

## **A renaissance in understanding technology dynamics? The emerging concept of transition management in transportation**

Harry Geerlings<sup>a\*</sup>, Jasper Lohuis<sup>a</sup>, Bart Wiegmans<sup>b</sup> and  
Arnoud Willemsen<sup>a</sup>

<sup>a</sup>*Department of Public Administration, Erasmus University Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands;* <sup>b</sup>*Department of Transport and Infrastructure, OTB Research Institute for Housing Urban and Mobility Studies, P.O. Box 5030, 2600 GA Delft, The Netherlands*

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For the last five years the technology factor (by which is meant both process and product innovation) has received renewed attention in the transport sector as society is confronted with new challenges. This leads to a call for change and transitions. Technology is considered as a potential answer to new needs and new problems, like the reduction of CO<sub>2</sub> and the supply of alternative energy. It is important that there is a theoretical basis for the way of thinking on innovation and diffusion when it comes to technology dynamics. This paper, based on a literature study, addresses the question to what extent the theory of transition management can be considered as a new application of technology dynamics. The theory of technological innovations in the broad sense is analysed and applied to the transport sector.

**Keywords:** transport; technology dynamics; transition management

### **Introduction**

Traditionally, the process of technology development has been considered as an activity that belongs to the domain of the natural sciences. Nowadays, the process of technological developments is also studied in both the economic sciences (economic modelling, dynamic economic theory, etc.) and in the social sciences (sociology, environmental science, business administration, etc.). We see that the scope has moved from a strong techno-centric perspective towards a (more) process-oriented approach.

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\*Corresponding author. Email: geerlings@fsw.eur.nl

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Section 'The historic background of technology dynamics' sketches the historical context and provides an overview of the various streams of analysis from the (neo)classical approach towards the development of the present innovation theories and concepts. The main subject of the following section is the concept of innovation and diffusion and the evolutionary theory of technology dynamics. In Section 'The relevance of transitions for sustainable transportation', attention is paid to the systems approach and its application to transportation in relation to sustainability. The emerging concept of transition management and its ambition to contribute to a (more) sustainable transport sector is discussed in Section 'The emerging concept of transition management'. And finally, in Section 'Transition management: a good example of "Neue Combinationen"', observations and comments are made on the relevance and usefulness of transition management as a new concept.

## **The historic background of technology dynamics**

### ***The relevance of technology forecasting***

It could be held that history has little to offer when it comes to the predictability of technological developments. Many books and articles have been published which have attempted to predict the future. Some authors, like Jules Verne, frankly acknowledged that they hardly used any serious methods. However, even scientific approaches have sometimes been completely inaccurate.

In 1920, *Scientific American* published an editorial predicting the future, based on the developments of the previous 75 years. Although, in retrospect, that article seems to make strikingly accurate predictions, two omissions can be distinguished; none of the authors foresaw that only a month after publication of the article, radio telegraphy would be invented and neither did they predict that in the same year, sound would be added to films. Both developments were important breakthroughs in those days. As early as 1900, a well-known futurologist like George Sutherland had predicted the rise of telegraphy, the wireless clock and recording apparatus, whereas he shut his eyes to aviation and space travel – that was stuff for dreamers and daredevils. In 1937, the US National Resource Committee published a report entitled *Technological Trends and their Social Implications* (NRC 1937). This report,

which is still worth reading, sketches several technological trends which were predicted to happen in a number of social sectors, including transport.

The description above could easily create the impression that the prediction and directing of technological innovations have no value. This would be the wrong conclusion; some of the predictions were indeed correct, many developments were already foreseen in the past. Nowadays, there is more knowledge and insights into the process of innovation. In current academic work this is the domain of technology dynamics. Technology is presently judged as a crucial factor in the economic performance of firms, nations and even supra-national organisations. Technology has become an essential factor in everyday life.

### ***Technology: a definition***

Before attempting to define technology, it is important to stress that a distinction has to be made between a technique and a technology. A technique is a concrete artefact or handling activity. A machine, an engine based on the principle of combustion, or a catalytic converter, are examples of a technique. The working of a technique is closely related to principles of the natural sciences.

A technology has a much broader meaning. Before defining what is considered as a technology, two characteristics have to be discussed. First, a technology should not be equated with a machine or an artefact, but is rather some form(s) of knowledge. Technology is directed by 'perceptions' and 'beliefs' with the aim of solving a problem. Geerlings *et al.* (1997) mention, in this respect, 'rules for instrumental action'. From this perspective a definition of technology needs to include a cognitive component and a social competence. Second, technology should not be seen as a one-cyclic process with separate rules, but rather as a network of intermeshing rules in an ongoing process. Analysing technology development divorced from the social context from which it originates and in which it finds its application, would suggest that technology originates independently from society and can, therefore, be judged separately from the social context in which it is applied. This is, however, never the case. It is significant to judge technology as something that relates to and interacts with a (social) environment. To arrive at the successful introduction of technological innovations, of overriding importance is finding the right basis for the development and acceptance of a considered technological policy. We consider in this study a technology basically as: 'a set of cognitive and social concepts and techniques employed by a community in its problem solving and consists of a combination of current theories, goals, procedures, handling and using practice' (Geerlings 1999).

