The dynamics of transitions and system innovations: A transformation route in the transition from horse-and-carriage to automobiles (1860-1930)

dr. ir. F.W. Geels¹

Prepared for presentation at the Open Meeting of the Global Environmental Change Research Community, Montreal, Canada, 16-18 October, 2003, IHDP-Conference ‘Taking stock and moving forward’

Abstract
Transitions and system innovations promise great improvements in environmental efficiency. To facilitate policy making, it is important to understand their dynamics. This paper develops a conceptual perspective to understand how transitions and system innovations come about. System innovations not only involve technological changes, but also changes in user practices, regulation, industry networks, infrastructure, symbolic meaning. To understand the dynamics of system innovations, this paper describes a multi-disciplinary perspective, based on insights from evolutionary economics, sociology of technology, and innovation studies. The transition perspective is illustrated with a historical case-study: the transition from horse-and-carriages to cars in the United States (1860-1930). The case-study also leads to further refinement of the perspective, the identification of a particular transformation route in transitions.

1. Introduction

In recent years, there is increasing interest in transitions and systemic changes, because of their promise to achieve jumps in environmental efficiency. In transport systems, energy systems, agricultural systems etc. there are promising new technologies with better environmental performance. But many of these new technologies are not (yet) taken up. This is partly related to economic reasons, but also to social, cultural, infrastructural and regulative reasons. Existing systems seem to be ‘locked in’ at multiple dimensions. Hence, the analytical focus is widened from artifacts to socio-technical systems (e.g. Unruh, 2000; Jacobsson and Johnson, 2000; Berkhout, 2002). The research question in this paper is: how do transitions to new systems (i.e. system innovations) come about?

I define socio-technical systems as a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks, supply networks (see Figure 1 for an example for land-based transportation). This means that system innovations not only involve technological changes, but also changes in the other elements. System innovations are co-evolution processes.

¹ Eindhoven University, Department of Technology Management, IPO 2.10, PO Box 513, 5600 MB Eindhoven, Email: F.W.Geels@tm.tue.nl, tel. ++31 (0)40 247 54514
Section 2 describes a conceptual multi-level perspective to understand system innovations. This perspective is tested with a historical case-study (section 4). Section 3 gives reasons for a case-study research approach and selection of the particular case. Section 5 makes an analysis of the case-study, leading to the conceptual refinements. One refinement is to distinguish a particular route in transitions, namely a wider transformation route. In this route a new technology appears as a last step in a much longer process. The paper ends with a discussion of the findings, and draws some lessons for policy making.

2. Conceptual multi-level perspective

This section briefly outlines the multi-level perspective, which has been described more elaborately elsewhere (Kemp, 1994; Schot, Hoogma and Elzen, 1994; Rip and Kemp, 1998; Kemp, Rip and Schot, 2001; Geels, 2002a,b). The perspective pragmatically uses insights from evolutionary economics, sociology of technology and innovation studies. The perspective distinguishes three levels, which are not ontological descriptions of ‘reality’, but analytical and heuristic concepts to understand system innovations.

The meso-level is formed by socio-technical regimes. This concept builds upon Nelson and Winter’s (1982) ‘technological regimes’, but is wider in two respects. Firstly it is wider than Nelson and Winter’s cognitive routines, referring to the wider sociological category of ‘rules’. “A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures” (Rip and Kemp, 1998: 340). While the cognitive routines of Nelson and Winter are embedded in the practices and minds of engineers, regime-rules are embedded more widely. Second, socio-technical regimes not only refer to the social group of engineers and production firms, but also to other social groups. Socio-technical systems are actively created and maintained by several social groups (Figure 2). Their activities reproduce the elements and linkages in ST-systems. Because each of these social groups has its own distinctive features and its own ‘selection’ environment, they have relative autonomy. On the other hand, the groups are also interdependent and interacting with each other. Interdependence and linkage between sub-systems occurs because activities of social groups are coordinated and aligned to each other. This is represented with the concept of socio-technical regimes. By providing orientation and co-ordination to the activities of relevant actor groups, ST-regimes account for the ‘dynamic stability’ of ST-
systems. This means that innovation still occurs but is of an incremental nature, leading to ‘technical trajectories’ and path dependencies.

**Figure 2: Social groups which (re)produce ST-systems (Geels, 2002a: 1260)**

The micro-level is formed by technological niches, the locus for radical innovations (‘variation’). Because the performance of radical novelties is initially low, they emerge in ‘protected spaces’, which shield them from mainstream market selection. Niches thus act as ‘incubation rooms’ for radical novelties (Schot, 1998). Niches are important, because they provide locations for learning processes about the technology, user preferences, regulations, infrastructure, symbolic meaning etc. Niches also provide space to build the social networks, which support innovations (e.g. lobby groups, user associations). These internal niche processes have been analyzed and described under the heading of strategic niche management (Kemp, Schot and Hoogma, 1998; Kemp, Rip, and Schot, 2001; Hoogma et al., 2002).

The macro-level is formed by the socio-technical landscape which refers to aspects of the wider exogenous environment which affect sociotechnical development (e.g. globalisation, environmental problems, cultural changes). The metaphor ‘landscape’ is used because of the literal connotation of relative ‘hardness’ and to include the material aspect of society, e.g. the material and spatial arrangements of cities, factories, highways, and electricity infrastructures. Landscape form ‘gradients’ for action; they are beyond the direct influence of actors.

The relationship between the three concepts can be understood as a nested hierarchy. Regimes are embedded within landscapes and niches within regimes (see Figure 3). The work in niches is geared to problems of existing regimes (hence the arrows in figure 3). Actors support the niche hoping that novelties will eventually break through. This is not easy, because the existing regime is entrenched in many ways (e.g. institutionally, organisationally, economically, culturally). Radical novelties may have a ‘mis-match’ with the existing regime (Freeman and Perez, 1988) and do not easily break through. Nevertheless, niches are crucial for system innovations, because they provide the seeds for change.
Transitions and system innovations come about through the interplay between dynamics at multiple levels and in several phases (see also Rotmans et al., 2001). In the first phase, novelties emerge in niches in the context of existing regime and landscape developments. The novelty links up with values at the landscape-level or with small and local problems in regimes. Both the technical form and ideas about functionality are strongly shaped by the existing regime. There is not yet a dominant design, and there may be various technical forms competing with each other. Actors improvise, engage in experiments to work out the best design and find out what users want.

In the second phase the novelty is used in small market niches, which provide resources for technical specialisation and exploration of new functionalities. Gradually a dedicated community of engineers and producers emerges, directing their activities to the improvement of the new technology. They meet at conferences, discuss problem agendas, promising findings and search heuristics. Engineers gradually develop new rules, and the new technology develops a technical trajectory of its own. The new technology gradually improves, as a result of learning processes. As users interact with the new technology and incorporate them into their user practices, they build up experience with it, and gradually explore new functionalities. This second phase results in a stabilisation of rules, e.g. a dominant design, articulation of user preferences.

