An Assessment Method for System Innovation and Transition (AMSIT)[1]

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ABSTRACT

In order to address comprehensive system innovations that may occur in a future transition, a suitable ex ante assessment method is required. The Technological Innovation System approach (Hekkert, Suurs, Negro, Kuhlmann & Smits, 2007) is useful for the retrospective study of the conditions for success or failure of innovation trajectories, and the Multi-Level Framework (Geels, 2002; Afuah and Bahram, 1995) helps to understand transition dynamics. Drawing on these concepts and on the Hypercube of Innovation (Afuah and Bahram, 1995; Markard and Truffer, 2006), we suggest as an ex ante approach the Assessment Method for System Innovation and Transition (AMSIT). This method not only helps to anticipate the requirements for a system innovation and transition, it also provides an indication if these requirements are being met. The method helps to assess innovation system initiatives that not only faces technological challenges in the niche in which it operates, but also challenging factors related to the socio-technical regime and the political and societal landscape in which the niche is located. This paper describes the construction of the anticipatory Assessment Method for System Innovation and Transition and illustrates its application in a case linked to the Dutch railway network involving a transition to a system operating at an increased voltage.

Keywords:
System innovation, transition, TIS, MLF, AMSIT

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1. Introduction

Various environmental forces related to finite oil reserves, water scarcity, traffic congestion, and a desire to reduce carbon emissions have increased the need for sustainability in important sociotechnical systems such as transportation, construction, and energy and food production. The success of related sustainable transitions depends upon large-scale aligned changes in both technologies and societal/cultural dimensions (Neuman et al., 2002). Given these complexities, innovation systems struggle with transitions from one technological regime to the next, and often undergo incremental, rather than the required radical, systemic changes (Markard and Truffer, 2006; Hekkert et al., 2007). Despite the importance, there is a lack of strategic system-oriented innovation instruments that can help policymakers with assessing possible systemic innovations. In responding to this need, the goal of this study has been to design and test an ex ante assessment method for system innovation and transition (AMSIT). This assessment method provides organizations with the opportunity to map key factors that influence systemic innovations and facilitates in discovering opportunities to improve the process concerned with technological transitions. With AMSIT, organizations are better able to identify the complexities and opportunities in a technological transition. To achieve this study's purpose, we draw on three complementary frameworks from transition studies (Markard et al., 2012): the Multi-Level Framework (MLF), the Technological Innovation System (TIS), and the Hypercube of Innovation (Afuah and Bahram, 1995).

In the transition literature, it is argued that the Multi-Level Framework and Technological Innovation Systems could each address the other's shortcomings e.g. (Hekkert et al., 2007; Markard and Truffer, 2008b). The MLF includes three levels on which technology transitions can be described as these have occurred: the niche in which an innovation is generated, the involved regime where the innovation is supposed to break-though, and the landscape that restricts or supports the regime or demands a regime-shift (Geels, 2002). Research using the TIS explains how networks of firms and institutions interact in a specific technological field (Hekkert et al., 2007) and how this contributes to the generation, diffusion, and utilization of innovations e.g. (Markard and Truffer, 2006; Markard and Truffer, 2008b; Geels and Schot, 2007; Bergek et al., 2008; Rogers, 2010). Specific attention has been paid to the functions, or key interaction processes, that need to be present and to run smoothly in the system in order to coordinate the interdependencies between the relevant actors in the system. Sociotechnical transitions differ from technological transitions in that they not only include technological changes but also changes in user practices and institutional structures. Therefore, in our Assessment Method for System Innovation and Transition (AMSIT), we also take into account how the various actors involved in, or influenced by, an innovation can experience it in very different ways. The Hypercube of Innovation explains the various faces that innovations can show to different actors in the innovation value-adding chain (Afuah and Bahram, 1995). For example, an innovation could be incremental for the innovating entity, architectural or modular to suppliers of complementary innovations, and radical in the perceptions of customers. Successful technological transition strategies need to take these differences into account as they often imply divergent behaviors on the part of the actors involved in the innovation (Afuah and Bahram, 1995; Henderson and Clark, 1990). We have combined these frameworks in a method that can be used to assess system innovations in advance or at an early stage. Using this method provides an opportunity to depict a qualitative development of innovation system initiatives and define plausible transition paths for system innovations. In order to explore the feasibility of the proposed AMSIT method we applied it to a potential system innovation involving the Dutch railways. This application illustrates how the method could be used in the early assessment of system innovations as part of regime transitions. This illustrative case study is based on document analyses and interviews.

2. AMSIT Components

To develop our assessment method for system innovation and transition, we draw on three complementary perspectives on technological transitions. We use the *Multi-Level Framework* to describe the levels that interact during technological transitions. The *Technological Innovation System* is used to describe the dimensions and functions that contribute to the generation, diffusion, and utilization of new technologies. Finally, the *Hypercube of Innovation* is used as this helps innovation managers think in terms of what the impact of the innovation will be on various actors including customers and the suppliers of critical components, equipment, and complementary innovations. Together, these theoretical frameworks provide the building blocks for our method for an early assessment of transitions. In this section we explain these frameworks and combine them to develop the AMSIT.

2.1 The Multi-Level Framework

The Multi-Level Framework addresses transitions with a technological nature as interactive processes of change. These processes are conceived as existing on three levels of analysis: the micro-level with niches, the meso-level representing the sociotechnical regime, and the macro-level with elements of the exogenous environment e.g. (Hekkert et al., 2007; Geels, 2005; Verbong and Geels, 2007). Thereby the Multi-Level Framework can be used in retrospect to describe transitions as these have occurred.

The micro-level is defined by the niches that act as 'incubation rooms' or 'protected space' for systemic radical innovations (Kemp et al., 1998). Such incubation rooms include specific markets or application domains that shield innovations from the selection pressures of the prevailing regime (Markard et al., 2012; Kemp et al., 1998). It can be especially hard for radical innovations that depart from established practices and knowledge to survive in an environment that strongly supports these established practices and knowledge. However, if radical innovations address weaknesses in the established sociotechnical regime, they have the possibility of breaking through.

The meso-level defines the sociotechnical regime in the Multi-Level Framework (Geels, 2002), and is based on the concept of 'technological regimes' (Nelson and Winter, 1982). The sociotechnical regime is characterized by several dimensions such as user practices, techno-scientific stocks of knowledge, and established norms and regulations. Geels (2002) listed the following dimensions of the sociotechnical regime as being affected in the event of a technological transition:

1. Technology
2. User practices and application domains (markets)
3. Symbolic meaning of technology
4. Infrastructure (e.g. physical, knowledge)
5. Industry structure
6. Policy
7. Techno-scientific knowledge

A strong sociotechnical regime whose dimensions are misaligned with the new technology will complicate the diffusion of a radical innovation from the niche-level to the meso-level of the sociotechnical regime since this requires a radical change in the dimensions that characterize the established regime. In contrast, in a weak regime, a radical innovation can more easily breakthrough and lead to a regime shift. The strength of the seven dimensions identified by Geels will depend on the regime (Hekkert et al., 2007; Markard and Truffer, 2008b; Schot and Geels, 2007). This means that not every dimension has a similar influence in every regime. A regime contains a multi-actor network whose actors behave and act in a certain predefined way that is established in the regime. These behaviors and activities are reproduced within social groups and maintain the characteristics of the regime. The social groups are interdependent and interacting, leading to alignment and coordination between and within the social groups. Through this, sociotechnical regimes create a dynamic stability in the sociotechnical systems (Markard and Truffer, 2008b). As a consequence, the regime represents a selection environment for technological developments (Markard and Truffer, 2008b). Markard and Truffer (2008b) p.603 explain this as follows: *"The macro-level, the so-called landscape, includes a set of factors that influence innovation or transition processes but are hardly (or only in the long run) affected by themselves. Coherence of the regime is supported by its fit to the exigencies posed by external factors over the course of a specific historical time span."*

The landscape factors tend to support the established regime and therefore impede regime shifts as they are difficult to change by the actors in the sociotechnical regime (Hekkert et al., 2007; Markard and Truffer, 2008b; Geels, 2002; Rayner and Malone, 1998). While such factors are likely to resist a regime shift, other changing landscape factors may act as driving forces toward a regime change. For example, the need to reduce carbon emissions in inner cities is a strong positive force for change. Over time, changes in the sociotechnical regime can act upon the landscape factors that in turn act upon movements in the sociotechnical regime (Hekkert et al., 2007; Markard and Truffer, 2008b; Schot and Geels, 2007; Verbong and Geels, 2007).

2.2 Technological Innovation Systems

According to a widely accepted understanding, an innovation system encompasses *"the 'biotope' of all those institutions which are engaged in scientific research, the accumulation and diffusion of knowledge, which educate and train the working population, develop technology, produce innovative products and processes, and distribute them; to this belong the relevant regulative bodies (standards, norms, laws), as well as the state investments in appropriate infrastructures. The innovation system extends over schools, universities, research institutions (education and science), industrial enterprises (economic system), the politico-administrative and intermediary authorities (political system) as well as the formal and informal networks of the actors of these institutions"* [Kuhlmann (2001), p.958]. In developing AMSIT, we draw on the Technological Innovation System (see Figure 1) since this provides an insight in which function should be or are fulfilled in order to innovate the system. This system can be defined as a network of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion, and utilization of a new technology (Carlsson and Stankiewicz, 1991; Kemp et al., 1998; Nelson and Winter, 1982). Hekkert et al. (2007) propose a set of functions that describe the key activities of a Technological Innovation System:

1. Entrepreneurial activities: entrepreneurs realize the potential of new knowledge networks and markets.
2. Knowledge development: knowledge is developed by learning and R&D.
3. Knowledge diffusion through networks: it is essential to exchange information in networks. Not only within the R&D setting, but also between R&D, government, competitors, and the market. Policies can be adjusted to the latest technology and R&D agendas can be modified.
4. Guidance of the search: guidance is needed because the resources are almost always limited. Guidance is also needed from a social perspective. The society has to adjust itself, or needs to be adjusted, to the new technology/innovation.
5. Market formation: a new technology often has difficulties in competing with established technologies. This issue can be addressed by the formation of temporary niches.