Technology has to be introduced to the market and has to be accepted by potential users (adoption). A classical approach to the adoption of technology

is the invention–innovation–diffusion model based on the work of Schumpeter (see also Section ‘From macro-trends to micro-analysis’). This model is based upon a specific interpretation of technology developments, namely the identification of three different stages in technology development: invention, innovation and diffusion. However, this model has been heavily criticised since its publication and many modifications have been made. Nevertheless, it still has an important meaning in clarifying and conceptualising the process of innovation.

### *From macro-trends to micro-analysis*

Technological innovations have been studied for many years. Classical economists, like Smith (1776), Malthus (1798/1858) and Ricardo (1819/1978), had already implicitly linked economic growth to innovation. In the mainstream of classical economics, technology has always been considered as an exogenous factor. Other variables such as population growth, capital formation, diminishing returns in agriculture were regarded as more important. In the last decades of the nineteenth century, attention was focused upon the principles of optimal resource allocation, usually within a static framework from which technological change has been deliberately excluded (Rosenberg 1982).

It was Kondratieff (1926) and, elaborating on Kondratieff’s work, Schumpeter (1935, 1939) who explicitly linked economic development and technological change. Kondratieff focused attention on the interaction between economic and technological development in a long-term perspective. He argued that capitalist economies went from boom to bust in a long cycle or wave of about 55 years. In his view, economic depression stimulates the need for invention which, coupled with investment and a critical situation of declining price levels, leads to an upswing and the commencement of a new wave.

Schumpeter expanded the idea of technological development. He developed the proposition that important innovations occur at the beginning of an economic recovery and maintained that particularly in times of economic crisis firms are willing to take risks and open new channels for trade. Scientific inventions and discoveries are turned into commercial innovations through the initiative of entrepreneurs in a process he called creative destruction. A clustering of innovations and a diffusion of radical technologies causes the long economic cycles. Long waves in economic development determine the evolutionary path of successive replacements of traditional by new forms of development and economic growth, driven by the diffusion of technologies and institutions. Vice versa, a clustering of innovations and diffusion of radical technologies cause the long economic cycles and interlaced economic restructuring and transformations in social relations. In this model, technological development in the decline stage will follow a linear pattern.

The theory of Schumpeter has been a rich source of inspiration for many authors in the area of innovation theory. There is widespread agreement with the Schumpeterian hypothesis that there is a creative interaction between technology development and economic development, which affects the process of innovation and diffusion. Due to this, technology development is almost a synonym for innovation, despite the fact that Schumpeter made a distinction between different forms of innovation. The type of technological innovation, with the character of a technological breakthrough is also called an 'assertive' innovation (AWT 1997), which refers to the fact that the innovation includes a conceptual change in acting by people, including new rules for acting and communication.

In addition to the opinion that technology develops as a process of major technological changes and technological breakthroughs, there are other scientists who state that the process of innovation is a much more discontinuous process of small (incremental) improvements. The development of technologies is in their opinion more a process of 'adoption' and an 'innovation permanence'. Representatives of the view that technological changes are gradual are Usher, Ruttan and especially Rosenberg (1982). These authors criticise the simple linear model which, inspired by Schumpeter, has been widely used by economists and historians. They consider technological innovations as a continuing process of small changes which could accelerate. Usher (1955/1971) points out the amalgam of previous independent changes, which effect an cumulative and synergetic pattern. Ruttan (1959/1971), elaborating on the cumulative theory of Usher, considers this approach as complementary to the Schumpeterian theory. Ruttan states that important strategic inventions are represented by the cumulative synthesis of many individual dealings (Figure 1).

Rosenberg demonstrates that the cumulative result of small technological innovations could be of more significance than the result of a sudden large technological breakthrough. Rosenberg lays great emphasis on the incremental and evolutionary character of technological development.

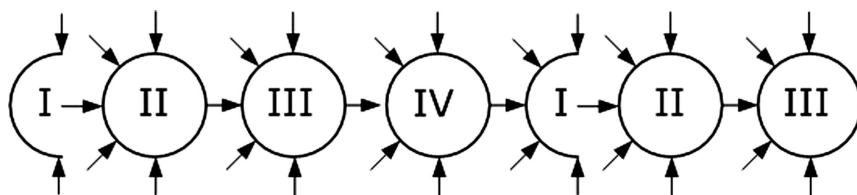


Figure 1. The process of cumulative synthesis.

Source: Ruttan (1959).

Note: This process includes a full cycle of strategic invention and a part of a second cycle. Large circles and semi-circles I–IV represent steps in the development of a strategic invention.

Innovations are, according to Rosenberg, not automatically superior to old technologies. New techniques have to prove they are superior after invention. In a process of learning, further improvements are introduced rendering the new technology suitable for the specific environment in which it must be used. To describe this process, Rosenberg introduces the concepts 'learning by using' and 'learning by doing'. He also stresses the complementarity between innovations. Basic innovations are the central item of expanding concentric circles in which interaction takes place. In each sector (the large circles and the semi-circles I–IV), progress is the necessary condition to ensure progress of the total (complementary of innovations). The combined effect of these small improvements will lead to improved productivity.