The third phase is characterised by a breakthrough of the new technology, wide diffusion and competition with established regime. New technologies may remain stuck in niches for a long time (decades), before they break through. On the one hand, there are internal drivers for breakthrough. For instance, actors with interests may push for further expansion of the technology. Or price/performance dimensions gradually improve. On the other hand, breakthrough depends on external circumstances, i.e. ‘ongoing processes’ at the levels of regime and landscape, which create a ‘window of opportunity’ (see Figure 4). There may be changes at the landscape level, which put pressure on the regime. There may be internal technical problems in the regime, which cannot be met with the available technology. There may be negative externalities, which are problematised by societal pressure groups (e.g. Greenpeace). Or there may be tensions within the existing regime, because of changing user preferences or stricter regulations. The key point of the multi-level perspective is that system innovations occur as the outcome of linkages between developments at multiple levels. The breakthrough of radical innovations depends on internal drivers and niche-processes and on external developments in regimes and landscapes. As the new technology enters mainstream markets it enters a competitive relationship with the established regime. Economic considerations play an important role in this phase, e.g. price/performance ratio.
Figure 4: A dynamic multi-level perspective on system innovations (Geels, 2002b: 110)

In the fourth phase the new technology replaces the old regime, which is accompanied by changes on wider dimensions of the sociotechnical regime. This often happens in a gradual fashion, because the creation of a new sociotechnical regime takes time, e.g. new infrastructures, new user practices, new policies. Furthermore, incumbents tend to stick to old technologies, because of vested interests and sunk investments. They may also try to defend themselves, e.g. by improving the existing technology, political lobbying or evasion to other markets. The new regime may eventually influence wider landscape developments.

3. Research strategy, case selection and data collection

The phenomenon of system innovation is a process that unfolds over time, involving major changes in ST-systems. As such, system innovations are a complex phenomenon, consisting of many interacting elements and linkages. Investigations of this kind of phenomenon require a research strategy that is both rich in context and can track complex developments over time. Case studies are the only methodology to study a phenomenon in relation to its real-life context and to understand causal links in complex situations where many variables interact (Yin, 1994). Furthermore, case-studies have a distinct advantage over other research strategies when a ‘how’ question is being asked. This is because such questions deal with operational links needing to be traced over time, rather than mere frequencies or incidence (Yin, 1994: 6). In the multi-level perspective the focus is on the interlocking of multiple processes and activities, not on linear cause-and-effect relationships. Case-studies are well suited to tell rich stories in terms of dynamics and interacting processes.

I have chosen a historical case-study: the transition from horse-and-carriages to cars in the United States (1860-1920). This transition has been studied before, but from too narrow
perspectives. For instance, the transition is often presented as a simple technological substitution (Nakicenovic, 1986). There are also historical descriptions, which look at the emergence of automobiles. Basalla (1988: 197-204), for instance, focused on the competition between steam automobiles, electric vehicles and gasoline automobiles. And in industrial economics there are descriptions of automobile developments in relation to industry structures (Klepper, 2002). My case-description will give a more complex account of this transition and show aspects of transformation. The case-study is revelatory, because it highlights aspects which have remained hidden in previous accounts.

The case-study is not intended primarily to unveil new historical facts, but to test and refine the conceptual perspective. Hence I have used secondary, published material from the history of technology, transport history, and urban history.


The transition from horse-and-carriages to automobiles is often portrayed as a substitution process in which horses were replaced by cars (see Figure 5). The emergence of new technologies is assumed to go at the expense of old technologies. A closer analysis, however, will show that actual dynamics were more complex. The transition was not caused by a change in a single aspect, but by the interplay of many aspects and actors.

![Figure 5. Population of road horses and number of cars in US (Nakićenović, 1986: 320)](image)

Figure 6 gives a more detailed view of the diffusion of automobiles, showing that it existed of two S-curves. The empirical description only includes the first S-curve (i.e. to the 1930s).

![Figure 6: US automobile registrations (based on data from Mowery and Rosenberg, 1998: 50)](image)
The empirical description has a focus on urban passenger transportation, because new transport-technologies were first used in urban areas, and then spread wider. The description focuses on America, because this country led the way in the shift to automobiles. The description is organised along the four phases of the multi-level perspective. For each period, dynamics at landscape-, regime- and niche-level are described.

4.1. Expansion of horse-based transportation (1860-1885)

On the landscape level, industrialization and urbanization were two important macro-developments. The emergence of steam power enabled a relocation of factories to cities, where railroads provided cheap coal. This stimulated urbanization. The growth of cities led to longer travel patterns, which were hard to do by foot. Health and hygiene became important cultural issues, supported by a hygiene-movement. Health professionals thought that the abundance of decaying organic filth filled the air with poisonous vapours, miasmas, which caused epidemic diseases. Light and fresh air were thought to improve public health. Hence, parks were built to function as the lungs of the city. In the growing cities, working class people lived in crowded and filthy slums. Cities came to be seen as filthy, unhealthy and dangerous. Many middle-class American families began to see suburban living as desirable, a haven from the tumultuous society (McShane, 1994: 23). A social change was the emergence of a middle class emerged, which had more money and more work-free leisure time, to be enjoyed in the form of entertainment. A new popular culture emerged in America, with values such as entertainment, excitement, fun, and active sporting.

The urban horse-based transportation regime was not static, but dynamic and innovative. Several transport innovations were developed, mainly for middle- and high classes. Middle-classes began to use the omnibus, carrying 15-25 people. New York had 70 omnibuses in 1830, 350 in 1849 and a peak of 683 in 1854 (McShane, 1994: 8). Upper classes had their own private carriage or used taxi’s (hackney or cabriolets). An important innovation was the horse-tram, i.e. horse-drawn carriages on railroads. This way a horse could pull a vehicle at 30% higher speed and haul 100% more passengers (McShane, 1994: 14). They replaced omnibuses on busy routes in the 1850s and 1860s and became the first urban mass transportation mode. In 1880 there were around 19,000 horse-trams in America, operating on an infrastructure of 4800 km (Mom, 1997: 29). Large horse-tram companies operated fleets of thousands of horses, housed in large stables. The large stables also entailed risks, in particular disease or fire. Hence cities created a wave of stable regulations. Thousands of stable boys, blacksmiths, and carriage manufacturers were involved in feeding and stabling of horses, and maintaining the carriages. Feeding and stabling accounted for more than 50% of the tramway companies’ costs (Chant, 1999: 130). City authorities formed sanitation departments to clean the streets from horse-excrements. In sum, an entire regime was created around horse-based transportation, involving many social groups. This regime expanded until the end of the 19th century. Horse-trams, carriages, wagons and pedestrians all mixed in the streets. Although streets were used for transportation, they also functioned as social meeting places (for play, social talk, and street vending). Streets were unpaved dirt roads or covered with rough cobbledstones. Horse-drawn vehicles experienced cobbledstones as problematic, because it damaged the wheels. Hence, there was pressure to smoothen street surfaces. A first wave of street improvements began after the Civil War (1861-1865), using macadam (alternating layers of stones, large ones at the bottom, smaller ones on top). The street improvements encountered setbacks in the early 1870s, because of financial scandals, overspending and corruption. Road improvement was also hindered by the power of local residents to administer their streets. Local residents had no interest in smoothening street surfaces, because traffic was
more of a hindrance than a benefit. Many residents felt that smooth road pavements were for the rich, not for average citizens (McShane, 1994: 64).

