38] In addition expanding and new network technologies (gas, telephony, electricity supply) increasingly interfered, posing new challenges to city engineers in Public Works departments of larger municipalities. These departments expanded rapidly. In the case of Rotterdam, where expansion reflected the growth of the harbour, the number of employees increased from 33 in 1878 to almost 1200 by 1910.

Civil engineers, initially dominating Public Works departments, usually worked on an ad hoc basis, starting out from the design of particular network technologies. This approach gradually gave way to a new integral approach to city planning, first formulated by the Haarlem architect H.W. Nachenius in 1880: 'technical, sanitary, economic, and estethic qualities in city building [*stedebouw*] are related, and cannot be separated.'[39] An influential example of the new integral approach was the famous architect H.P. Berlage's 'Plan-Zuid' for a new urban area in Southern Amsterdam. Using primitive statistics, Berlage's plan allocated specific zones to different social classes. It also developed an aesthetic vision on architecture and its relation to public housing in a modern city. There was a crucial role for the design of different transport networks, including a railway station, new broad avenues and tramlines.[40]

After the First World War, Public Works departments increasingly developed their own planning expertise. Simultaneously the profession of urban developer or town planner institutionalized. The new professional community organized conferences, founded its professional organizations, and published technical journals. After the Second World War, it became a specialization at Delft technical university.

Within urban plans, transport networks assumed a central role. A new expansion plan for Amsterdam (1928–35) considered them crucial in connecting living, working and pleasure quarters; a plan 'might even fail from a societal and economic perspective due to an unpurposeful traffic system'.[41] Furthermore, the new overview provided by urban plans stimulated local innovation. Urban ring roads, first applied in the city of Tilburg in 1915 and perceived as solutions to traffic congestion in inner cities, became an interface technology connecting urban networks to provincial and national road networks.

Moreover, urban planners increasingly affected trans-urban network development as their ambitions transcended the urban level.[42] In the Interwar Years city planners added provincial space to their portfolio, originally because it constituted a crucial context for urban development. Provincial plans allocated space to urban zones, agriculture, recreation and nature, and again infrastructures played a prominent role.

Planners also increasingly affected and addressed the national space. In 1924, the Nederlands Instituut voor Volkshuisvesting en Stedebouw (NIVS, Dutch Institute for Housing and City Planning, 1918) established a road committee to influence national road planning and construction. Moreover, planners discussed the idea of a national plan first suggested by a member of the Vereninging tot Behoud van Natuurmonumenten (Association for the Conservation of Nature Monuments) in 1922. A national plan, in the vision of a prominent city planner, allocated space to habitation; labour in agriculture, industry, and services; nature and recreation; and infrastructures including transport, electricity supply and water supply and national defence.The NIVS pleaded for a national plan with the government in 1938, and the German occupants actually introduced a National Spatial Planning Agency. After the war, the agency was placed under the predecessor of the current Ministry of Housing, Spatial Planning and the Environment. By the 1960s, housing problems were perceived less urgent and spatial planning came increasingly into focus. Successive national policy documents on spatial planning gave prominent roles to network technologies, culminating with the 5th policy document (2001) invoking the concept of 'network society.'

Planners affected network technology development on several spatial and political levels, but it is important to note that they could not determine such developments Plans might inspire network building, but could also lag behind actual developments set in motion by other actors. In particular, national planning never gained a determining character. In the 1960s, it run into competition with the national water management and traffic agency *Rijkswaterstaat*, which had its own decision making procedures. In the 1970s, furthermore, counter culture shockwaves produced extensive public participation procedures in national, provincial and urban planning sparking off what (with Hughes) can be termed an era of 'postmodern network building'.[43] In the 1990s, the national government temporarily succeeded in centralizing decision making on 'projects of national importance' such as high speed train and freight freeway railway lines, but the current government withdraws from direct interference and prefers a co-ordinating role. National spatial policy, however, still conceptualizes a 'National Spatial Framework' organized around the mainports of Amsterdam Airport and the Rotterdam harbour. The connection of these mainports by network technologies 'with the metropolitan areas in the Netherlands and elsewhere in Europe is of crucial importance'.[44] Furthermore the framework includes one 'brainport', the Eindhoven innovation region, and several 'greenports' (agricultural production centres). Nature zones, world heritage sites, and landscapes complete the picture.