Rosenberg observes that technology is not freely transferable from one situation to another, but has to be acquired and appropriated. Technological development is time, sector and location specific. Technology development depends to a large extent on cultural as well as organisational factors. In addition, Rosenberg puts great emphasis on the incremental and evolutionary characteristics of technological development.

### *Evolutionary theory*

In the traditional Schumpeterian model, technological development will follow a linear pattern dependent upon the innovative attitude of the potential adopters. According to Rosenberg's model, there is a place for all kinds of feedback and further developments. We can speak of a process of co-evolution of old and new technologies in which the environment plays an important role.

A major integration, but also scientific breakthrough in the thinking on innovation theory, took place in the work of Nelson and Winter (1977, 1982) and Dosi (1982, 1988). Nelson, Winter, Dosi and many others have, elaborating on the Schumpeterian theory, focused attention on the role that the social-cultural and institutional factors play in processes of innovation and diffusion of technology.

Nelson and Winter (1977) observe that technological change depends on variation and selection processes aimed at solving technologically defined problems. These processes are not a select or random, but clearly structured by formal and informal rules. There is a certain rigidity and inertia in the degree of change in technology, as a result of which the variation is not unrestricted. The presence of rules implies that technological development follows quite specific directions, while other possible directions are ignored. In this sense, technical change can be conceptualised as a constant succession of variation and selection within a certain framework. Nelson and Winter introduce for this phenomena the concept of a technological regime: the 'direction of progress' of technological change. Here, a technological paradigm or regime is interpreted as the dominant cultural matrix of technology-developers and includes a limited number of scientific principles, understanding and

heuristics (search directions) and a limited number of material technologies – what they call a frontier of achievable capabilities.

According to Dosi (1982), a technological trajectory contains the changes in technology which take place in the framework of a technological regime or paradigm. Here the concept of paradigm originates from Kuhn (1962) where he states that, as a consequence of competition between different paradigms, a new paradigm becomes dominant. This crisis, the identification of irregularities, is a necessary condition for a scientific breakthrough. A technological paradigm or regime is defined by Dosi as a model or pattern of solutions of selected technological problems, based on selected principles derived from the natural sciences and on selected material technologies. In this approach there is the growing recognition that history counts. Past technological achievements influence future developments via the specificity of knowledge that they entail, the development of specific infrastructure, the emergence of various kinds of increasing returns, etc. In this context, it can be simply said that a paradigm is a prevailing rationality. The paradigm can be understood as the state of knowledge, skills and technology existing at a particular point in time.

In a way technological developments can be considered as a process of variation and selection. This process is interlocked and has specific feedbacks. This phenomena is called path-dependency or locked-in development. For example, David (1976) has shown that the QWERTY standard for keyboards remained dominant, despite the fact that new (and better) alternatives were designed. One of the reasons for this was the specific skills of typists trained on QWERTY keyboards. Path-dependency (and the irreversibilities of diffusion patterns) also implies a fundamental role for ‘routines’ and ‘trajectories’. Routines differ from trajectories because routines are related to the process of decision making and learning. They are in many cases persistent and hard to change, partly due to the fact that not all relevant variables can be included in the decision-making process. Social systems also consist of routines. Trajectories on the other hand, concern the process of technological development and are very common. A technological trajectory starts with a discovery or an idea. Fundamental research will lead to the discovery being recognised as an invention. Proving the technological feasibility of the technique will lead to the availability of a basic innovation. This basic innovation will be the leading principle for further development along the natural trajectory, and the ongoing process of incremental improvements will result in the implementation of a product.

In summary, technology development may be viewed as the culmination of a number of processes in which technology develops in stages (Table 1).

Within this trajectory, the research is primarily focused on working out the basic innovation, and not the search for new types of innovation. This search process is directed by heuristics. Heuristics are the rules and scope of technological development, and are the most important variable in explaining technological development. We wish to stress the importance of heuristics as a

Table 1. Innovation processes and outcomes.

Process	Outcome
<ul style="list-style-type: none"><li>• Discovery</li><li>• Fundamental research</li><li>• Proving technological feasibility</li><li>• Product research and development</li><li>• Product demonstration</li><li>• Product implementation and diffusion</li></ul>	<ul style="list-style-type: none"><li>• Idea</li><li>• Invention</li><li>• Basic innovation</li><li>• Innovation</li><li>• Prototype</li><li>• Product</li></ul>

Source: Geerlings (1999).

leading principle in technology development. Presently, technological development can be explained ex-post by giving attention only to past heuristics. Identifying heuristics in advance can provide one of the keys to develop a proactive technological innovation policy. In this context, heuristics can contribute to a more environmentally sound technology development in the transportation sector. This creates the opportunity to develop a technology policy ex-ante. Defining a heuristic in environmental terms, and seeking the conditions which are necessary to make it work, is challenging for further technological development.

Dosi (1982) expands the ideas of Nelson and Winter by making use of the concepts of trajectories and paradigm shift in explaining the relationship between technological innovation and industrial change and, analogous to the approach of Nelson and Winter, opposing the neo-classical theory of technological change. But one of the differences is that Dosi distinguishes a difference between firms. Previously Nelson and Winter had considered every firm as equal. This asymmetry is in an evolutionary process steered by innovations and imitations embedded in an environment of competition.