Very new transport options emerged in particular niches. The earliest bicycles were developed in the 1830s as toys for the upper classes. At the end of the 1860s a new application domain was articulated: bicycle racing on racetracks. The users were athletic young men, wanting to prove their skill, courage and strength. These user preferences gave rise to the Penny-farthing with a very large front wheel, which enabled high speed, but was unstable. Because the bicycle functioned as an ‘adventure-machine’ (Mom, 1997), this instability was not seen as a problem. Another radical novelty were electric automobiles. Although first experiments date back to 1842, these vehicles suffered from weak electric motors and heavy batteries. There were also attempts to use steam engines. Steam busses were commercially used in London in the early 1830s. But steam engines were heavy and cumbersome, and prone to boiler explosions. In the 1860s steel made possible new boiler designs and lighter steam automobiles. In America, this resulted in a new design trajectory: smaller and lighter steam vehicles. Roper, for instance, built a light (650 pound) steamer in 1863, capable of doing 20 miles per hour. In the 1860s and 1870s, steam automobiles were used as fascinating novelties at racetracks and in circus parades (McShane, 1994: 92). Although further technical improvements were made in the 1870s and 1880s, steam automobiles did not catch on, because of public resistance and regulation. The regulators reflected public opinion when they banned steamers because of their speed, smoke, steam exhaust and potential for explosion (McShane, 1994: 97). Because people had not (yet) been accustomed to high speeds, they opposed steamers in their streets. Other innovative efforts were directed to finding mechanical ways to propel trams. Steam trams achieved moderate success. Steam was also used in cable cars: trams were pulled by (underground) cables powered by a central steam engine. Electric trams were tried out at expositions and exhibitions between 1879 and 1888.

4.2. Heating up and fluidity in transportation (1885-1903)

At the end of the 19th century America was a society in flux. Some landscape developments of the earlier period continued, such as growth of industrial cities, emergence of a new middle class and a new popular culture, hygiene movement. A new macro-development was immigration. In the 1880s and 1890s about 600,000 people entered America, most of whom settled in cities (Faragher et al., 1997: 596). The quality of life in cities was low. The city centre became more congested and noisy. Cultural values such as excitement, entertainment, adventure, speed and contests gained in importance. Electricity was culturally experienced as the symbol of a new age, stimulating investors to put their money in electric electric trams, electric light, electric automobiles. Another macro-development was the expansion of public administration. With regard to politics, the period between 1890 and World War I is often characterized as the ‘Progressive Era’, aiming to end political corruption and address poverty and urban problems. Urban social reformers believed that sub-urbanisation would eliminate social problems associated with slums. To reach this goal, they encouraged the spread of electric trams and engaged in street improvements (McShane, 1994: 77). Cities also encouraged the creation of impressive structures, leading to the City Beautiful movement. Grand concrete boulevards were constructed at high public cost, and individual parks were linked through a series of ‘parkways’. The Parkway movement climaxed in the 1890s, and helped give transportation a new function: driving in the open air became associated with fun. There was a wider trend to segregate and reform public space (Baldwin, 1999). Streets were cleaned up, selling on the street was forced off thoroughfares, recreational activities were
pushed into parks and playgrounds. These changes in public space occurred before the breakthrough of the automobile.

Between 1870 and 1900 the use of horses for transportation grew exponentially (for horse-trams, freight wagons, taxi’s). But wider landscape-developments increased pressure on the urban transport regime, highlighting several problems. As a result the regime heated up, leading to more fluidity and diversity (trams, bicycles). The first problem was high cost for tram companies (feeding and stabling horses). This provided an incentive to look for alternative ways of propelling trams, e.g. with steam or electricity. The second problem was congestion. Horses and wagons occupied much street space, and different transport modes operated at different speeds hindering each other. A few slow vehicles could create major traffic jams. The third problem was safety, through kicking and biting of horses or being overrun by carriages. The fourth problem was pollution. Horses produced huge amounts of excrements, over 150,000 tons annually in New York (McShane, 1994: 52). Manure was thought to provide a likely vector for bacilli that caused respiratory infections. Hence, horses acquired a negative public image.

These problems created a window of opportunities for the diffusion of transportation technologies which were developed in the previous period. Electric trams diffused rapidly. In 1890 16% of American street railways were electrified, about 70% were horse- or mule-powered, and 14% consisted of cable cars or steam railways. By 1902, 97% of American street railways were electric (Hilton, 1969: 126). One reason for the rapid rise of electric trams were operational advantages. It was about twice as fast as the horse-tram (12 mph versus 6 mph). It eliminated tons of horse-excrements. A problem were high initial costs for new infrastructures (e.g. electricity wires, stronger rails) and purchase of electric trams. But, the price of electric trams decreased, from $4500 in 1889 to $750 in 1895 (Mom, 1997: 41). Eventually electric trams were cheaper, reducing the cost per car-mile from 8-11 cents for horse power to 1.5 cents for electric power (Hunter and Bryant, 1991: 209). Second, trolleys benefited from the cultural enthusiasm about electricity. Investors were willing to put money in trolleys. Third, there were powerful social groups to support trolleys. Horse-tram companies wanted to discard their expensive horses. Real estate promoters invested in tramlines because it increased the value of their land (Nye, 1998: 166). Electric light companies stimulated electric trams, because it provided an electricity market at daytime. As the trolley diffused, it had wider effects, which transformed the urban transport regime. First, the trolley created the first urban system of mechanized mass transit. The fare of tram trips was relatively low, five cents, with free transfers (Nye, 1990: 96). Second, the trolley also greatly contributed to sub-urbanization, allowing people to travel between work and home. Third, trolleys stimulated tourism for lower classes, e.g. day trips, picnics or walks in the country, particularly when local networks were connected to each other after 1900, resulting in an interurban transport network (Nye, 1990: 121). Fourth, trolleys stimulated a change in the perception of the function of streets, which was increasingly defined as transport artery. Another cultural change was that residents became used to higher speed-vehicles in the street.

The bicycle also diffused wider, following the introduction of the safety-bicycle (1885), based on two wheels of the same size and a tubular frame. This new bicycle served user groups such as women and elderly men, for whom stability, safety and easy riding were important selection criteria. In the 1890s the bicycle became linked to the new function of ‘touring’ and the cultural values of recreation and fun as well as health and ‘practicing hygiene’. The popularity of cycling led to the bicycle craze of 1895-1896, followed by a collapse of the world market in 1897. The bicycle industry was faced with over-production and prices went down, bringing the bicycle into reach of laborers. The bicycle became a general work-tool, making urban street traffic more heterogeneous and dense. Another effect
of the market crisis was that many bicycle producers diversified their activities to developing automobiles (Mom, 1997: 95). As the bicycle diffused, it had wider effects, which introduced new elements in the urban transport regime. First, experience with the bicycle gave rise to the articulation of new user preferences and mobility practices. Individual driving and flexible driving were two new functionalities, celebrated in the mobility practice of touring. Another new element was the creation of bicycle clubs, which developed into lobby organizations for better roads (Good Roads movement). Third, bicycles led to the further articulation of production technologies, e.g. interchangeability of parts, automated manufacture using special-purpose machine tools. The bicycle industry also introduced new elements in metalworking, in particular sheet metal stamping, and electric resistance welding (Flink, 1988: 5). These techniques facilitated quantity production, and were later used in car manufacturing.