The Vulnerability Paradox

By way of conclusion, we will briefly note that network technologies' succesful penetration of Dutch society, which despite their contested and complex dynamics is an empirical fact, implies a new kind of societal vulnerability. Disturbances in the normal flow of people, goods, water or energy will severely disrupt society. The new societal dependency on network technologies has been called a 'vulnerability paradox': the more reliable the networks, the more society is build on their well functioning and the larger the implications in case of mal-functioning.[45] We will briefly return to the Rotterdam harbour and electricity supply networks to illustrate this point.

As we noted, the Rotterdam harbour developed into one of the largest transit harbours worldwide and constitutes a crucial node in the Dutch network society. Its position in various transport networks is an essential part of its success story. However, the First World War exposed serious negative side effects. Despite Dutch neutrality international coal, ore and grain transports were blocked. Harbour activity came to a nearly complete standstill. Suddenly realizing the dependency on bulk cargo, the harbour parties and the municipality started to look for alternatives to bulk cargo.[46] During the Second World War, moreover, the strategic importance of the harbour attracted the attention of military commanders. To enforce Dutch surrender, the German invaders bombed the Rotterdam city centre in 1940, destroying some 25,000 houses but leaving the harbour largely intact. In 1944, however, German occupation forces started a systematic destruction of the harbour facilities, already hit several times by allied bombers. In 1952, the pre-war harbour capacity was again reached.

The dependency of modern Dutch society on electricity supply increased spectacularly after the Second World War. Its services are nowadays taken for granted; only occasional power supply failures or perceived threats to the network, such as terrorist attacks or extreme weather conditions, make visible the network's role in society to a wider audience. Steetskamp and Van Wijk speake of a 'double vulnerability paradox' in the case of electricity supply: increasing layers of societal functions are based upon uninterrupted electricity supply.[47] Examples are the dependencies on computers, mobile phones, DVD recorders or magnetrons, which all rely on electric power. Even the old function of drainage in the polders, the Dutch areas that require continuous pumping to prevent flooding, came to depend on electricity supply during the 20th century—causing one of the most prominent near-disasters of the Second World War's energy shortage.

The Dutch power grid was designed with a particular eye to reliability and the chance of a major power failure in the Netherlands remained very low for most of the 20th century. However, the liberalization process is accompanied by increasing imports, decreasing investment in generation capacity, and the end of central control, all causing uncertainty on present day grid reliability. Recent power failures in the USA and Europe dropped out huge regions for a day or even longer and disrupted daily life. The Dutch grid regulator recently estimated that the social costs of one hour without electricity in the western part of the Netherlands would amount to 72 million euros.[48]

Although it is too early to assess the full impact of the liberalization process, it is clear that managing (electrical) networks will become more complex. The use of ICT-technology and power electronics will provide solutions to many problems, but the impact of major power failures will only increase as Dutch society becomes increasingly addicted to the uninterrupted flow of energy.

These changes coincide with a dramatic change in perception on the material basis of the Netherlands at large. Two decades ago, several planners and authorities complacently stated that the (re)construction of the Netherlands was almost completed, but nowadays a major restructuring of the Dutch network society is considered inevitable. The Netherlands are still under construction.

Notes

[1] This point was first made in Kaijser, 'From Local Networks.' Kaijser, *I fädrens spår* systematically juxtaposes all 'infrasystems' in Swedish society. Hughes, *American Genesis*; Hughes, *Rescuing Prometheus*; and Gras, *Les macro-systèmes techniques* treat multiple large technical systems.

[2] We follow the notion of 'unification' or 'integration' of Dutch society introduced in Knippenberg and De Pater, *De eenwording*. Compare Van der Vleuten, 'De materiële eenwording.'

[3] Van de Woud, *Het lege land*.

[4] Ministry of VROM, *Fifth National Policy Document*.