In his later work, Dosi (1982) introduces the concept of stylised facts as a leading principle of diffusion. ‘Stylised facts’ are described as general characteristics of a technological trajectory. In a wide sense, the term technological style (or form) corresponds to the concept of a technological paradigm. The technological forms or paradigms are evolving along trajectories which describe the technology–economy duality as a dynamic system. In his opinion this notion underlines the fact that the process of diffusion is never instantaneous. Diffusion of innovations takes time and occurs at different rates that naturally depend on the features of those technologies which are to be adopted. These features might be the availability of information, the technological competence, the competence of the existing technologies which will be substituted, incentives from the economic, cultural, organisational and political environment for adoption, etc.

However, it has to be recognised that variation and selection, precisely because of competition and accumulating knowledge, is a dynamic concept.



First, the rationality is continuously changing through new knowledge and opportunities. Second, there always exists a dominant paradigm, sub-paradigms and even anti-paradigms, which are competing with the dominant one. Therefore, variation and selection are highly interactive. Consequently, variation and selection also include a hierarchical aspect, which creates variations of a higher and lower order. The hierarchical structure of technical developments means that there are many types of change possible, which cause more or less discontinuity:

- (1) Incremental innovations: an ongoing process to improve existing products and processes. The combined effect has far-reaching consequences for the productivity. The effect of isolated incremental improvements is negligible.
- (2) Radical or basic innovations: these are discontinuous innovations in time and they have cyclic characteristics.
- (3) Technological revolutions: comparable with Schumpeter's concept. These changes have the potential to influence the cyclic effects in economic development and cause a paradigm shift, a change in the technological regime, and influence other sectors in the economy.

In practice, it is difficult to identify the difference between categories b and c. Only in a limited number of cases do these innovations influence the cyclic effect of economic development and include a paradigm shift. In most of the other cases, the impact is not so significant. Therefore, it is preferable to make a distinction between incremental innovations (category a) and mega-technological innovations (categories b and c – cf. Geerlings 1999). Mega-technological innovations can be defined as technologies which includes a long-term R&D trajectory. There are substantial risks and uncertainties involved and the level of implementation is global.

Some of the technological developments, including those which aim to reduce the environmental impact of transportation, are not transportation specific. These are called enabling technologies. Other technologies are sector specific. For instance, transport technologies are in most cases developed in line with the dominant trend within the transport sector.

Overall, it can be stated that the borders of the evolutionary process are dependent on the trajectories and paradigms. The trajectory is a cumulation of increasing knowledge, learning, experiences and a limited number of technological alternatives. When a selection of the alternative has taken place, other alternatives hardly have any opportunity to be developed (path-dependency). Consequently, the selection of the trajectory determines the success of the innovation. In Dosi's view, trajectories are narrow and the succession of technological changes determines an irreversible process. This process is in line with technological development as described by Kuhn, with the addition that the new paradigms are determined by social and institutional factors. In Dosi's view, the creation of economic value is relatively

unimportant in the determination of technological developments and radical discontinuities (paradigm shifts). From this perspective, the theory of Dosi is in contrast to the theory of Schumpeter who explains radical innovations by the fact that economic rationality changes the production function.

The distinction between 'ordinary progress' and the 'paradigm shift' as defined by Kuhn is to a large extent similar to the difference between continuity and discontinuity in the assumed development of technology. The probable interdependence between trajectories and timing of new paradigms support the hypothesis of discontinuity and clustering. An interesting recent development is the co-operation between economists and Darwinian biologists in the explanation of these processes. The common ground between economics and evolution, concentrating on technology dynamics, is also called the evolutionary theory of technology. One step further is the social construction of technology approach (CTA) elaborated by Latour (1987) and Callon (1995). Their concept of a technology frame shows a strong relationship with the neo-Schumpeterian paradigm concept. For this reason technology is defined by Bijker *et al.* (1987) as 'the concepts and techniques employed by a community in its problem-solving [ . . . ] (it is) a combination of current theories, tacit knowledge, engineering practice, specialised testing procedures, goals, and handling and using practice'. The important difference with the paradigm concept is that technology development is not limited solely to technicians and engineers, but also involves other groups like management, consumers and governments. These other groups have to share the technology frame and use it when pursuing their policy goals. On the basis of this premise, CTA can be defined as aiming at broadening the design and implementation of technologies in order to stimulate the integration of social criteria into the actual technical development (Schot 1991). Both authors stress that the contextual approach of technological changes is crucial. An important notion in the actor approach has to be stressed, which is the phenomenon of niche management (Van den Belt and Rip 1989). The authors observe that actors try to create a space (or niche) to protect variations (and the expectations of them) from too rapid and rigid selection. Schot (1991) describes this phenomenon as strategic niche management. According to Schot, this space can be diminished in stages. On the firm level this is done by a phased development of research via testing, scaling-up testing, trial production and production. Likewise, on the governmental level similar stages can be distinguished in the ongoing process of fundamental research, proving technological feasibility, production development and demonstration and technology diffusion (see also Table 1).