Another important development in the transport regime was the change in road pavement. Dirt roads and macadam pavements became unsatisfactory, because heavy wagons tore them apart. The 1890s were characterized by a new wave of street improvements, using concrete and asphalt. This was related to the City Beautiful movement and Parkway movement. The street improvements involved a power struggle between local residents and middle-class reformers. Local residents resisted road improvements, because for them roads were social meeting places rather than transport arteries. But middle class reformers were able to implement legal changes in the administration of streets. In the context of wider political and bureaucratic changes, power from local residents was gradually eroded and transferred to public authorities. Middle class reformers increasingly acquired positions such as municipal engineers, city planners, reform-minded politicians, and judges. In these positions, they were able to push through their ideas about the function of streets (McShane, 1994). As a result, by 1900, American cities had built hundreds of miles of parkways and boulevards, paved with macadam, concrete or asphalt.

In this context a radically new technology emerged: automobiles. The early period was situated in Europe. Automobiles were introduced in America in 1893. In its early years, it was widely thought that the new automobile would be an urban car. Early cars were fragile and did not have much horsepower. Only cities had large amounts of smooth asphalt and brick pavements for the early fragile novelties. The newly created smooth roads and boulevards thus functioned as proving grounds for early cars. Early automobiles were constructed by adding engines and motors to existing coaches or tricycles. Light steam automobiles were improved, using petroleum instead of coal to heat the boilers. Serpollet’s flash boiler (1889) made it possible to start steamers within 5 minutes. Electric vehicles were improved, using lighter batteries (Fauré, 1881). Although the first electric vehicle was a light carriage (1881), heavy carriages were easier to electrify, because they could better carry the weight of batteries. Batteries powered small electric motors placed close to the wheels. Electric vehicles borrowed the mechanical ‘controller’ from the electric tram, which allowed easy starting, acceleration and gearing. Electric cars were considered clean, quiet, reliable and easy to handle. With regard to gasoline cars two trajectories were followed. The first trajectory was to add gasoline engines to bicycles and tricycles, e.g. Benz’ car of 1885. The second trajectory was to add gasoline engines to carriages, e.g. Daimler in 1885 (see Figure 7).
Internal combustion engines (ICE) have specific technical characteristics. An ICE cannot deliver power from standstill, because energy is required to start the movement of pistons, connecting rod and crankshaft. During starting the engine needs to be uncoupled from the wheels, to prevent stall. Hence, a clutch is needed. Another characteristic is that the ICE works better at higher speeds and numbers of revolutions. A common complaint was that early gasoline cars easily stalled at low speeds (Mom, Werff and Bos, 1997: 217). Another problem was to transmit power from the engine to the wheels. Several options were tried, e.g. cogwheels, belts, chain-drive borrowed from bicycles. The complex gearing and transmission techniques in gasoline cars required extra space. Builders of gasoline cars began change the chassis, in the form of an extra ‘nose’ (hood). Over time this ‘nose’ became longer, while the boxy coachwork was built lower. Gasoline cars thus developed a particular form.

In the early 1890s the main technical teething problems were solved. Pioneers now searched for suitable application domains. Four main niches were explored. The first was the taxi-niche. The gasoline car was not very suited, because of difficulty of driving them at low speeds and frequent stops (Mom, Werff and Bos, 1997: 217). Electric vehicles were easy to start and accelerate. In the context of the electric trolley, it seemed logical that electricity would be the way to mechanise transportation. The electric car was thought to fill in the gaps of the electric tram network. The short range of electric vehicles was not perceived as a major problem and could be dealt with through fleets of urban taxis. In the late 1890s many countries experienced a ‘lead cab fever’, as electric taxi’s appeared on the streets of major cities: London (1897), Paris (1898) and Berlin (1899). In America electric cabs were first operated by the Electric Vehicle Company (EVC) in 1899. Between 1899 and 1902 electric vehicles enjoyed great popularity in the taxi niche (Kirsch, 1996: 19). But this enthusiasm died away, because batteries proved to be vulnerable, suffering from frequent breakdowns. Furthermore, the EVC got embroiled in legal and financial scandals, and went bankrupt in 1903 (Fogelberg, 1997). The second niche was the luxury niche of promenading in parks. Because early gasoline cars were difficult to start and operate at low speeds, electric vehicles seemed an appropriate choice. The resulting electric ‘society cars’ were exclusive and meant to show off wealth. In this niche short-range was not a problem for electric vehicles. The third niche was racing. The first official road race was in 1894 over 199 km from Paris to Rouen and back. This race attracted much interest and press publicity. The first American race was the Times-Herald race in 1895. Car races were very popular, attracting many spectators and press interest (Mom, 1997). Car races resonated with cultural values such as excitement and danger, courage, physical prowess, elite status, masculine courage, aggressiveness and striving for records. Automobile clubs were set up to organize races, France (1895), Belgium (1896), Italy and England (1897), United States (1899). In short-distance races on tracks, electric vehicles gave good competition to gasoline cars, taking advantage of their momentary energy outburst. But in long-distance races electric vehicles encountered problems with the limited energy content of the lead acid battery, and low reliability and sturdiness. The racing niche
played a major role in forming the perception of what ‘the automobile’ should be able to do. Long-range and high-speed were established as prominent performance criteria. These performance criteria influenced the technical form of the car, which changed from a high boxy carriage to a low and long vehicle, more aerodynamic and sportive. The new user preferences materialised in a dominant design, the Mercedes of 1901 (see Figure 8).

Figure 8: The Mercedes from 1901 (Hard and Knie, 1994: 145)

The fourth niche was tourism in the countryside. Early touring was mainly for sportive ‘dare-devils’, because cars were weak and often broke down. After cars had become stronger, the period 1902-1907 witnessed great expansion of touring in the countryside (Kline and Pinch, 1996: 771). Touring was very popular because it linked up with a range of cultural values, e.g. adventure and technical skill. It succeeded the bicycle as ‘adventure machine’. Touring was also experienced as ‘active travelling’, and strengthened two new functionalities, which were first introduced with bicycle: individual and flexible mobility. One could choose his own route, not constrained by fixed rails. Touring also linked up with the health and nature movement. Driving cars in the countryside was perceived as ‘practising health’. Because touring was a popular niche, different automobiles tried to establish a foothold. There were attempts to use electric cars for touring, but these failed because of limited range, and the lack of a rural electric infrastructure for recharging. Steam car manufacturers did not really champion the use of their cars for touring. Steam car manufacturers were often master craftsmen, mainly interested in making beautiful steam cars. Because they did not care much about consumers, it remained unclear which market they targeted (Van de Velde, 1997: 10).