6. Resources mobilization: both financial and human capital are needed as inputs to activities within the innovation system.
7. Creation of legitimacy/counteracting resistance to change: the technology has to become part of the incumbent regime or even overthrow it.

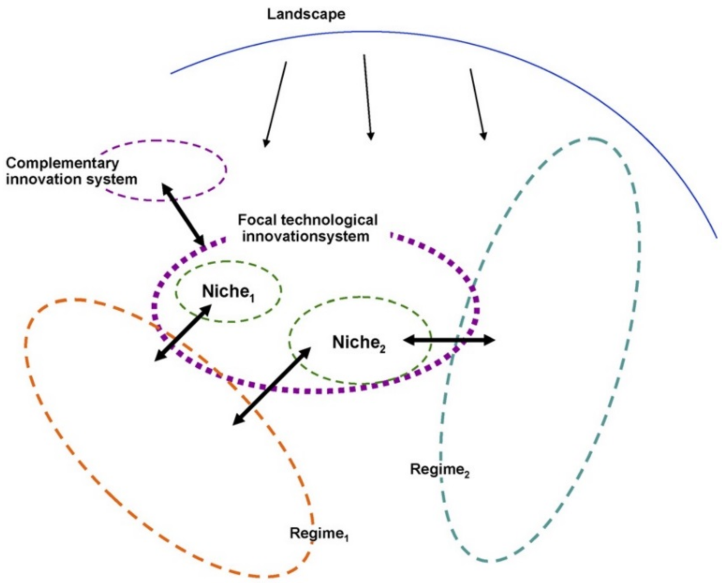

Figure 1: Technological Innovation System and interactions (shown by the arrows) with the Multi-Level Framework ((Kemp et al., 1998) p.612)

Markard and Truffer (2008a) did not differentiate between the levels on which the various functions should be performed. However, in the proposed AMSIT method, we do explicitly link the MLF levels and the functions of the TIS. To facilitate a technological transition, each function should be fulfilled by one of the actors in the TIS. However, network actors are not always supportive of a technological innovation (Bergek et al., 2008) and therefore it is important to map the network actors and their potential control over the key functions in a TIS. The likelihood that network actors in the TIS will actually fulfil one or more of the key activities depends to a large extent on their perceptions of the innovation's cost-benefit ratio and the degree of change which can be predicted using the Hypercube of Innovation (Afuah and Bahram, 1995) which is explained in the next subsection.

2.3 The Hypercube of Innovation

The hypercube model helps to evaluate innovations in terms of the impact of those innovations on the competence and assets of all the members of the innovation value-added network (Afuah and Bahram, 1995). An innovation which is considered incremental on the manufacturer level might well appear radical on the customer level (Afuah and Bahram, 1995). This will have consequences for its adoption (Afuah and Bahram, 1995; Rogers, 2010). The way an innovation will be perceived can be estimated by measuring the impact of the innovation. A radical innovation can be less favorable than an incremental innovation as it represents a drastic departure from the existing core concepts and the linkages within the existing product system. An innovation's degree of change can be categorized as radical, incremental, modular, or architectural (Afuah and Bahram, 1995; Henderson and Clark, 1990):

1. Incremental: The existing core concepts are reinforced while the linkages remain unchanged.
2. Modular: The existing core concepts are overturned while the linkages remain unchanged.

3. Architectural: The existing core concepts are reinforced while the linkages between them are changed.
4. Radical: Both the existing core concepts and the linkages between them are overturned.

The degree of change, represented in the hypercube, can best be explained by focusing on the extreme cases: radical versus incremental innovations. Incremental innovations occur on an evolutionary basis and so fit easily within the existing sociotechnical regime. A radical innovation overturns the underlying core concepts of the components and the linkages between those concepts and components. Such radical changes do not fit with the established technological regime. Between these two extremes, there are architectural and modular innovations. These innovations are less disruptive than radical ones since these change either the internal working concepts of components or the linkages between them. Still prior empirical studies indicate that for incumbent firms it can be very hard to succeed at architectural innovation (Henderson and Clark, 1990). Alongside the type of innovation, the value-proposition of the innovation is an important criteria to take into account. An innovation's cost-benefit ratio quantifies the degree to which possible losses, incurred as a result of destroying a positive network of competence externalities, are compensated by the benefits (Markard and Truffer, 2006; Tidd and Bessant, 2011). While the overall cost-benefit ratio for a whole network of actors may show benefits outweighing costs, this is not necessarily the case for each individual actor in the network (Markard and Truffer, 2006). When the costs to an actor outweigh the benefits, an individual actor might well act against the proposed system innovation (Dhanaraj and Parkhe, 2006). A 'fair' allocation of costs and benefits helps ensure a stable network which supports processes that provide benefits to the network as a whole. The perceived cost and benefits can differ from actor to actor and include for example return on investments, additional investment in learning and/or new production facilities, changing product or service quality, obsolescence or strengthening of the employees' skills and improvement or loss in network externalities (Afuah and Bahram, 1995).

2.4 Constructing the AMSIT

We have combined the three different frameworks discussed in the previous subsections to create the AMSIT which is illustrated in Figure 2. This framework covers the three levels of the MLF: the niche, the sociotechnical regime, and the landscape. At the niche and socio-technical regime-level, various actors are identified that are involved in different key functions of the TIS. We combine the MLF and TIS as both frameworks have complementary strengths and weaknesses. A strength of the Multi-Level Framework is that it explains transition processes by focusing on three distinct levels and that it leaves room for external influences that are part of the landscape level (Geels and Schot, 2007). However, the Multi-Level Framework is less informative on the specific roles of the different actors within the different levels. This complicates operationalization and use of the concept. The inward oriented Technological Innovation System addresses this shortcoming by its framework of complementary structural and functional analyses (Bergek et al., 2008; Markard and Truffer, 2008b). It reaches beyond the processes in the niche level with clear and elaborated descriptions of the different functions in the TIS and the way this system should be applied. Within this structure, it deals with the interaction between actors. In sum, the Multi-Level framework is complemented with the structured and functional Technological Innovation System, while the inward oriented TIS is complemented by the MLF's inclusion of external dynamics of in the regime and exogenous factors from the landscape level. To assess the likelihood that each actor fulfills their relevant function, we map their perceptions of the innovation in terms of the type of innovation and the expected cost-benefit ratio. Together, this information provides an opportunity to assess *system innovations and transitions* at an early stage and to identify the most likely transition paths. Plausible transition paths are represented by the full and dashed lines in Figure 2. For each level, we will now explain the steps involved in the AMSIT.

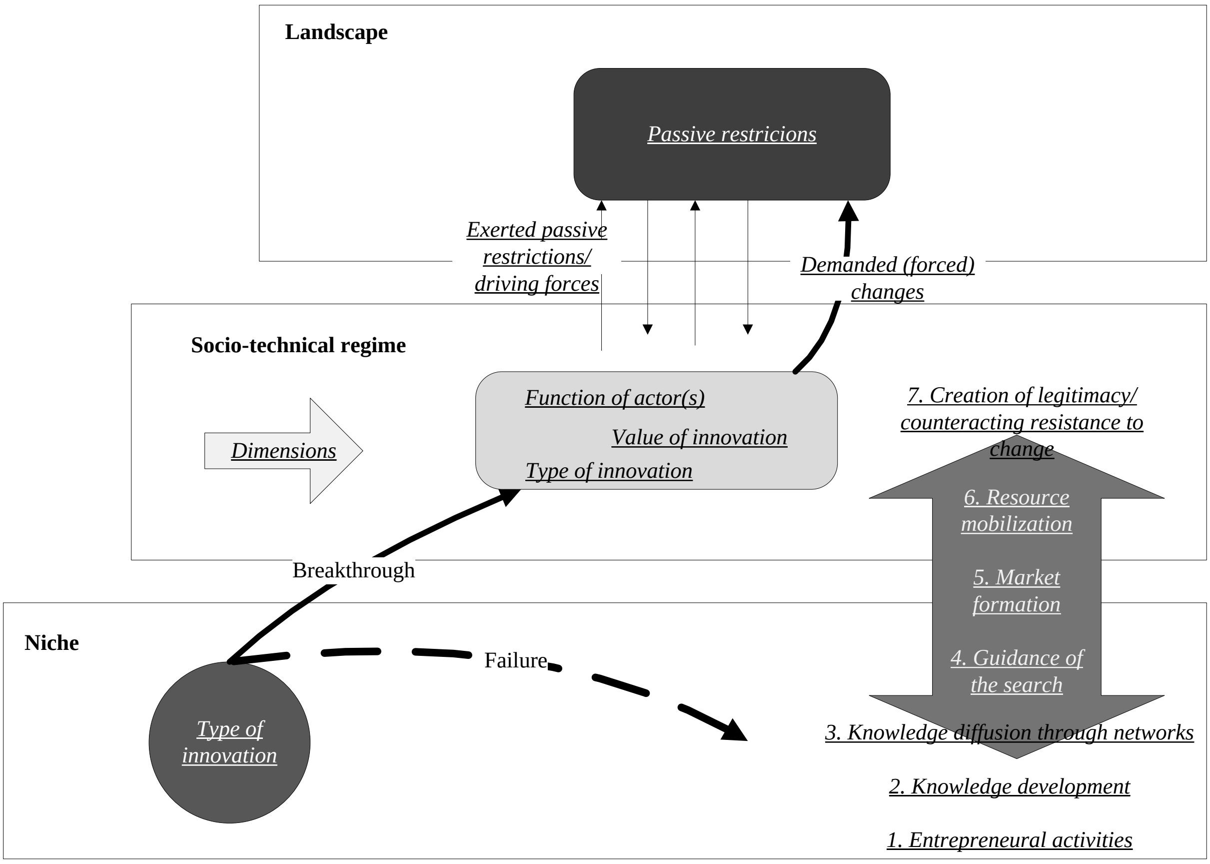

Figure 2: The Assessment Model for System Innovation and Transition (AMSIT)