Molenaar (1993) stresses in this context the importance of the relationship between innovations (cognitive structure) and the social configurations (i.e. the social setting in which technology develops). In their opinion it is not the actor-approach which is dominant for technological development but the social configurations. These configurations are structured by two counter-vailing forces, on the one hand, individual preferences, cultural aspect and

values, and on the other hand, market principles, price setting, etc. Within this process, technology develops in a specific direction, depending on the balance between the different influences. This process has also been identified by Geerlings (1999). In his work on paradigm shifts, he suggests that there must be a set of rules or heuristics that indicate what the relevant problems are and in which direction the solution should be sought.

## **The relevance of transitions for sustainable transportation**

### ***Technological innovations and sustainable development***

The thinking about sustainable development in relation to technological development is currently receiving a lot of attention. On the international level, the discussion has received a new impetus owing to the Rio de Janeiro Summit organised by the UN Commission on Environment and Development in 1992, where the action plan Agenda 21 was adopted (UNCED 1992). In this programme it was stated that it is especially imperative to develop local initiatives in order to achieve sustainability. At the same time we observe that from this time on, the concept of sustainability became a leading principle in many policy domains, varying from transport to industry and agriculture.

A first initiative which demonstrates in a more structured way how technology can contribute to sustainable development is presented by Weterings and Opschoor (1992). In this study, sustainability is made operational by way of a number of criteria crucial for recording the use of the 'environmental space' available – where 'environmental space' can be defined as the room for all feasible combinations of activities to manoeuvre in the natural environment with reference to statutory standards for environmental quality (e.g. emission standards) and stocks of renewable resources.

General criteria are formulated for three different dimensions which are important for ecological sustainability, namely pollution, exhaustion and environmental degradation. These criteria are then detailed in a number of quantitative criteria and, in terms of technology dynamics, they can be easily transferred into heuristics. Weterings and Opschoor (1992) examine the role technology can play as a direction for solution via the satisfying of quantitative criteria. They distinguish three strategies for satisfying the (quantitative) requirements, namely influencing strategies, expansion strategies and environment-efficiency strategies.

Following this programming study of Weterings and Opschoor, the Dutch Ministry of Environment and Spatial Planning (VROM) initiated the research programme Sustainable Technological Development (DTO 1992). This programme aims at determining the characteristics of technological developments that have to exist in order to contribute to sustainable development. In the DTO study it is assumed that technology provides social functions (such as transportation), but technology itself develops in close correlation with

cultural and structural factors. Against this background it is argued that the analysis of sustainability-oriented technologies must include:

- (1) An analysis of the cultural and structural pre-conditions within which the technology concerned must function.
- (2) An analysis of the cultural and structural ex-ante conditions that have to be fulfilled so that specific techniques or systems can function.

Subsequently, the programme is marked by a unique approach. It is established that a great deal can be achieved by the implementation of (improved) 'end-of-pipe technologies' and process-integrated technologies. But the real challenge for sustainable development is to be found in fundamental change. However, it will take many decades for the development of these technologies. This time-perspective demands a phased approach. This is no longer concerned with improving the existing technology, but tackles the challenge of finding new technological combinations and concepts by which the proposed improvement of the environmental efficiency can be realised. One can think of an improvement of efficiency by a factor 4 to 100. Realisation of this aim demands a quantum leap as well as a new approach to assess the technological potentials. This new approach, in which technical, scientific, communicative and innovative factors are integrated, is indicated by the term 'back-casting'.

Within the framework of technology development, 'forecasting' aims to extrapolate developments towards the future as well as to explore the achievements that can be realised with technology. Back-casting, on the contrary, sees a reverse reasoning: (1) the direction the process must take is determined, starting from a coherent image of the requirements that the specific technology has to meet in the future and (2) the needs of society translated into 'criteria for sustainability' for the year 2040. In order to explore a direction within this searching process, a number of processes, which are likely to be successful from a techno-economic point of view are subsequently developed.

Nevertheless, despite the above points of criticism, the programme should be positively evaluated because it recognises that only by means of fundamental innovations, some of which are mega-technological innovations, can a sustainable development be achieved. Moreover, the project shows that heuristics can be deployed pro-actively in technology policy, which contributes to steering technological innovations in the desired direction. Later in this study, it will be shown that the various levels of government already utilise these insights.

### ***Technological development in the transport sector***

Since the early 1990s, we observe an increasing interest in technology development in transportation. Technological development in the transport

sector can be explained as a process of small incremental changes. According to Montroll (1978), evolution is the result of a sequence of replacements. Often, new technologies create new 'niches' that lead to products and services hitherto unavailable. More frequently, successful innovations can pre-empt an established niche by providing improved technical and economic performance or by promoting the social acceptability of existing services through new ways of fulfilling them. Circumstantial evidence shows that many pervasive systems have evolved through both of these evolutionary paths. They replaced older technologies, and then created new and additional market segments that did not exist before. This process is illustrated by Seiffert and Walzer (1989) who show that the technological development of a basic innovation changes over time due to the dominant heuristic (Figure 2).

A more detailed analysis of the factors that explain technological developments in the transport sector, based on the concepts of the evolutionary theory of technology dynamics, is made by Bilderbeek *et al.* (1993), Korver and van Riet (1994) and Jansen (1995). In these studies, five characteristics of technology development are identified which explain technological development in the transport sector.