[5] Filarski, *Kanalen*. In English see Fremdling, 'The Dutch Transportation System.'

[6] Van Sas, 'Nederland.'

[7] For an extensive treatment and additional references see Van der Vleuten, 'De materiële eenwording' and Van der Vleuten, 'Infrastructuur.'

[8] Disco, 'Waterstaat.' Disco and Van der Vleuten, this issue.

[9] This characterization is contested. Fremdling, 'The Dutch Transportation System.'

[10] Schot, 'Transport.'

[11] De Wit, 'Telegrafie' and De Wit, 'Communicatie.'

[12] Verbong, 'Energie.'

[13] CBS, *Vijfenegentig jaren statistiek,* 12.

[14] For a summary, see Ministry of VROM, *Fifth National Policy Document*, Chapter 2.

[15] Hughes, *Networks of Power*. Hughes, 'The Evolution.' Evolutionary economists speak of 'path dependency' or 'lock-in'. A classic publication is David, 'Clio'.

[16] Thue, 'Electricity Rules'; Kaijser, 'The Helping Hand.'

[17] Van der Vleuten, 'Electrifying Denmark.'

[18] Hesselmans en Verbong, 'Binnen provinciale grenzen.'

[19] Van Empelen, 'Entwicklung'; Verbong, 'Dutch Power Relations'; Van der Vleuten, 'Constructing.'

[20] Verbong, 'Dutch Power Relations.'

[21] For comparable developments in the USA, see Hirsch, *Power Loss.*
[22] This point was first made for the Swedish case in Kaijser, *I fädrens spår.*
[23] Van Overbeeke, 'Kachels, Geisers en Fornuizen,' 73–96.
[24] Correljé and Verbong, 'The Transition.'
[25] Castells, *The Information Age* 1, 413 sees 'hubs' as mere exchangers facilitating smooth interaction, while 'nodes' constitute functional and power gravity points in networks.
[26] Kaijser, *I fädrens spår*, chapter 4.
[27] Castells, *The Information Age* 1, 413.
[28] The concept of innovation junction is introduced in Schot *et al.*, 'Methoden'; see also De Wit *et al.*, 'Innovation Junctions.'
[29] Van Driel and Schot, 'Ontstaan gemechaniseerde massagoedhaven,' 77–80.
[30] Hughes, 'The Evolution.'
[31] Van Driel and Schot, 'Ontstaan gemechaniseerde massagoedhaven,' 94–5. Van Driel and Schot, 'Radical Innovation.'
[32] Van Lente, 'Machines.'
[33] Van Driel and Schot,'Indirecte overslag,' 114–15. Van Driel, 'Co-operation.'
[34] Hosting some 160 million people in a radius of 500 km, the Rotterdam harbour was the worlds largest for some decades—in 1976, doubling the tonnage passing through the second largest harbour in Kobe, Japan.
[35] Van der Vleuten, 'De materiële eenwording.'
[36] Dierickx *et al.*, 'Van uithoek tot knooppunt,' 134–6.
[37] Tarr and Dupuy, *Technology.*
[38] Van den Boogaard, 'Innovatie op locatie,' 95–100.
[39] Cited in Van den Boogaard, 'Innovatie op locatie,' 96. Our translation.
[40] Van den Bogaard, 'Geplande stad,' 58–9.
[41] Cited in Van den Boogaard, 'Innovatie op locatie,' 98. Our translation.
[42] Van der Ham, *Heersen en beheersen*, 281–99.
[43] Hughes, *Rescuing Prometheus*. Van der Vleuten, 'De materiële eenwording.'
[44] Cabinet, *Nota Ruimte*. Quote in English from the VROM Ministry's website www.vrom.nl, accessed 25 July 2004.
[45] Steetskamp, *Stroomloos*, 10–11. Compare Van der Vleuten and Disco, this issue.
[46] Van Driel, 'Indirecte overslag,' 97–8.
[47] Steetskamp, *Stroomloos*, 10–11.
[48] The value of the electricity not delivered only amounts to 1.6 million euro. Bijvoet, 'Samenvatting.'

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