Most widely used in touring were gasoline cars, which could build upon an existing fuel infrastructure. Petrol was widely available at general stores, e.g. for lighting purposes and stationary gasoline engines (Kirsch, 1996: 52). Gasoline cars could also build on an existing repair network made up of farmers, smithies and mechanics with gas engine competencies. Although touring in the countryside was popular with upper classes, it met with resistance from the local population. Accidents happened, killing people or livestock, because drivers travelled at high speeds on bad roads. Speeding cars also caused dust waves (dust problem). The opposition from farming communities and anti-speed organizations jeopardised the standing of the automobile. In reaction, automobile clubs lobbied for favourable legislation and defended drivers against criminal suits. Public authorities began a regulatory process to embed the car institutionally, thus defusing opposition (Rao and Singh, 2001: 263). Car registration and car tags were introduced to facilitate identification of cars and drivers in case of accidents. An institutional response to reckless driving was the licensing of drivers. Speed limits were introduced, but these were rather favourable. Local speed limits were raised from 6 to 12 mph within city limits in 1901 and to 20 mph outside the city limits in 1905 (Baldwin, 1999: 216). Traffic rules were devised to create more order on the street. In 1903 the New York Police Commissioner issued traffic rules to separate different traffic modes to facilitate the flow (slow vehicles on the side of the street, fast vehicles in the middle).

In sum, by 1903 a stable distribution of functions emerged. Electric vehicles were defined as urban cars, used in the taxi-niche and the promenading niche. Gasoline cars were
defined as ‘adventure cars’, used in the racing and touring niches. Because these different
niches were relatively separate, electric and gasoline cars did not compete directly.

4.3. Expansion of electric trams and stabilisation of a technical car-regime (1903-1914)

An ongoing process at the landscape level was immigration, which increased to about 1
million emigrants per annum. Overcrowding, health problems and social reform remained
important issues. The Progressive Reform movement continued. Sub-urbanisation was seen as
a way to deal with urban social problems. Progressives were supportive of automobiles,
because they could be instrumental to facilitate suburban living (Ling, 1990: 6-7).

The electric tram regime enjoyed great expansion. By 1900 there were around 850
trolley systems in American cities operating over 10.000 miles of track. Figure 9 gives an
impression of the rise in yearly passengers. The trolley was widely used by middle classes for
commuting between work in the city and suburban houses. The strongest growth occurred in
the interurban tram systems between communities. The electric interurban mileage increased
from 2107 miles in 1900 to a peak of 15.580 miles in 1916 (Flink, 1990: 3).

![Figure 9: Yearly passengers in the electric tram in the US and Germany (Yago, 1984: 9)](image)

Despite its expansion, there were several problems in the electric tram regime. First, the
trolley was strongly regulated with regard to fares and transfers. City councils and state
commissions refused tram companies to increase prices, which long remained five cents (Nye,
1990: 134). They also instated universal transfer, paying per ride rather than distance. These
regulations made it difficult for trolley companies to increase their income (Flink, 1990: 363).
Nevertheless, trolley companies enjoyed large profits in the 1890s and the early 20th
century. Some trolley companies were involved in real-estate speculation, and publication of
speculative excesses gave them the public image of greedy and rich monopolists. A second
problem was declining standard of comfort, in particular overcrowding on rush hours.
Overcrowding resulted in delayed services, breakdowns and dirty carriages. Another reason
for complaint was the inflexibility of routing. As factories were set up on the outskirts of
cities, workers often first had to travel to the city centre, and then take another tram to the
factory. The failings of mass transit were seen as a broken promise. Trolley companies seemed
to be more interested in money than in ‘proper’ transportation.

In 1900 automobiles were still toys for the upper classes, playing a minor role in terms
of overall mobility. Gasoline cars were used by rich sportsmen and adventurous tour drivers,
while electric vehicles served as luxury cars in cities (e.g. promenading, tea parties). From
1903 to 1907 this relative separation persisted. Steamers and electric vehicles kept up their
numbers in their market niches (see Table 1). But the number of gasoline automobiles raced
ahead, because it linked to popular application domains: car racing and touring.

<table>
<thead>
<tr>
<th></th>
<th>1900</th>
<th>1905</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric cars</td>
<td>1.575</td>
<td>1.425</td>
</tr>
</tbody>
</table>
After 1905, new groups began using cars for business purposes, e.g. doctors, traveling salesmen and insurance agents. Wealthy farmers began to use cars as a practical vehicle for transportation of goods and people (Hard and Knie, 1994: 147). Another commercial niche was the taxi niche. Gasoline tax’s appeared in New York in 1907, replacing horse-drawn hackneys. The taxi-niche was the trailblazer of a more utilitarian use of gasoline cars. Automobile touring remained important, but gradually changed its character, as it developed into autocamping after 1910, a vacation alternative for the middle classes (Belasco, 1997: 7). In the early 20th century automobiles were still large and luxurious. Olds and Ford pioneered a new trajectory of cheap, strong, sturdy cars. Ford wanted to build cheap cars, without sacrificing strength. After years of experimenting Ford found the ‘right’ balance between cheap price and sufficient robustness in his Model T priced at $850 in 1908. Its basic merit lay in the combination of lightness, sturdiness, simplicity and power. The importance of the Model T was that it created a dominant design for the car industry. The new technical trajectory was accepted in the car industry, after sales drops in 1907, signaling saturation of the luxury market. This car stimulated manufacturers to find new markets, and they turned to Ford’s idea to go down-market (Mom, 1997). The emergence of a dominant design, allowed engineers to focus innovative attention on production technologies to bring prices down, and improve technical performance through incremental product innovations. One such innovation was the electric starter, developed in 1911. Starting had been a complicated matter in internal combustion engines, because a crank had to be turned around rapidly and with great force. The electric starter solved the problem of starting gasoline cars, using high voltage ignition on the basis of batteries. Because gasoline cars became easier to start, electric vehicles lost an important advantage.

By 1905 a second generation of electric cars was displayed at car shows characterized by more reliable and stronger batteries. But the electric vehicle did not stabilize into a dominant design, prevented mass production, scale economies and lower cost. Between 1907 and 1910 there was a brief resurgence of interests, the ‘golden age’ of electric vehicles (Wakefield, 1994). But the electric car was increasingly confined to small market niches, becoming a ‘society-vehicle’ for tea parties and promenading. Gasoline cars with electric starters increasingly invaded the urban niche of electric vehicles. Although electric and steam cars remained viable for several years after 1910, it was clear that the electric vehicle had lost the battle with the gasoline car.