R&D in transportation is a highly complex process because: (1) there are also many actors involved; (2) the R&D and implementation process is not considered as a linear process chronologically following the stages of inventions, innovation and diffusion; (3) it has the strong inter-relationship

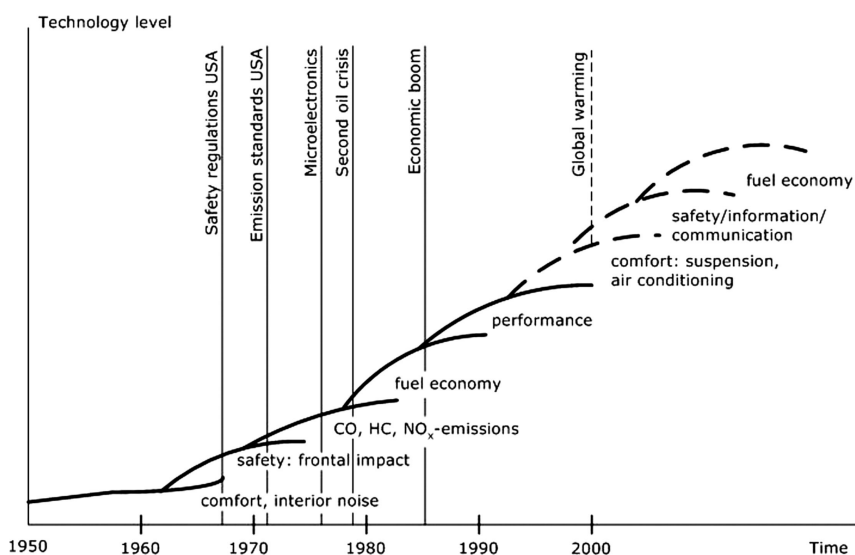


Figure 2. Dominant heuristics in technological development of the car 1950–2010. Source: Seiffert and Walzer (1989).

with other technological sectors (like the chemical industry, energy production sector, etc.); (4) the process is very dynamic, especially due to market forces, which are considered as a crucial factors for variation and section processes; and finally, (5) specific barriers are identified for the transport sector, which makes the forecasting of innovations very uncertain:

- (1) There are conflicting interests in passenger transport with respect to perceived individual freedom, environmental interests, regulation, etc. This makes the outcome of the decision-making process very uncertain.
- (2) Traffic demand is the derived result of social and cultural changes in society. Consequently, technology is not the only factor in decision making; in some cases technology potential is not the decisive factor.
- (3) The role of the government in transport (and related technology) policy cannot be overestimated. At present governments already play a significant role in the economic area (energy prices), environmental policies (emission standards), spatial organisation and (de)regulation of the transport market.

The dominance of basic innovations in the transport sector is also considered very important. Technology development is the result of selection and variation processes of a basic technology (road, rail, etc.) that usually exist for 50 years or more. For the last 50 years, there has been no scientific breakthrough in transport technology. This underlines the analysis of Schumpeter and Kondratieff.

The authors underline the role of heuristics in technology development. Heuristics direct technological innovations in a specific direction. Important heuristics in transportation systems are, respectively, safety, performance, price, comfort, energy reduction, noise, capacity and suitability. Note that heuristics are unambiguous and self-ordering, but technological development can be directed by means of a match of more than one heuristic at the same time. The authors observe that basic innovations cluster in time and space. For instance, in all transportation sectors (road, rail, air and waterways) there is a strong interdependency between the development of new types of engines, the energy production sector and the distribution sector. Innovations are not 'stand alone' developments but they have to be integrated in a complete set of modifications in time and space. This creates a kind of natural resistance in the innovation process for the transport sector. Nijkamp *et al.* (1990) show that a complicating factor in these processes is the lifetime of the different technological cycles. In the energy production sector a life cycle is about 40 years, related to the life cycle of the refinery; in the car manufacturing industry the life cycle of a car model differs between three years (Japanese cars for the home market) and eight years (European cars). The clustering is also stimulated by the industrial trend towards the concept of 'main supplier'. This concept includes the assumption that sub-suppliers of components and

materials fulfill the needs of the car industry, on the basis of exclusive contracts. On the one hand, this creates a reduction in costs, flexibility and agreement on the quality standards but, on the other hand, there is no incentive and space left for the suppliers to create new basic or revolutionary innovations.

There is a protection of market niches. However, many technological developments might be dependent on the dominant basic innovation and heuristics, and as such are to a large extent predictable, even so unexpected radical technological innovations may be introduced. This type of innovations only have the chance to be introduced when market niches are protected. Also in this context, an active role of the government could become crucial for development (Bilderbeek *et al.* 1993).

Elzen *et al.* (1996) propose governments make use of three different types of strategies, namely: (1) technology forcing, which is a strategy directed to force (or stimulate) the development and implementation of new technologies-this strategy is judged to be successful for system optimisation; (2) strategic niche management – this strategy is based on experiments with new technologies. The aim is to find a correct balance between the technology, the infrastructural requirements and the practical use on a small scale. Niche management is especially appropriate for developing new transport systems; and finally, (3) network management as a third strategy. This strategy is mainly proposed to scale-up the experiments of the niche strategy. The government is assigned an important role in this strategy. Still the authors are rather vague concerning the operationalisation and it has not been worked out satisfactorily. In their own ranking, the authors judge strategy as some sort of a ‘second-best option’. A more detailed analysis of the role of government in technology policy is made by Gwilliam and Geerlings (1994). In a detailed assessment of technology options the authors underline the need to assess technologies against the institutional background as well as in terms of their technological characteristics. Economic aspects and institutional barriers are explicitly linked with political feasibility.