2.4.1 The micro-level in AMSIT: the niche

A niche innovation could be incremental, modular, architectural, or radical. Each type of innovation represents a certain degree of change to the sociotechnical regime (Markard and Truffer, 2006). Establishing the degree of change is important since a limited degree of change does not require a niche or a regime shift. On the other hand, an innovation which involves a high degree of change often does not materialize without first a niche being created or by it being adopted by the established regime. Therefore, the need for a regime shift and the required change in the sociotechnical regime can be established from the degree of change involved with the innovation. This degree of change can be classified in terms of whether it overturns the existing knowledge of core concepts and components, and the linkages between those concepts and components.

A niche is almost always created by entrepreneurs and institutions in response to an innovation. Entrepreneurs initiate activities because they believe in the innovation's potential, and one of the first steps is to set up a niche with allied actors and institutions on board. This involves the first function of the Technological Innovation System: entrepreneurial activities (Markard and Truffer, 2008b). Innovation also requires knowledge development, which is the second function of the Technological Innovation System. Both functions occur within the niche since they need the protection this provides. Before trying to introduce a system innovation, it is useful to assess the potential impact of the innovation on the various actors within the TIS. If the innovation provides sufficient additional value over the current system, it becomes worthwhile to initiate changes in this system. If not, the innovation will probably not be adopted (Rogers, 2010). Launching the innovation from the niche into the established regime is facilitated by the third function of the Technological Innovation System: knowledge diffusion through networks (Markard and Truffer, 2008b). This function is part of the interface between the niche and the sociotechnical regime. The four other functions are also part of this interface and are performed by actors from both the niche level and the sociotechnical regime as they interact through the interface. Thereby the interface can be defined as the joint activities of actors from both the niche and the sociotechnical regime, concerning functions from the TIS. These functions, as well as the degree of change for the various actors, define the niche level and to an extent the interface between the niche and the sociotechnical regime. A completed version of Table 1, shown below, can provide a clear insight into the actors, the degree of change involved, and the extent to which the relevant functions of the TIS are being fulfilled. However, such an insight will not be useful unless it is placed in the context provided by the framework's three levels. As such, the present insight fails to suggest plausible transition paths or enable an assessment of the AMSIT's niche. Nevertheless, it does provide insight into the niche required to assess the full context of any plausible transitions.

	Type of innovation	**Functions of the Technological Innovation System performed. (The third is partially carried out in the interface)**
Actor(s)	- Radical - Architectural - Modular - Incremental	1. Entrepreneurial activities 2. Knowledge development 3. Knowledge diffusion through networks partially

Table 1: Possible niche factors

2.4.2 The meso-level in AMSIT: the system

The sociotechnical regime can be described in terms of networks of actors and by several dimensions (Hekkert et al., 2007). These dimensions, as shown in Table 2**,** all involve the actors established in the sociotechnical regime. As such, they are also expected to perform several functions in the Technological Innovation System. While the actors normally perform a specific function through which they define certain dimensions, they are also influenced by the already established definitions of these dimensions.

The way in which they perform this function, and might therefore define the involved dimension, depends on the innovation and the way the innovation would affect them personally and its function in the network. In fulfilling functions of the TIS, the established dimensions can be redefined. The functions of actors within the regime's multi-actor network may influence the way the actors execute the function in which they are involved in the Technological Innovation System (TIS). Since Functions 3 to 7 (see below) of the TIS are all active in the interface between the niche and the regime levels, these will depend on actors from both levels.

The functions within the interface between the micro-level and the meso-level are:

- Knowledge diffusion through networks (Function 3 of the TIS)
- Guidance of the search (Function 4 of the TIS)
- Market formation (Function 5 of the TIS)
- Resources mobilization (Function 6 of the TIS)

Further, the following function is within the system but active in the interface:

- Creation of legitimacy/counteracting resistance to change (Function 7 of the TIS)

The way an innovation is perceived by the actors in the network influences the likelihood that each actor will fulfil a function of the TIS, how, and whether this will redefine the key dimensions and maybe also influence the innovation's perceived value-proposition. For example, a radical innovation may involve large investments and for that reason an actor might resist adoption. However, a fair allocation of costs and benefits may ensure network stability and the likelihood that actors fulfill their required function. The way actors perceive the cost and benefits depends on the innovations' impact on the existing assets or activities of the involved actors (Afuah and Bahram, 1995). This impact may differ from actor to actor and can be identified by using both qualitative and quantitative data. These data can be collected by for example interviewing the involved actors but also by using other data sources such as industry reports or expert views. . For example for a customer an important determinant for adoption of the innovation is whether the innovation is compatible with complementary products that the customer has already in use. While for a supplier, the possible impact of a system innovation may range from enhancing or destroying the supplier's existing design and manufacturing knowledge which could affect the likelihood of fulfilling the supplier's required function.

As noted earlier, an innovation can be experienced in various ways. Afuah and Bahram's (1995) reasoning suggests that a radical innovation will cost more than an incremental innovation. This seems logical when considering just the moment of implementation. For example, the costs incurred in discarding skills and the complementary values of existing products when introducing a radical innovation are likely to far outweigh the losses associated with an incremental innovation (Carlsson and Stankiewicz, 1991). Nevertheless, while a radical innovation may initially destroy the value of existing concepts, it could in the long term provide greater value by possibly addressing one or more weaknesses of the established concepts (Hekkert et al., 2007). As such, a radical innovation that addresses weaknesses in the current concepts may eventually provide greater benefits than an incremental innovation. That is, while a radical innovation might initially overthrow existing concepts, and therefore seem radical and costly, in the long term it can be part of a punctuated equilibrium (Gersick, 1991). Given these requirements, a radical innovation requires the ‘shared responsibility’ of the actors in the sociotechnical regime. Sharing the responsibility will also involve a shared value-proposition.

A structured display of the possible content of the sociotechnical regime is provided by Table 2. From the actors’ roles and how these define the system, one can establish the TIS function that an actor is likely to fulfil. The way actors perceive the innovation, together with their expected cost-benefit ratios, will determine whether these actors are likely to fulfil their function and so stimulate the innovation. The insights so far obtained illustrate the sociotechnical regime. However, since the regime is also influenced by landscape factors, we require more information before we can construct plausible transition paths. This is only possible when the niche, the sociotechnical regime, and the landscape of the AMSIT are considered in each other’s context.

	Actor specifics in the sociotechnical system		**Proposed function to stimulate innovation**	**Likelihood that actor fulfils the proposed function**	
	Role of the actors	**Dimension in system**	**TIS function (3 to 6 are partially in the interface)**	**Perceived innovation type**	**Value of innovation (cost-benefit ratio)**
Actor(s)	- Financial network - Research network - Producer network - Suppliers - User groups - Societal groups - Public authorities	- Technology - User practices - Application domains - Symbolic meaning of technology - Infrastructure - Industry structure - Policy - Techno-scientific knowledge	3. Knowledge diffusion through networks 4. Guiding the search 5. Market formation 6. Resource mobilization 7. Creating legitimacy and counteracting resistance to change	1. Radical 2. Architectural 3. Modular 4. Incremental	Qualitative expression of the long-term value-proposition and the impact on existing assets and activities.

Table 2: Factors in the sociotechnical regime

2.4.3 The macro-level in AMSIT: the landscape

The landscape level contains the passive restrictions and driving forces that exert inertial pressures on the sociotechnical regime. These restrictions are factors that cannot or at most in the long-term, be influenced by actors as exist in the system. However, in times of crises the landscape level might rapidly change due fast system innovation. This might also occur the other way around.

The proposed innovation acts as a driving force on those restrictions in an attempt to make them support the regime. While the restrictions will generally support the established regime, a changing landscape could also provide support for a shift in the regime. As an example, finite oil reserves and climate changes due to CO_2 emissions strongly support the development of alternative energy sources. In addition to determining the established passive restrictions and driving forces, one must also determine what needs to be changed about the passive restrictions and driving to enable them to support the innovative system. It is possible therefore that changing the landscape factors may also require changes to the regime. Since the description of the landscape might be considered abstract, table 3 lists examples of factors that could be used in mapping the landscape. These factors where determined in the case study, but due to their generic character, these are included here in order to clarify the content of the landscape.