4.4. Towards a car-based personal transportation regime and its impact (1914-1930s)

The regime of the electric tram gradually fell apart in the 1920s and 1930s. One problem was financial. Wage and material costs increased, especially during World War I. But because fares were strongly regulated, tram companies had few ways to increase incomes. Tram companies build up financial debts, and had no funds for expansion and improvement of the lines. Track mileage began to shrink, although the number of passengers did not begin to decline until 1924 (Hilton, 1969: 128-129). Because they had reaped large profits in early years, the public had little sympathy with trolley companies. Public authorities were not inclined to help. Only in the late 1920s were fares allowed to go up to seven cents. In fact,

<table>
<thead>
<tr>
<th>Steamers</th>
<th>1.681</th>
<th>1.568</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline cars</td>
<td>936</td>
<td>18.699</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4.192</strong></td>
<td><strong>21.692</strong></td>
</tr>
</tbody>
</table>

*Table 1: Annual car sales in the United States (Kirsch: 1996: 60-61; Mom, 1997: 223)*
Policy makers saw transit companies as handy villains. They embraced the car and motorbus, and fought with trolley companies. While the trolley was taxed, the private automobile and motorbus were massively subsidized by publicly funded street improvements (Flink, 1990: 363). The motorbus was used as a pawn in a political power struggle (Schrag, 2000). The trolley was ill-prepared for the competition from buses and automobiles which offered more flexible routes, faster service and greater independence of movement (Nye, 1990: 134). User satisfaction with the trolley declined after the mid-1910s. Trams got more crowded, especially during rush hour. Another complaint, especially from women, was sexual harassment. The overcrowding in trams created ample opportunities for ‘accidental’ contact and blatant fondling. The feelings of unsafety were mixed with racism, as more Negro workers used trolleys to get to work (Ling, 1990: 86). Another effect of low investments were more breakdowns and decreasing punctuality of service. Furthermore, the experience of speed changed. Automobiles moved 40-45% faster than the tram (Davis, 1995: 317). Street railways tried to improve their schedule speeds, but increased traffic congestion offset their efforts. In sum, the de-alignment of the trolley regime was the result of a range of political, social, economic and technological causes. The real decline in passengers took place in the 1930s. The decline in trolley track mileage levelled off temporarily during World War II. After the war, tram ridership fell sharply and consistently.

A new sociotechnical regime was created around the car. Market developments occurred in tandem with the creation of infrastructures, traffic rules, new routines and social networks. Between 1914 and 1930 the automobile was sold in ever-larger numbers. One driver were major price reductions, enabled by mass production. Ford experimented and pioneered the assembly line in the 1910s, consisting of conveyor lines, specialised machine-tools, interchangeability of parts. The Model T was offered for increasingly cheaper prices, from $850 in 1908 to $360 in 1916. The decreasing price opened up new market niches. Farmers were a major market niche in the 1910s. Cars provided an answer to some existing rural problems (isolation, declining rural institutions such as school, church and shops). Middle class suburbanites also formed a major market niche in the 1910s using cars for commuting between work and home. The diffusion of cars was accompanied and made possible by wider changes in the sociotechnical regime. Already in the early 20th century there was some institutional embedding of automobiles. This was continued in the 1910s by relaxing speed limits, adopting regulations to ease traffic flow, and undertaking educational efforts to control pedestrian behaviour (Baldwin, 1999: 214). The guiding principle in 19th-century traffic regulations was the safety of street users. But in the early 20th century, rapid and efficient traffic flow became more important than pedestrian safety. As the speed and number of automobiles increased, so did the number accidents. Around 75% of the car’s victims were pedestrians, mostly children playing in the street (McShane, 1994: 176). In response more playgrounds were built to give children alternative spaces. Another response was to learn adults and children new routines. Educational campaigns in the 1910s (e.g. at public schools) taught that pedestrians could cross safely only if they remained alert and followed special procedures (McShane, 1994: 189). Another response was the expansion of driving schools, where drivers learned new routines. The task was not to teach general driving skills, but to discipline drivers not to speed, not to get agitated and respect general traffic rules. Before World War I a ‘morality of good traffic manners’ was articulated (Mom, Werff and Bos, 1997: 174). As a result of these changes, streets were the exclusive property of automobiles by 1920, confining pedestrians to the sidewalks. To facilitate the car, major road improvements were made, e.g. smooth asphalt pavings, widening of existing roads and building of new roads. Road improvements required high investments, paid by public authorities. In 1906, for instance, $300 million was spend on urban roads (McShane, 1994: 189).
218). Rural roads were still in a bad state. In the 1910s several social groups joined the Good Roads movement to lobby for improved rural roads. One group were farmers who saw roads as a way to get around the railroads transport monopoly and high freight fees (Ling, 1990: 16). Another group were motorists themselves, who formed the American Automobiles Association. A third group were road builders and cement manufacturers. Inside policy making bodies highway engineers professionalised themselves by creating specialised highway departments and professional associations. Through these developments an institutional and organizational framework was created, which laid the foundations for the road-building boom of the 1920s and 1930s (Lewis, 1999).

The expanding car use led to problems of congestion and parking in cities. One response was new regulation to increase traffic flow, e.g. banning left-hand turns, and introducing 60 minute parking limit. Another response was to expand road infrastructures. This required a reconstruction of cities, which linked up to the City Beautiful movement and the emerging profession of city engineers and urban planners. These two groups created a new suburban territory around cars, and reshaped downtowns by repaving, street widening and bridge construction (Lewis, 1999: 44). The reforms also resulted in a new kind of road, highways, only to be used by motor vehicles. Highways became more widespread in the 1920s. Policy makers invested massively in roads, but only limitedly in public mass transit (Flink, 1990: 369-370). New uses for cars opened up in the 1920s (urban travel, intercity travel), associated with new customer groups (less mechanically sophisticated, less tolerant of inconvenient operation) (Clark, 1985: 247). Ease of operation, smoothness of ride, comfort and convenience became important performance criteria. Cars became ‘rolling living rooms’.

As the car diffused it had wider impacts on society. It facilitated the emergence of a ‘car culture’, supported by new institutions such as fast food restaurants on highways, shopping malls on the edge of cities, drive-in movies. Touring with automobiles developed into a popular recreation activity. The car developed many forward and backward linkages in the economy of the 1930s. The automobile industry was a huge consumer of sheet steel, glass and paint, components (tyres, lamps, generators, etc.), machine-tools (Landes, 1995: 443). And the use of the car boosted the petroleum industry and construction and public works (roads, bridges, tunnels). In sum, the car became strongly embedded in society. Although not everybody owned a car in the 1930s, the automobile was clearly the way forward.

Although horses were substituted in personal transportation, they held on in freight transport until World War II. In this market niche there was long competition between horse-drawn wagons, electric trucks and gasoline trucks (Mom and Kirsch, 2001). Freight transportation thus provided a niche where horse-drawn transport could persist. This way, related social groups were not immediately threatened with unemployment, reducing social unrest (e.g. smiths, wheelwrights, cart, van and wagon makers, fitters, painters, coachmen, carriers, horse-keepers, stable-keepers).