## **The emerging concept of transition management**

### ***The new approach of transition management***

The previous paragraph about technology development in transportation clearly illustrates the shift from a strong techno-centric perspective towards a (more) process-oriented approach to technology dynamics. As mentioned before, Korver and van Riet (1994) state that there are several factors involved in developing technological innovations in transport. From this perspective, technology dynamics can best be described as a highly complex and dynamic process characterised by a multi-actor setting, strong interrelationships with other technological domains and non-linearity. Furthermore, several authors

referred to the role that government could play in the development of technological innovations (in relationship to sustainability).

The new approach of *transition management* seems to evolve in a logical way from the existing process-oriented perspectives on technology dynamics and system innovation. Transition management is a management strategy for public decision makers and private actors and deals with the question how and to what extent complex societal transformation processes can be directed in a certain desirable direction (Rotmans *et al.* 2001).

The theoretical concept of transitions – which has its roots in population dynamics and been applied subsequently in economics – refers to a transformation process in which society changes in a fundamental way over a generation or more. Transitions can best be understood as gradual transformation processes as a result of simultaneous developments in different societal domains and the combined action of macro, meso and micro-level developments (Rotmans 2003). An important hypothesis in transition theory is that fundamental change only breaks through if developments at the macro, meso and micro-levels reinforce each other and if developments within different domains come together at a particular scale level. A transition then is the result of a mixture of long-term, slow developments and short-term, fast developments (Martens and Rotmans (2002). This is illustrated in Figure 3, where the classical linear approach and the evolutionary way of thinking are combined and integrated in the concept of transition management.

It is generally accepted that physical infrastructure is considered as a relative stable environment where change is difficult to realise (cities, road infrastructures, etc.). Transition management considers the institutional

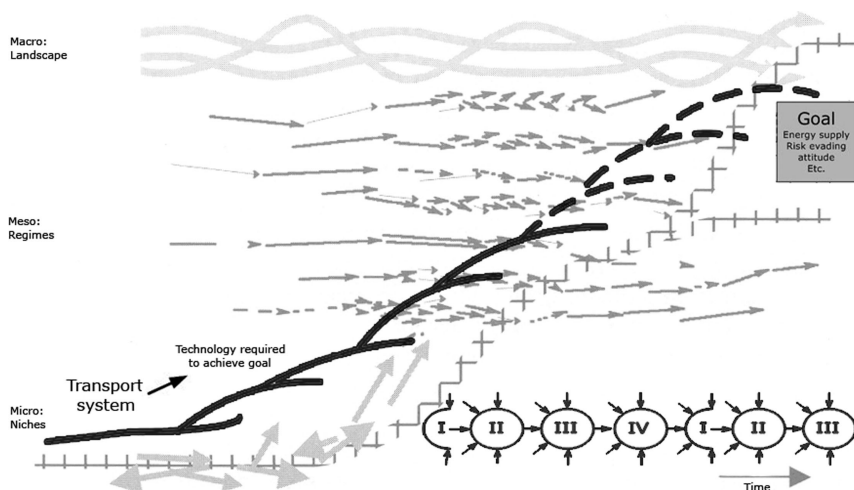


Figure 3. The process of transition management in the transport sector. Based on Geels (2004).



environment also as an inert system, whereas the socio-technical landscape has to deal with often slow changing factors like cultural values, political coalitions and long-term economic developments inducing incremental innovation. As such, transition management is an evolutionary steering tool based on mutual learning and adaptation (Rotmans 2003).

In so-called transition arenas, heterogeneous multi-actor, multi-level and multi-domain groups of individuals are challenged to form shared long-term visions with respect to the desirable transition. This latter example illustrates that transition management focuses strongly on micro-level interactions inducing fundamental societal change and the process oriented approach to technology dynamics.

### ***The meaning of transition management for sustainable transportation***

The concept of transition management is applied in various sectors, such as the energy sector, agriculture and water management. The transportation sector is considered as another suitable sector in this regard (cf. Kemp and Rotmans 2004, Avelino 2005, Consortium Transumo-A15 2007). The situation relating to transport is becoming more and more challenging. The continuous growth of transport in all parts of the world creates problems as emission of CO<sub>2</sub>, noise, congestion and a strong dependency on energy supply. However, it seems to be clear that sustainable solutions need to be found for the transportation problems and that technology in relation to transition management might be a promising approach: a significant environmental amelioration can be gained from the implementation of new technologies. These prospects are in line with the revaluation of the role of technology in society that is taking place presently. We observe a certain fascination with technology, which is seen as the key to a number of different problems (by introducing filters, alternative fuels, etc.) From this perspective, technological innovations are considered the motor for economic welfare. This opinion is expressed particularly in the transport sector (EU 2006). Indeed it is indisputable that technological development has made possible the more efficient use of energy, materials and capital that, in turn, has led to higher productivity and, as a direct effect, more transportation in the world (Geerlings *et al.* 2002).