Passive restrictions/driving forces exerted	**Changes demanded of the passive restrictions** **(in order to support an innovative regime)**
- Demographic factors - (Macro)economic factors - Environmental factors - Geographical factors - Societal factors	- Adjustments to demographical factors - Adjustments to (macro)economic factors - Adjustments to environmental factors - Adjustments to geographical factors - Adjustments to societal factors

Table 3: Possible landscape factors

2.4.4 Establishing transition paths

The three tables outlined above provide illustrations of the niche, the sociotechnical regime, and the landscape of an innovation. However, independently, these do not fully explain the relationships between the various factors and the possible transition paths. For this, the tables have to be placed in a framework as shown in Figure 3. This model can be used to develop and ex ante assess the system innovation that not only faces challenges at the niche in which it operates, but also factors related to the socio-technical regime and the (political and societal) landscape in which the niche is located. This is in the model manifested by the “staircase” form taken by the three levels of development.

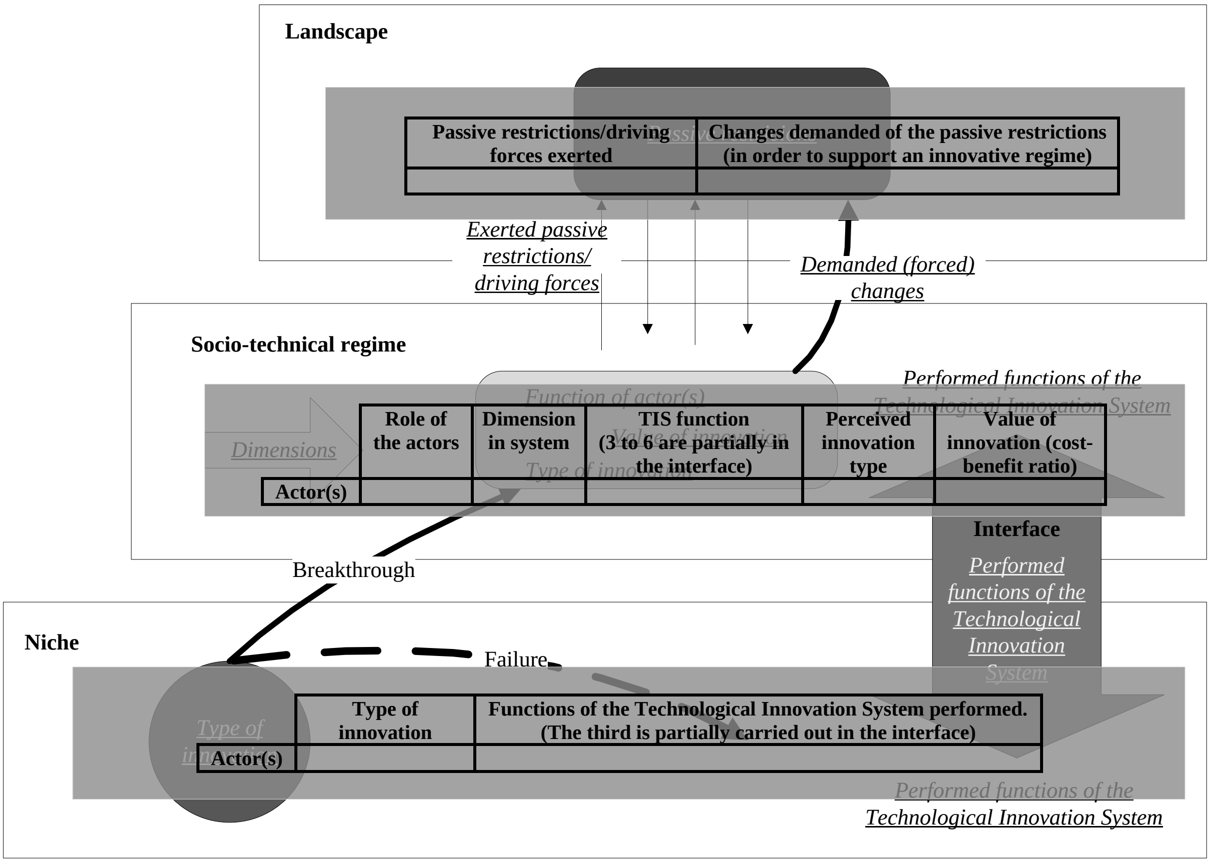

Figure 3: Combining the tables in a Multi-Level Framework

The contents of the niche and the sociotechnical regime tables provide specifics on the various actors involved who all have a specific role, define a dimension, or maybe fulfil a certain function in the TIS, and who will perceive and value an innovation differently. By placing these factors in the multi-actor network, these actors provide one or more possible paths for the innovation.

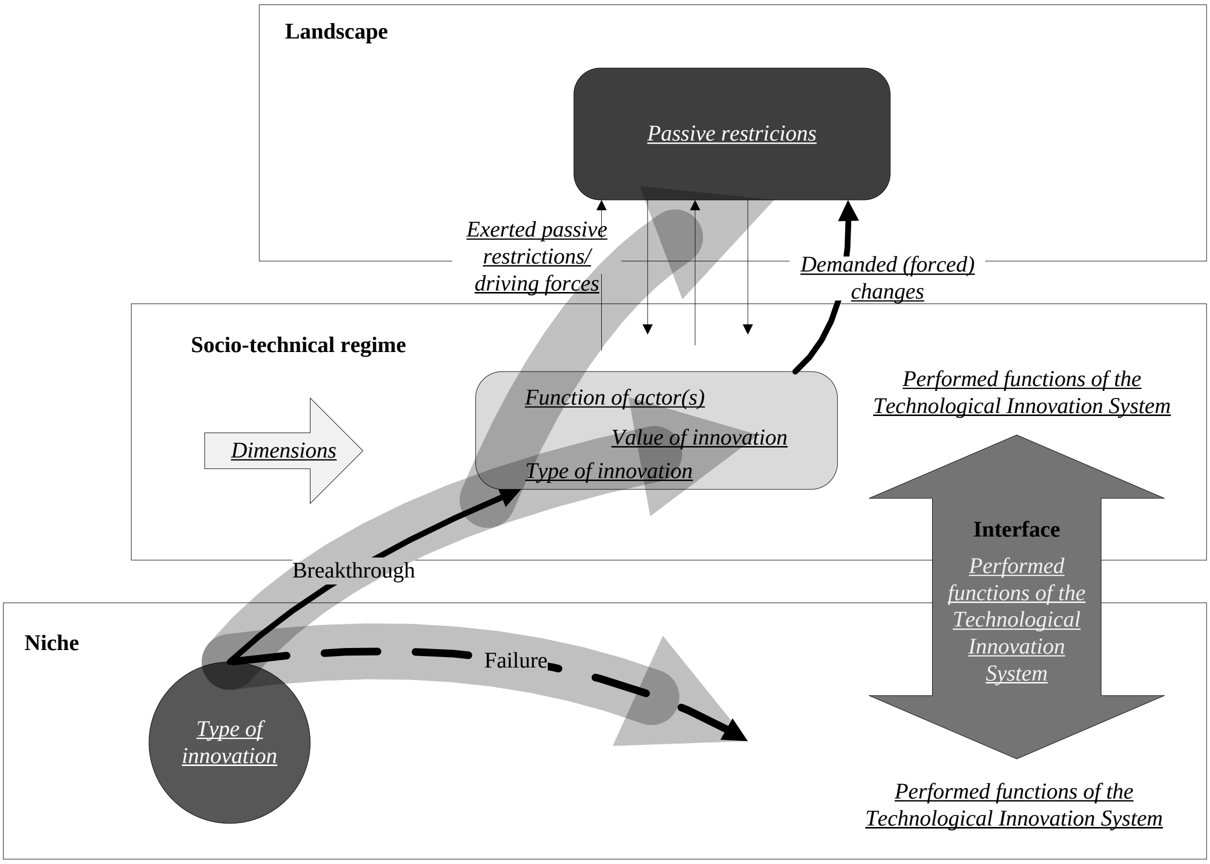

Figure 4: Possible paths within a transition

In addition to the paths that imply a transition, there are also possible paths that lead to ‘failure’. The model should be understood to depict different degrees of development and inbuilt challenges at the “niche” level but success or failure also depends upon circumstances that are related to “socio-technical regime” and “landscape”, For example while an innovation could fail to breakthrough in the socio-technological regime it is also possible that it is not adopted in the regime due to incomplete performed functions of the TIS. C failure is possible on different levels in the AMSIT model. Possible paths that involve a breakthrough in the regime are dependent on characteristics of the factors that are part of the multi-actor networks as well as on the pressure(s) exerted by the landscape. Of the possible transition paths, the most likely could be determined based on how radical the innovation is perceived to be and its value. Further, the reasoning behind the established factors provides insight into the critical issues and possibly how these might be resolved. This information can be used to provide recommendations concerning a plausible successful transition path. Having proposed a method, we will apply the method to a system innovation involving the Dutch railway system.

3. Illustration: an innovation on the Dutch railway network

The following illustration serves to explore the usability of the AMSIT in a possible transition involving an innovation in the Dutch railway network. In this illustration the authors of this paper collected, analysed and interpreted the required information. However, any person with advising skills and an adequate level of knowledge on transition theory and innovation systems can fulfil this role. Therefore external advisors or for example policy makers could be selected to guide this process in applying the AMSIT.