5. Analysis

Testing the multi-level perspective: Pattern matching

One aim of this paper was to test the usefulness of the multi-level perspective. I will use ‘pattern matching’ to do this (Yin, 1994), and compare the perspective with the alternative explanation of technological substitution. An important claim of the multi-level perspective was that radical innovations emerge in niches. I showed how steam, electric and gasoline automobiles emerged as technical novelties in the 1880s, and became linked to functional niches. Electric vehicles became linked to the semi-public taxi-niche, and the urban luxury niche, for tea parties or promenading in parks. Gasoline cars were used in the racing and
touring niche, where they further articulated a new mobility practice, ‘mobility for fun’, exploring new functionalities of individual and flexible driving. For steam automobile manufacturers it remained unclear which market they targeted.

Another claim was that ongoing processes on regime and landscape level are important to understand the emergence and breakthrough of novelties. Immigration, urbanisation, suburbisation, concern about public health, new popular culture with values such as excitement, speed, entertainment were landscape developments which created pressure on the horse-based transport regime and created opportunities for novelties. Pollution by horse excrement became a more serious problem, because of higher sensitivity about hygiene. Suburbisation led to longer travel patterns and more congestion in narrow streets. Horse-based transportation had difficulties to meet demands for faster transport and longer distance. Box 1 summarises some landscape development to which the automobile linked up, and Box 2 does the same for ongoing regime processes. I conclude that it is crucial for the analysis of transitions to pay attention to ongoing processes at the regime and landscape level.

**Box 1. Landscape developments to which the automobile linked up**

- Because of urbanisation and immigration, American cities grew rapidly, leading to slums, social and health problems. Public health was seen as an important issue. Horses were under pressure because they linked up negatively with this issue. Bicycles and automobiles, on the other hand, were seen as positive ways to experience nature and inhale fresh air.
- As real wages rose, a new middle class emerged with more money and more leisure time. A new popular culture emerged, focused on entertainment, excitement, adventure, and outdoor activities. In this context, car racing and touring in the countryside became popular.
- Public administration was expanded and took on greater responsibility for regulating society. Cities also encouraged the creation of large structures, grand concrete boulevards and connections between parks (City Beautiful movement). These boulevards and parkways functioned as demonstration grounds for early fragile automobiles.
- In the 1890s corruption was increasingly criticised (Good Governance movement). This provided a suitable context for the rise of experts, because they were seen as neutral and rational. City planners and highway engineers acquired powerful positions in public policy making, allowing them to stimulate road building.

**Box 2. Changes in the transportation regime to which the automobile linked up**

- The gasoline automobile linked up with new user preferences, which had been articulated with the bicycle (individual and flexible mobility). The automobile also linked up with the application domains of racing and touring, which happened to be popular because of wider cultural values.
- Sub-urbanization was started by the electric tram. The automobile linked up with this trend and greatly reinforced it. Sub-urbanization came to be seen as the solution for urban problems. Policy makers and urban planners embraced the automobile as a means for this wider goal.
- Because people had become accustomed to vehicles with higher speeds, there was no widespread resistance against automobiles in the early 20th century. Higher speeds were in fact experienced as exhilarating and exciting. In that sense, automobiles linked up with wider cultural ideographs.
- The automobile build upon streets with smoother pavements (e.g. concrete, asphalt). The Good Roads lobby, which was started by bicycle clubs, literally prepared the way for cars.
- The automobile linked up with the trend to segregate public space, and define the function of streets as transport artery.
- The power of public authorities increased by the late 19th century. While local residents traditionally had much control over streets, they increasingly lost this power to public authorities. Public authorities could thus push through road improvements and stimulate the automobile.

*Shortcomings in an alternative explanation*
The alternative explanation, that the transition was a simple substitution process, has several shortcomings. Although the substitution approach suggests immediate competition between horses and automobile, the case-study showed that this was not so. Early automobiles were not used for instrumental transportation purposes, but for pleasure and excitement. While the substitution approach suggests that the number of horses declined because of automobiles, the case-study showed that urban horses were first replaced by the electric tram. In fact, the electric tram is lacking from the aggregate substitution approach, although it was the dominant transportation mode in cities between 1890 and 1930.

Another weakness is that the substitution approach suggests that there is one homogeneous selection environment, in which automobiles diffused and replaced horses. But the case-study showed there were many different market niches, with different selection criteria. The diffusion of automobiles took place gradually as a trajectory of niche-accumulation (see Figure 10).

Figure 10. Trajectory of niche-accumulation for the emergence and diffusion of automobiles
Another weakness of the substitution approach is that it only looks at technologies and markets. It does not pay attention to wider co-evolution processes, e.g. changes in user preferences, policies and regulations, infrastructures, symbolic meanings.

The economic substitution approach also does not show that there were different technical options in the early period of automobiles: electric vehicles, steam automobiles and gasoline cars. There was much uncertainty about the best design. But contrary to common perception, these different options did not immediately compete, because they were used in different niches. Only around 1910 gasoline vehicles invaded the urban electric vehicle niche.

*A transformation route in transitions*

As a refinement to the multi-level perspective I suggest a particular transition route: wide transformation. The case-study showed that the regime was already in flux on multiple dimensions before the breakthrough of automobiles. Instead of a heroic story of how automobiles defeated horse-and-carriage, the horse-based urban transportation regime was heating up in the 1870s and 1880s, because it suffered from several problems. In response, several innovations emerged (e.g. horse-tram, bicycle, electric tram), which, in turn, contributed to further changes in the 1890s. The bicycle, for instance, transformed the transport regime on several aspects (Box 3).

**Box 3: Articulation and learning processes in interaction with the bicycle**

- New technical elements were produced for bicycles, e.g. steel-tube frames, chain drive and differential gearing, ball bearings and air tires. Early automobiles made use of these elements.
- The bicycle industry was important in the articulation of techniques of quantity production utilizing special machine tools, e.g. sheet metal stamping, and electric resistance welding. These new process technologies later became essential elements in the production of automobiles.
- With regard to user preferences the bicycle led to an articulation of new preferences: individual and flexible transport. The bicycle also opened new application domains which later became linked to early automobiles: touring (in the countryside), and racing.
- In social and infrastructural dimensions the bicycle gave rise to the creation of a Good Roads lobby, which made political efforts for streets with smoother surfaces (e.g. asphalt).
- The bicycle gave rise to bicycle clubs and bicycle papers, periodicals etc. The bicycle clubs, in turn, put pressure on public authorities to improve the road infrastructure. More asphalt pavements were created in the 1890s to facilitate cycling and street-sweeping. This literally prepared the way for automobiles.

The electric tram also had transformation effects. It was involved in changes in the perception of the function of streets (from social meeting places to transport arteries). Furthermore, city residents became used to higher speeds of vehicles, through their experience with the trolley.

These transformations on regime-dimensions took place before the emergence of automobiles. With the introduction of these new elements, the transport regime was already changing substantially. Many of these changes prepared the ground for the automobile. The automobile fell in fertile soil, prepared by transformations in the regime. Thus, the transition did not start with automobiles. Instead, automobiles formed the final piece in a much longer process. This means that historical descriptions, which only focus on the emergence and diffusion of automobiles, make a limited cross-section of the transition process.