Rotmans (2003) states that a significant improvement of the transport problem is simply not attainable with present technological insights and policy structures. Measures to these problems often lack widespread support or fail to bring true solutions. In his opinion the transport system seems to be locked-in and is not developing in a sustainable direction. He thinks that this is caused by lack of sustainability objectives and innovation at the system level. Rotmans pleads in this context for a change in thinking, leading to new perspectives, with far-reaching measures and integrated solutions based on the new theory of transition management.

Some authors present the concept of transition management as an innovative approach to overcome barriers from the past (cf. Rotmans *et al.* 2001, Martens and Rotmans 2002, Rotmans 2003, Kemp and Rotmans 2004, Avelino 2005). They advocate solutions for the system as a whole instead of parts of the system (see Figure 3). Therefore, top-down governance needs to be (partly) abandoned in favour of user demands and market developments (Rotmans 2003). In this way a transition path is not chosen, but created in the attempt to traverse (Kemp and Rotmans 2004). In this way possible breakthrough solutions have to be generated instead of designed and technology might play a role.

The above-mentioned approach of transition management sounds ambitious, but the practical implications still remain rather unspecific. Past transport policies are described as ineffective, a thorough analysis has not been made and appealing alternatives are lacking. In this context it is interesting to note that Rotmans (2003) has stated that road pricing does not offer any solution for the transportation sector in the long run, whereas in another contribution about transition management (Kemp and Rotmans 2004) road pricing is advocated as an instrument that has led to benefits in several countries and should have been applied earlier in the Netherlands.

Specific expertise on technological aspects for the transport sector is needed to understand the underlying processes and mechanisms. Now the impression is created that transition management is a methodology that consists of a toolbox applicable to every sector, in every situation and at any moment. In its case studies the approach is rather descriptive, not analytical and hardly ex-ante oriented (applicable). In advocating a 'radical' approach and ideas, the different scholars do not acknowledge the achievements realised in the past.

As transition management is still in its initial phase and has yet to generate sound concepts, it is time for future contributors to be more specific about their approach. Until that time the practical merits of transition management for a change towards a (more) sustainable transport sector remains an open question.

### **Transition management: a good example of 'Neue Combinationen'**

From a long-term perspective it appears that the Kondratieff cycle, as a model of the discontinuous nature of economic development, couples the dynamics of both the discontinuous introduction and diffusion rates of innovations with strong discontinuities in long-term economic development. From this point of view, the evolution of technology dynamics reveals a process of gradual replacement of old systems by new ones along structured development trajectories that can be formalised mathematically by simple, biological growth and interspecies interaction models corresponding to Schumpeter's 'neue Combinationen' (literally 'new combinations') (Schumpeter 1934).

Older systems are made obsolete through technological advance and economic development, and new ones are introduced that are better adapted to continuously changing social, economic and environmental boundary conditions. An important impetus to the thinking of technical change as a sequence of variation and selection is conceptualised by the evolutionary theory of technology dynamics. The presence of games and rules implies that technological development follows quite specific directions, while other possible directions are ignored. Variations and selection processes are interdependent, heterogeneous and include a complex range of technical, economic, social, cultural and other aspects of technical change.

Since the early 1980s, there has not only been an increased attention on the impact of technological innovation in society, but there is also increasing concern for the environment. However, these two developments took place quite independently of each other. This was partly due to the fact that technology dynamics was focusing on specific techniques (for instance the development of the VCR video recorder) or 'privileged' economic sectors (the aircraft industry and semi-conductors) as the object of study and within the environmental sciences an ambiguous attitude concerning the role of technology. On the one hand, technology was welcomed as part of the solution but, on the other hand, technology itself was considered as the origin of the problem. But since the theory on technology dynamics was not able to transform for a well-respected ex-post approach to a methodology that could be used for ex-ante evaluations, the attention under academics and policy makers reduced significantly in the late 1990s.

This is why another approach is needed, which combines the specific concepts of paradigm shift and path-dependency as helpful tools to reach a more sustainability-oriented technology development within the transport sector. The challenge is to develop a pro-active and ex-ante methodology, which addresses the ecological, economic and social objectives in a coherent strategy. At the same time there has to be recognition of the need for cooperation and interaction between government and private firms to fulfill the changing societal needs. The methodology to develop a sustainably sound technology policy should be based on operationalising heuristics in a pro-active way, by translating environmental, economic and societal targets for the longer term.

The ambition above is combined in the new approach named transition management. From a theoretical perspective this approach is challenging as it attempts to combine different notions: the macro and the micro-level, the systems approach and phenomenological studies, the techno-centric perspective and the process orientation, the interest of producers as well as governments and consumers. To what extent the theory on transition management can contribute to the operationalisation of the concept of sustainable development, and especially the main priority of a sustainability-oriented technology policy in transportation, is not yet clear. In this context,

the challenge is to address accessibility and sustainability needs. So far, the concept of transition management creates a common basis for understanding the complexities related to this challenge. But from a methodological perspective it is far too early to speak of a renaissance in the thinking on technology dynamics in the field of transport.

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