Now we will turn to the different steps we set in applying the AMSIT. First we identified the relevant actors by using a snowball sampling technique where known actors were asked to share information and connections to other relevant contacts.
Second the relevant information within the AMSIT were collected among these actors. As the sample build up, enough data was gathered to be useful for our assessment. The relevance, reliability and validity of this information was established by a cross-analysis of the multiple data sources. These sources included among others, interview data, documents and archival records[2] which were obtained by desk research and railway experts. In total we conducted fourteen semi-structured interviews among
representative actors to complete Tables 1, 2, and 3 . During each interview the AMSIT was explained and predetermined questions were asked on the three different levels within the AMSIT. For example, the interviewees were asked to clarify their and role in the rail sector and which socio-technical dimensions they could identify (Geels, 2002). Other questions focused on how they perceive the innovation from their individual perspective and from the regime's perspective, how this affects the innovations value-proposition and whether the value is fairly distributed among the involved actors, and what factors are likely to facilitate or impede a breakthrough of the innovation. Next to that, each interviewee was asked which landscape factors affect the Dutch railways. Finally the interviewees were given the opportunity to address additional subjects and they were asked to reflect on the list of identified actors.
Third, using the Delphi method (Dalkey, 1969) the content of Tables 1, 2, and 3 was refined and the possible transition paths were drawn. In follow-up meetings with the interviewees, the findings including the possible and most likely transition paths were discussed and final conclusions were drawn. In this application of the AMSIT an illustration is provided into both the possible transition concerning the Dutch railway system as well as the usability of the developed method.

The innovation concerning the Dutch railways involves a shift to a system which facilitates greater sustainability in rail transportation. Sustainable transportation is an important issue given the effects of CO_2emission on climate change. This involves a search for sustainable transportation modes that reduce pollution, ideally to a zero-emission situation. One of the most sustainable ways to transport goods these days is by rail. Although trains are powered by electricity, which is already a relatively clean power source, the rail sector is making large efforts to become even more sustainable. Using less energy not only reduces CO_2emissions it also has financial advantages.

Reducing electricity losses in the infrastructure is an effective way to improve the energy efficiency of the railway system. One way to achieve this is to increase the voltage in the overhead wires since this will decrease the losses. In addition, with an increased voltage it is possible to recover energy from breaking.. Furthermore, increasing the voltage in the overhead wires also increases the capacity of the infrastructure. This reduces the need to build additional capacity, which would inevitably cause further pollution. An increase in capacity is required to support what is seen as the most sustainable means of transportation, and this also has a direct effect on mobility. Mobility is important for economic and societal development. An increased voltage in the overhead wires can help to solve capacity problems by allowing and facilitating a higher capacity on the railway infrastructure. Overall, a higher voltage in the overhead wires clearly provides advantages. A migration to an increased voltage of up to 25kV DC has been discussed by several actors but a decision has been postponed since the

[2] The non-confidential documents and archival records are listed in Appendix A

adaption of a new system is considered problematic in terms of financial, technical, exploitation, and organizational issues. One problem is that the current substations and trains do not support an increased voltage. This means that the transition from 1.5kV DC to, for example, 3kV DC would amount to a large, nationwide innovation of the current system. As an illustration of the application of our AMSIT method, we used it to assess this system innovation and transition in the railway industry.

3.1 The niche

The assessment of this possible transition starts in the niche. The niche contains those actors and specific departments that have undertaken entrepreneurial activities, developed knowledge, and diffused knowledge through networks. The activities and this knowledge included all related to the considered innovation. Before elaborating on these actors and the functions they fulfil in the niche, it is helpful to explain the innovation and its impact on the system.

The innovation developed in the niche involves migrating to an increased voltage in the overhead wires of the Dutch railway system from 1.5kV DC to 3kV DC. Already, 3kV DC electrified networks exist in over half of Europe. Therefore a system operating at 3kV DC is not an innovation, but migrating to the increased voltage in the Netherlands would be. A system operating at 3kV DC could be achieved by making changes to the existing technological concepts and the linkages between those concepts (e.g. engines, substations, safety systems which support the increased voltage). As such, a transition to 3kV DC involves add-ons to the established system rather than revolutionary changes. All the necessary changes involved in the proposed transition to 3kV DC can be classed as symbiotic innovations (Geels, 2002) that together innovate and thereby adjust the established system to the proposed 3kV DC system.

In the niche, several actors will work on this proposed migration. These actors involve a specific department of the responsible ministry, the infrastructure manager, and the principal passenger operator. These actors are directly involved in the possible transition and, next to these actors, there are two groups of actors that are indirectly involved: consultancy/research institutions and suppliers. By working on new technologies, ways to exploit these new technologies and challenges concerning the exploitation of railway transportation, these can develop and diffuse knowledge, but they have no direct influence over the possible transition. Several actors and specific departments have undertaken entrepreneurial activities, developed knowledge, and diffused knowledge in the process concerned with a migration to an increased voltage. Thereby one can think of. researching the possibilities for the proposed innovation on a technological level, the development of required technology, high-level plans for implementation and exploitation, calculations concerning return on investment. In addition, all the mentioned knowledge is diffused among relevant stakeholders. However, interviews with niche actors, and an analysis of relevant documents and archival records, indicate that not all the necessary knowledge was developed. The knowledge that was developed was well diffused.

Using the AMSIT involves creating, on every level, a Table from which the content of that level can be established. Thus, for the niche level, the type of innovation and the TIS functions performed by each actor should be established. Table 4 provides this information for the relevant niche.

	Type of innovation	Functions of the Technological Innovation System (TIS) performed
Consultancy/Research institutions	- Partly Architectural - Partly Modular	1. Entrepreneurial activities 2. Knowledge development 3. Knowledge diffusion through networks
Infrastructure manager	- Partly Modular - Partly Architectural	1. Entrepreneurial activities 2. Knowledge development 3. Knowledge diffusion through networks
Principal passenger operator	- Partly Modular - Partly Architectural	1. Entrepreneurial activities 2. Knowledge development 3. Knowledge diffusion through networks
Responsible ministry (a specific department)	- Modular	2. Knowledge development 3. Knowledge diffusion through networks
Suppliers	- Architectural	2. Knowledge development

Table 4: The niche contents in the Dutch railways innovation

As can be seen in Table 4, none of the actors perceived the innovation as incremental or radical, but as somewhere in between. The innovation is perceived as least radical by the specific department of the responsible ministry (perceived as modular, since this department focuses only the technological innovations required for increasing the voltage in the overhead wires), and most radical by the suppliers (perceived as architectural, due to the changes to the existing technological concepts and the linkages between those concepts which are developed by these suppliers). The actors with a significant influence on the decision-making are related in the sense that they are all part of an organization to be found within an institutional triangle (the responsible ministry, the infrastructure manager, and the operators). This indicates that these actors are strongly related to, and dependent upon, each other, implying that an innovative breakthrough in the system could only be achieved by the combined efforts of all these actors with their shared knowledge and visions.

3.2 The sociotechnical regime

The sociotechnical regime is populated by a multi-actor network. With some actors it is easy to establish that they are not involved in the proposed innovation, whereas the relevance of others maybe more difficult to establish. For example, the proposed innovation may have a large impact on the transport operators which use the railway. However, the present transport operators mainly use diesel-powered or dual/multi-voltage rolling stock. Since this rolling stock would not require conversion in the event of a voltage increase to 3kV DC, the transport operators can be classified as non-relevant actors here. The same is true for the European Commission (EC) in terms of its policies related to this topic since these support both the established system as well as the proposed innovative system. Consequently, the number of actors can be reduced to those who are directly relevant and who will form the backbone of any plausible transition paths established.

The actors in the multi-actor network have specific roles in the sociotechnical regime through which they define certain key dimensions. Directly relevant in this matter are the responsible ministry (defining policy, the industry structure, and the symbolic meaning of technology), the principal passenger operator (defining the technology by the used rolling stock, user-practices as are part of the exploitation of the railway transportation, and techno-scientific knowledge concerning the used technologies), and the infrastructure manager (defining technology concerning e.g. energy supply, safety systems and track specifications, user-practices in the exploitation of the railway network, infrastructure and techno-scientific knowledge). These actors are highly dependent on each other. For example, the policy and the industry structure, which are defined by the responsible ministry, also affect the activities of other actors in the system. Further, some of the actors jointly define some of the dimensions. Technology, for example, is defined by the three actors together. Such dimensions can only be

changed by the combined efforts of the involved actors, and changes would otherwise be worthless or even counterproductive. For example, converting all the rolling stock would not provide a benefit if the infrastructure manager did not convert the substations, or vice versa.
The actors as part of the regime fulfil certain functions of the TIS and so stimulate the innovation. Since this system is based on the institutional triangle (i.e. the responsible ministry, the infrastructure manager, and the operators), fulfilling these functions is largely a shared responsibility. However, given the different roles of the actors in the system, each actor will fulfil these functions in a different way. Given the structure of the industry, a large part of the resources required by the infrastructure manager and the principal passenger operator would have to be provided by the responsible ministry. Consequently, the ministry holds a key position. Another function in which the ministry is involved is creating legitimacy: as a public authority it has to consider the effects on society and how the innovation would be perceived.

Along with the value of a proposed innovation, how it is perceived also influences the likelihood that an actor will fulfil its TIS functions. In this example, the responsible ministry perceived the innovation to be radical due to its financial, technological, exploitative, and organizational characteristics. Further, the proposed innovation has a negative value to the responsible ministry. The other two major actors also perceived the innovation as radical due to the extent of the implications and operations involved, such as the operational difficulties in exploiting the system during the migration to the higher voltage. However, the perceived values differ. To the infrastructure manager, the proposed innovation has a negative financial value. However the innovation would provide a more robust rail network, and this is desirable. In the long-term, this might provide financial advantages, but these are uncertain. For the principal passenger operator, the innovation would require a large initial investment although it would lead to a considerable reduction in energy costs. All the actors, their specific attributes, their proposed roles in the TIS, and the likelihood that they fulfil these functions are captured in Table 5 as part of the AMSIT.