Another characteristic of the transformation route is that it involved multiple technologies. The opening up of the regime created space for experimentation with multiple innovations. The transition can be characterised by an initial widening of the number of options. Between 1880 and 1910 many options existed next to each other, e.g. horse-tram, electric tram, bicycle, automobiles. The electric tram was dominant in terms of total mobility.
In the 1910s there was a subsequent narrowing down of technical options. It was not until the
1920s that the electric tram regime disintegrated, and the automobile regime became
dominant. The opening up and narrowing down are represented in Figure 11, again showing
that the automobile was the last step in a wider and longer transformation process.

Figure 11: Widening up and narrowing down in the urban transport regime

6. Discussion and conclusions

Which lessons can we draw about system innovations? One finding is that the multi-level
perspective has become more robust. It had a better match with the case-study than the
alternative explanation of technological substitution. The case-study clearly showed that the
transition came about because processes at multiple levels linked up.

Secondly, the case-study pointed to the existence of a particular transition route:
a wider transformation route. One characteristic of this route is that the socio-technical regime
is already in flux before the emergence of a radical innovation. Transformations on
dimensions such as in policy, user preferences and cultural values precede technical
innovations. Another characteristic is that multiple technical innovations are involved. The
‘opening up’ of the regime creates space for multiple options. These technical options may co-
exist for a long time, before a ‘winner emerges’ and the regime narrows down again. This
creates major uncertainties in this transition route. Because this route could be described in
terms of the general conceptual perspective, it seems to have wider relevance. For instance,
dynamics in the current electricity regime may well be described in terms of this
transformation route. Deregulation and liberalisation in the 1990s have opened up the
electricity regime, which was relatively closed for decades. New actors have entered the scene
or positioned themselves for new roles (e.g. energy distribution companies, electricity
auctions). The flexibility of the gas turbine and the location of large natural gas reserves have
led to a dash for gas in many countries, and the emergence of co-generation of heat and power (CHP). Climate change is a landscape development, which is increasingly putting pressure on the regime. In response, a wide range of technical options has emerged, some of which are almost cost-competitive for base-load electricity generation (e.g. wind turbines, biomass). Other technical options (e.g. photovoltaic solar cells, fuel cells) are used in small market niches with particular characteristics. Some of these options may trigger a wider shift to decentral generation. In sum, the transformation route may occur in future transitions.

A third finding is that system innovations are a long-term process (decades). Old technologies may hold on in particular market niches for a long time, even after the new technology has become dominant. Horses were used in freight transport until World War II. Replacement may thus be partial. The persistence of old technologies in particular markets may help to reduce social unrest, because actors associated with the old regime do not immediately lose their jobs. System innovations are also gradual because new technologies only gradually conquer market niches with different selection criteria (niche-accumulation).

A fourth finding is that new technologies may open up new application domains and introduce new functionalities. This may have the beneficial effect that they need not immediately compete with the existing regime. Early automobiles did not compete with horses, but were used in the domain of pleasures and excitement, i.e. racing and touring. Individual and flexible mobility were new functionalities (which had to some extent already been articulated by the bicycle). Only in a later stage were automobiles used for instrumental transportation purposes, and began to replace horses and electric trams.

A fifth finding is that a winning technology may eventually fail. The electric tram was the dominant urban transportation mode between 1890 and 1930, but eventually lost from the automobile. While a technology is dominant for a certain period, it may (in retrospect) form a stepping-stone in a wider transition process.

A sixth finding is that technologies not only compete with each other, but can also have positive interactions, e.g. accumulation effects, building upon each other (e.g. how the bicycle and tram prepared the way for the automobile in many way). Competing technical trajectories may also ‘borrow’ technical elements from each other. The electric vehicle borrowed the mechanical ‘controller’ from the electric tram, a device, which allowed easy gearing. The gasoline car borrowed batteries and high voltage ignition from the electric vehicle. The electric starter made it much easier to start gasoline cars, allowing them to invade the urban, luxury niche in which the electric vehicle had persisted.

A seventh finding is that diffusion is a slow process of niche-accumulation. New technologies do not suddenly enter mainstream markets, but are used in subsequent application domains. This way experience is built up and the technology is improved.

Which lessons can we draw for policy making regarding system innovations? The case-study showed the importance of policy support in the creation and stimulation of niches. Initial protests against automobiles (high speed, dust problem, accidents) were mitigated with public regulations (e.g. car registration, car tags, licensing of drivers). Some of regulations were relatively favourable (e.g. high speed limits). A major stimulus for the diffusion of automobiles in the 1910s and 1920s was public spending on roads and highways. Some of the money actually came from taxes on electric trams. One reason for public support was that progressive politicians and urban reformers came to see automobiles came as a means to solve urban problems through sub-urbanisation. There were also policies, which affected the trolley, mainly in a negative way. Trolley companies were forbidden to raise tariffs to pay for rising costs. And the trolley was heavily taxed. Some of this money was used to help pay for publicly funded street improvements, which stimulated automobiles.
We can also derive policy suggestions from the multi-level perspective. A general strategy to stimulate transitions is to increase pressure on the existing regime on the one hand. This can be done with generic instruments, such as tradable emission rights, carbon tax, emission norms. On the other hand, radical innovations (variety) should be stimulated to emerge and develop in niches. This requires more technology-specific policy, e.g. targeted subsidies for experimentation with new options, network management to enroll the right actors in the niche, and the development of guiding visions and future expectations (e.g. Rotmans et al., 2001; Hoogma et al., 2002).

Transition management should be further operationalized in terms of instruments, timing of intervention, roles for different actors etc. From the literature on path dependence we know that bifurcations occur in trajectories, and that interventions at the right time can have large impacts. Insights in transition mechanisms may help identify the right moments for intervention to facilitate accelerations or changes of direction. Some suggestions are the following:

- Pay attention to trajectories of niche-accumulation. Radical innovations do not break through in one step, but through a sequence of small steps. Stimulation of a niche should be accompanied by a strategic view on steps to other niches.
- Use add-on and hybridizations as stepping stones. A transition may occur easier if one first links up with dynamics in the existing regime. A new technology may first be introduced as an add-on to the existing technology. Gradually it may then develop a trajectory of its own (gasoline engines were first added to existing carriages and then developed their own form).
- Link up with emerging new markets. If radical innovations have to fight their way into existing markets, they have a hard time. If they open up new markets, they diffuse more easily (e.g. gasoline vehicles which linked up with touring in the countryside).
- Try to bring outsiders into the game. Incumbent actors may have too many vested interests to nurture a radical innovation. An outsider may speed up dynamics, and introduce new ways of doing and thinking.

References

Flink, J.J. (1990), *The automobile age*, Cambridge, Massachussets: The MIT Press,
Fogelberg, H. (1997), The electric car controversy: A social-constructivist interpretation of the California zero-emission vehicle mandate, Göteborg: Chalmers University of Technology


Ling, P.J. (1990), America and the Automobile: Technology, Reform and Social Change, 1893-1923, Manchester and New York: Manchester University Press