In this innovation, none of the key functions of the TIS are fulfilled. Since the development and the diffusion of knowledge (the second and third functions of the TIS) are incomplete, the innovation still needs space for incubation as provided by the niche. The extent to which the various actors would fulfil the required functions is determined by how the actors perceive the innovation and the value-proposition for themselves. As can be seen in Table 5, the relevant actors directly involved perceive the innovation as radical. Furthermore, there is no obviously positive value, and when as it comes to finance it seems mostly negative. This is partly a reflection of the passive restrictions and driving forces on the system - the so-called landscape factors.

	Actor specifics in the sociotechnical system		Proposed function in stimulating innovation	Likelihood of actor fulfilling proposed function	
	Role of the actor	**Dimension in system**	**Role in the TIS**	**Perceived innovation type**	**Value of innovation (cost-benefit)**
European Commission	Public authority	- Policy	4. Guidance of the search	Incremental: since it would be a relatively minor change.	Positive: interoperability will increase.
Responsible Ministry	Public Authority	- Industry structure - Policy - Symbolic meaning of technology	3. Knowledge diffusion through networks: 4. Guidance of the search 5. Market formation 6. Resources mobilization 7. Creating legitimacy / counteracting resistance to change	Radical: since it is perceived to be financially, technically, exploitatively, and organizationally problematic.	Negative: large investments required. Technically, exploitatively, and organizationally problematic.
National infrastructure manager	Infrastructure manager	- Infrastructure - Technology - Techno-scientific knowledge - User-practices	3. Knowledge diffusion through networks 4. Guiding the search 6. Resource mobilization 7. Creating legitimacy / counteracting resistance	The technological implications are at most incremental, whereas the innovation of the system is quite radical.	Neutral: improving the infrastructure has a positive value but the financial value is negative.
Transport operator	Operators (User groups)	- Technology - User-practices	5.Market formation	Incremental: most of the rolling stock is dual/multi- voltage or diesel-powered.	Unknown: the economic advantage of the possibility of larger and heavier trains is unknown.
Principal passenger operator	Operators (User groups)	- Technology - Techno-scientific knowledge - User-practices	3. Knowledge diffusion through networks 4. Guiding the search 6. Resource mobilization 7. Creating legitimacy / counteracting resistance	Radical: while the technological change is only incremental, the effects on operations will be large.	Depends on compensation provided. The advantages provide a positive value but the investment is not supported by the principal passenger operator as part of its own strategy.

Table 5: The content of the sociotechnical regime (system) of the Dutch railways

3.3 The landscape

The landscape consists of those factors that exert pressure on the system. These factors cannot, or at best only in the longer term, be influenced by the actors in the system. If an innovation requires a short-term change in a landscape factor, then a system innovation might well not occur. Important landscape factors identified in migrating to a higher voltage are demography, macroeconomic developments, the environment, geography, and society.

Demography is an important factor since it can influence the demand for mobility, and conversely the level of mobility might in the longer term have effects on demography. The latter effect reflects the concept of constant travel time budgets; i.e. that people accept a certain travelling time, rather than a maximum distance (Hupkes, 1977), (van Wee et al., 2006). Thus, commuters will be willing to travel longer distances providing the travelling time remains the same. Constant travel time budgets in combination with increased mobility may change demography. (Macro)economic developments can have a strong influence on mobility: economic welfare can demand increased mobility which, in turn, can stimulate economic welfare. The effects of (macro)economic developments on the investment climate should also be considered since the willingness to make large investments in a system innovation in times of economic crises is likely to be lower than in periods of economic growth. When it comes to environmental issues, there is a growing desire for sustainable transportation. Existing transport modes mostly use polluting engines that consume scarce natural resources. The need to reduce pollution and to cope with the increasing scarcity of resources puts pressure on the current system to change. The Netherlands, strategically situated in Europe, has one of the largest harbors in the world that is accessible by rail, road, and three major European rivers. This geography is an important landscape factor. Furthermore, public transportation has an important societal function with about seven percent of the Dutch population commuting daily using the public railway network. This mobility is a necessary condition for economic and societal development. This need for mobility provides an impetus for a modal shift (from one means of transport to another) that reduces or avoids traffic congestion. One can say that Dutch society demands a well-organized, safe, and structured public transport system (of which the passenger railway system is part).

In terms of the environmental factor, the proposed system innovation not only demands but also forces change. For example, the improved energy efficiency implies less CO_2emission. The demographic and geographical factors put pressure on the current regime, but these factors could change due to the effects of the innovative system, such as if increased mobility and reduced travel times lead to demographic changes. An economic factor is that the innovation would require economic support in the form of large investments and significant payback periods. The increased mobility provided by the innovation would both demand and support evolvement of the societal landscape factor.

The Table for the landscape level is shown below. Note that the demanded changes are based on the requirements of the regime surrounding the possible innovation.

Exerted passive restrictions/driving forces	Changes demanded to passive restrictions/driving forces (in order to support the innovated regime)
- Demographic factors (e.g. mobility in specific areas) - (Macro)economic factors (e.g. economic pressure/crises) - Environmental factors (e.g. climate change, need to reduce CO_2 emissions) - Geographic factors (e.g. position of the Netherlands in Europe/World) - Societal factors (e.g. society requires mobility)	- Adjusted demographic factors (e.g. spatial development and mobility) - Adjusted (macro)economic factors (e.g. supportive investment climate) - Adjusted environmental factors (e.g. scarce natural resources, improved climate) - Adjusted geographic factors (e.g. growing importance of the situation of the Netherlands) - Adjusted societal factors (e.g. improved mobility due to changes in demographics and population density)

Table 6: The content of the landscape in the case of the Dutch railway innovation

3.4 Possible transition paths

The three tables above provide insight into the niche, the sociotechnical regime, and the landscape of the proposed innovation. In order to provide further insight into the relationships among the various factors and possible transition paths they are combined in the AMSIT as shown in Figure 5.

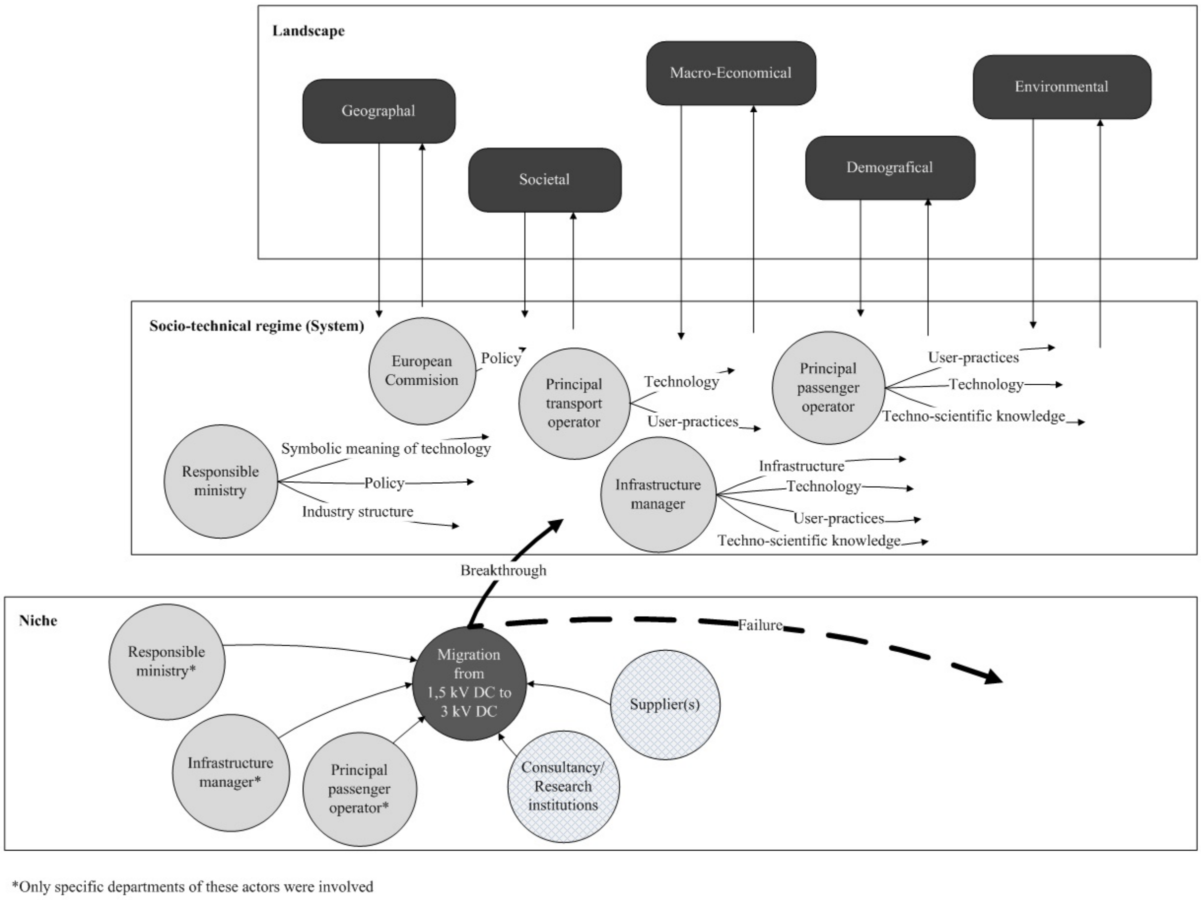

Figure 5: Combining levels in the AMSIT for the proposed Dutch railway innovation

The information collected in the case study related to the functions fulfilled, the roles of actors, the dimensions in the system, the innovation types, the value-propositions, and issues involving landscape factors enable us to establish possible transition paths. A transition could occur under the condition that switching to 3kV DC supports a more intensive use of the Dutch railway network. For this transition to take place, the responsible ministry needs to change its policy and provide additional funds to the infrastructure manager and the principal passenger operator. This might be justified as part of a long-term strategy to address identified landscape factors.

In this situation, various trajectories are plausible, including a transition through the use of *corridors*. Here, specified rail routes, which form corridors between two or more locations, are sequentially addressed. This would allow the immediate use of the advantages provided by a 3kV DC system on the specific corridor. The conversion of a corridor would be strongly interrelated with the conversion of rolling stock, through the use of segmented fleets and specific allocations of rolling stock (currently the rolling stock can be employed anywhere in the Netherlands). Further, it would involve an increase in the number of voltage changeover sections and other adjustments which would significantly complicate operations (and therefore likely add to costs). A transition using corridors would involve investments which would rapidly depreciate as the subsequent migration of other corridors would make some of the initial adjustments worthless (e.g. a voltage changeover section loses its value once adjacent corridors operate on the same voltage).

Another possible trajectory would be a sequential transition. This could be achieved through gradually converting rolling stock and substations (and other required changes to the infrastructure). This would mean that the migration could only start in eight to ten years. The transition would be started with converting the rolling stock to run on both voltages, and after about six years one could start converting the substations (and the other changes required to the infrastructure). When everything is ready, the migration would take place. While this avoids the need for segmented fleets (and specific allocations of rolling stock) and involves relatively simple operations compared to a transition through corridors, it would mean that the advantages of 3kV DC could not be gained for the next eight to ten years. Further, the initial investments would depreciate over time, losing value before they were even used. Furthermore, only switching to 3kV DC after eight to ten years would mean investments still had to be made in the current system. Since this would involve assets which normally have an operating and economic lifetime much longer that ten years, significant value will be lost due to the rapid depreciation and unprofitable investments in these assets.

A third possible transition path leads to failure and therefore the absence of any breakthrough in innovating the system. In this scenario, the niche development of the innovation is not supported due to macroeconomic pressure from the landscape. Essentially, the scenario is that, as a result of the economic crisis, the national economic situation is under pressure and the national government reduces its investments generally, including in the railway sector. It is then unlikely that additional sources will be provided to fund a transition to 3kV DC. Further, there is a possibility that future technological developments will address the aforementioned weaknesses of the 1.5kV system (limited capacity, energy losses, and limited energy recovery possibilities) at a lower cost and with less risk than the proposed innovation. Another essential requirement is the further development of knowledge and its diffusion, and eventually the other functions of the TIS. If the actors involved decide not to put further effort into knowledge development and diffusion, the migration will fail.
The involved transition path towards a higher voltage ends in failure since the developed knowledge is incomplete and not very well diffused. The actor fulfilling the key position in the multi-actor network perceives the innovation as radical, with a negative value-proposition. The (macro)economic landscape factors put significantly more pressure on the system than the other factors. However, the failure of this innovation does not prevent future possibilities for other system innovations.

4. Results

The proposed AMSIT method was applied to the transition involving the possible migration to a higher voltage in the Dutch railway system in order to ex ante establish which scenario for a possible system innovation was most likely. It was shown that a niche innovation does not necessarily have to be radical in itself for it to be seen as radical for the system as a whole. In the situation studied, the innovation consisted of a number of modular and architectural innovations. The actors involved had partially fulfilled some of the TIS functions but they were unable to make the functions work at the interface, and hence a breakthrough did not occur. An important assumption made was that the system is restricted by landscape factors, which were not addressed as such, with key actors lacking a long-term strategy. Without a future perspective and given the set of rules and dimensions, together with an innovation that is perceived as radical and lacking clear value-propositions, it seems unlikely that there will be an input to initiate a system transition involving a migration to a higher voltage.

4.1 Theoretical implications

Often, the Multi-Level Framework is used to describe transitions (Hekkert et al., 2007), (Geels, 2002). In this research, it was used as the backbone of the constructed method since the abstractness of the Multi-Level Framework makes it very suitable for this purpose. The integration of additional theories (Technological Innovation Systems, Hypercube of Innovation, value-propositions) provided the ability to map and draw how a transition could or should look, suggested how one might steer a system innovation, and identified the (possibly missing) critical elements. On this basis, one could assess the likelihood of a possible transition taking place according to the possible transition paths. Since the theories used do not individually provide the ability to assess possible system innovations, the developed method can be seen as an enhancement by bridging the gap between the Technological Innovation System and the Multiple-Level Framework as described in section 2.4.

The broad perspective provided by the Multi-Level Framework provides a clear insight into the circumstances present on all levels and thereby the likelihood of certain events occurring (with the (macro)economic landscape factor clearly limiting the system while the demographic dynamics supported a system change). The TIS proved to be a useful addition when trying to understand the conditions required for a purposeful innovation. While, in this case study, only a few functions were fulfilled, the functional perspective revealed useful information about the transition stage. However, no indication was provided as to the extent a function (for example, knowledge development and diffusion) was being fulfilled. Since this depends on the innovation and the circumstances involved, it is not possible to provide a generally valid criterion for when a function is fulfilled. In the context of the constructed method, it would be valuable to be able to assess the extent to which the TIS functions are fulfilled.

On the basis of the case studied, it appears that the AMSIT works well. Using this method we were able to establish possible transition paths and determine the likelihood of a transition to occur according a certain path. Thereby we have provided an insight in which factors and actors support a transition according to described transition paths and which factors and actors need attention in case these do not support a transition path. The possible transition paths concerning the studied case and the factors, actors and functions that determine these paths, were shown to the involved actors after the research was conducted. These actors and participants in the study confirmed the additional value of the insights as provided by the

AMSIT since their current knowledge and opinion was based on the innovation itself, not the system innovation and transition involved The different levels in the AMSIT and the multitude of perspectives included provided them with a richer more complete view. Furthermore, this several interviewees indicated that this study contributed to the knowledge diffusion among actors which is a key function of the TIS. However, while AMSIT worked in this case it might not always suit every system innovation and transition. For example, if there were more unrelated activities concerning the same niche innovations, or if the system was more complex and dynamic, the AMSIT would probably require some adjustments and further differentiation. Therefore it would be useful to apply the AMSIT to several other cases in order to establish if some adjustments are required.

Due to the oligopolistic (almost monopolistic) character of the system studied, the possible trajectories all depended on specific actors. However, in a more developed competitive market, different actors might be able to play various roles and, therefore, considering network externalities might also be important. Since, in the researched case, the most important actors fulfil unique functions, the adoption curve is fairly linear. For example, the task of diffusing an innovation cannot be shared among infrastructure managers if there is only one. Further, it seems highly unlikely that a single actor would migrate since migration would not provide any additional value (even worse, it would destroy the current value). In our situation, additional value can only be created if all the actors cooperate. In other transitions this might not be the case. As observed by one of our respondents, there are also developments to less fuel-consuming, more sustainable, engines in the automotive industry. This is motivated by incentives such as tax advantages and focused public policies. Since these operate in a larger market, with many more independent privately owned actors, a measurement of the positive network externalities could be a very useful addition to the constructed method.

Although the AMSIT method could be applied to the study of any innovation or change involving system innovation, describing how a transition might develop does not guarantee that an innovation will be successful or that a transition will take place as described.

4.2 Managerial implications

While the AMSIT was applied to the specific case of migrating the railway network to 3kV DC, it could equally be applied to other innovations that involve system innovation. Due to the used methodology anunbiased advisor is required which has the right competences to collect, analyse and interpret the required information. This person can be an external advisor but may also be for example an expert policy maker with adequate level of knowledge on transition theory and innovation systems. A transition to the general use of electric cars or the transition to a optical glass fiber telecommunication network, in place of the traditional copper one, are examples of situations where the method could be applied. Further, the innovation does not have to be radical since, as shown, a system innovation can be radical while the innovation is not. For example, with the illustrations just offered, we can observe that electric cars existed before ones with combustion engines, and that optical fibers have existed for over fifty years. The point is that how radical an innovation really is depends on how it is perceived by the actors within the system. Further, the actors within a system fulfil certain roles, and various aspects determine how the various TIS functions are actually fulfilled. For example, it is only possible for a search to be guided when an actor has the possibility to guide a search, maybe through policy. Here, landscape factors can either restrict or support these dimensions (as when macroeconomic developments influence policies and investments). Overall, the likelihood of the TIS functions being adequately fulfilled appears to depend on how radical the innovation is *perceived* to be, what the perceived value-proposition is, and the state of the landscape factors (a good economic climate might have a positive effect, while a bad economic climate might exert to negative pressure). Actors are more likely to cooperate when this offers value and advantages, while not causing excessive interference with established operations and assets.

5. References

Afuah, A. N. and Bahram, N. (1995). The Hypercube of Innovation. *Research Policy,* Vol. 24 No. 1**,** pp. 51-76.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy,* Vol. 37 No. 3**,** pp. 407-429.

Carlsson, B. and Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of evolutionary economics,* Vol. 1 No. 2**,** pp. 93-118.

Dhanaraj, C. and Parkhe, A. (2006). Orchestrating innovation networks. *Academy of Management Review,* Vol. 31 No. 3**,** pp. 659-669.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy,* Vol. 31 No. 8-9**,** pp. 1257-1274.

Geels, F. W. (2005). The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). *Technology Analysis & Strategic Management,* Vol. 17 No. 4**,** pp. 445-476.

Geels, F. W. and Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy,* Vol. 36 No. 3**,** pp. 399-417.

Gersick, C. J. G. (1991). Revolutionary Change Theories - a Multilevel Exploration of the Punctuated Equilibrium Paradigm. *Academy of Management Review,* Vol. 16 No. 1**,** pp. 10-36.

Hekkert, M. P., Suurs, R. a. A., Negro, S. O., Kuhlmann, S. and Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change,* Vol. 74 No. 4**,** pp. 413-432.

Henderson, R. M. and Clark, K. B. (1990). Architectural Innovation - the Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly,* Vol. 35 No. 1**,** pp. 9-30.

Hupkes, G. (1977). Throttle open or throttle down. Scenarios for the future of the transportation system Part I and II.

Kemp, R., Schot, J. and Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management,* Vol. 10 No. 2**,** pp. 175-195.

Kuhlmann, S. (2001). *Management of innovation systems: The role of distributed intelligence*, Maklu-Uitgevers.

Markard, J., Raven, R. and Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy,* Vol. 41 No. 6**,** pp. 955-967.

Markard, J. and Truffer, B. (2006). Innovation processes in large technical systems: Market liberalization as a driver for radical change? *Research Policy,* Vol. 35 No. 5**,** pp. 609-625.

Markard, J. and Truffer, B. (2008a). Actor-oriented analysis of innovation systems: exploring micro-meso level linkages in the case of stationary fuel cells. *Technology Analysis & Strategic Management,* Vol. 20 No. 4**,** pp. 443-464.

Markard, J. and Truffer, B. (2008b). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy,* Vol. 37 No. 4**,** pp. 596-615.

Nelson, R. R. and Winter, S. G. (1982). The Schumpeterian Tradeoff Revisited. *American Economic Review,* Vol. 72 No. 1**,** pp. 114-132.

Neuman, M. G., Katz, G. G., Malkiewicz, I. M., Mathurin, P., Tsukamoto, H., Adachi, M., Ishii, H., Colell, A., Garcia-Ruiz, C., Fernandez-Checa, J. C. and Casey, C. A. (2002). Alcoholic liver injury and apoptosis - synopsis of the symposium held at ESBRA 2001: 8th Congress of the European Society for Biomedical Research on Alcoholism, Paris, September 16, 2001. *Alcohol,* Vol. 28 No. 2**,** pp. 117-128.

Rayner, S. and Malone, E. L. (1998). *Human choice and climate change: an international assessment*, Citeseer.

Rogers, E. M. (2010). *Diffusion of innovations*, Free press.

Schot, J. and Geels, F. W. (2007). Niches in evolutionary theories of technical change - A critical survey of the literature. *Journal of evolutionary economics,* Vol. 17 No. 5**,** pp. 605-622.

Tidd, J. and Bessant, J. (2011). *Managing innovation: integrating technological, market and organizational change*, Wiley.

Van Wee, B., Rietveld, P. and Meurs, H. (2006). Is average daily travel time expenditure constant? In search of explanations for an increase in average travel time. *Journal of transport geography,* Vol. 14 No. 2**,** pp. 109-122.

Verbong, G. and Geels, F. (2007). The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). *Energy Policy,* Vol. 35 No. 2**,** pp. 1025-1037.

Verschuren, P. J. M., & Doorewaard, J. A. C. M. (2007). *Het ontwerpen van een onderzoek.* Den Haag: Lemma.

Yin, R. K. (1994). *Case study research. Design and Methods.* California: SAGE Publications Inc.

6. Appendix A: non-confidential documents and archival records used by desk-research

ANP (2011a, March 14). Beurs Tokio keldert door natuurramp. Retrieved March 16, 2011, from http://www.trouw.nl/tr/nl/4504/Economie/article/detail/1859612/2011/03/14/Beurs-Tokio-keldert-door-natuurramp.dhtml.

ANP (2011b, March 17). *Schiphol vijftiende luchthaven ter wereld.* Retrieved March 22, 2011, from http://www.parool.nl/parool/nl/4/AMSTERDAM/article/detail/1861472/2011/03/17/Schiphol-vijftiende-luchthaven-ter-wereld.dhtml.

Bakker, P., & Zwaneveld, P. (2009). *Het belang van openbaar vervoer. De maatschappelijke effecten op een rij.* Den Haag: Centraal Planbureau en Kennisinstituut voor Mobiliteitsbeleid.

Beek, F. van, Flikkema, H, Francke, J., Besseling, P., Groot, W., Nijland, H. Eck, J.R. van (2006). *Mobiliteit.* Retreived May 6, 2011, from http://www.welvaartenleefomgeving.nl/pdf_files/A04_Mobiliteit.pdf.

Burkhardt, M. (2010). *GHG reduction through modal shift.* Retrieved May 7, 2011, from http://www.ghg-transpord.eu/ghg-transpord/downloads/WP6-workshop1/reduction-mesures-road-rail/road-technologies/19_Stakeholder_BurkhardtM_UIRR_Rail_vs_Road_potentials.pdf.

CBS (2011). *Europese economien blijven gematigd groeien.* Retrieved March 16, 2011 from, http://www.cbs.nl/nl-NL/menu/themas/macro-economie/publicaties/dne/economische-groei/archief/2011/2011-02-15-02-ne-e.htm.

CIA (2011). *The World Factbook.* Retrieved March 22, 2011, from https://www.cia.gov/library/publications/the-world-factbook/geos/nl.html.

Dhanaraj, C., & Parkhe, A. (2006). Orchestrating innovation networks. *Academy of Management Review*. 659-669.

Ebbink, B. A. J. (2010). *NMCA deelrapportage spoor. Overzicht van mogelijke vervoer- en infrastructuurknelpunten tussen 2020-2028.* Utrecht: Arcadis.

Eurlings C. (2007, August 21). *Energiebesparing bij het spoorvervoer.* Retrieved November 28, 2010, from http://www.senternovem.nl/mmfiles/Brief%20van%20de%20minister%20over%20energiebesparing%20bij%20NS%20en%20ProRail_tcm24-238886.pdf.

Eurlings, C., & Huizinga-Heringa, J. (2007, November 19). *Planologische Kernbeslissing Nota Mobiliteit. Spoor: vervoer- en beheerplan.* Retreived May 6, 2011, from https://zoek.officielebekendmakingen.nl/kst-29644-85.pdf.

European Climate Foundation (2010a). *ROADMAP 2050 A practical guide to a prosperous, low-carbon Europe.Technical Analysis Executive Summary*. Retrieved May 5, 2011, from http://www.roadmap2050.eu/attachments/files/Volume1_ExecutiveSummary.pdf.

European Climate Foundation (2010b). *ROADMAP 2050 A practical guide to a prosperous, low-carbon Europe. Policy Recommendations*. Retrieved May 5, 2011, from http://www.roadmap2050.eu/attachments/files/Volume2_Policy.pdf.

European Commission (2011). *WORLD ENERGY TECHNOLOGY OUTLOOK 2050 (WETO-H2)*. Luxembourg: Office for Official Publications of the European Communities.

European Parliament. (2010, November 25). *Climate: EU should move to 30% emissions reduction target, say MEPs.* Retrieved May 4, 2011, from Press service of the European Parliament: http://www.europarl.europa.eu/en/pressroom/content/20101125IPR00549/html/Climate-EU-should-move-to-30-emissions-reduction-target-say-MEPs.

Europese Commissie (2011a). *Europese Commissie.* Retrieved February 1, 2011, from http://ec.europa.eu/index_nl.htm.

Europese Commissie (2011b). *Begeleidend document bij de mededeling van de Commissie aan het Europese Parlement, De Raad, het Europees Economisch en Sociaal Comité en Comité van de Regio's. Routekaart naar een concurrerende koolstofarme economie in 2050.* Retrieved May 6, 2011, from http://ec.europa.eu/clima/documentation/roadmap/docs/sec_2011_289_nl.pdf.

Europese Commissie (2011c). *Mededeling van de Commissie aan het Europese Parlement, De Raad, het Europees Economisch en Sociaal Comité en Comité van de Regio's. Routekaart naar een concurrerende koolstofarme economie in 2050.* Retrieved May 7, 2011, from http://ec.europa.eu/clima/documentation/roadmap/docs/com_2011_112_nl.pdf.

Eurostat (2010a). *Eurostat regional yearbook 2010.* Retrieved March 22, 2011, from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-HA-10-001/EN/KS-HA-10-001-EN.PDF.

Eurostat (2010b). *Energy, transport and environment indicators.* Retrieved March 22, 2011, from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DK-10-001/EN/KS-DK-10-001-EN.PDF.

Financieel Dagblad (2011, March 16). Olieprijs sluit hoger. Retrieved March 16,2011, from http://www.fd.nl/artikel/21488682/olieprijs-sluit-hoger.

Fischer, R. (2004). *Het spoor naar een duurzame samenleving. Een onderzoek naar de knelpunten in de spoorsector die een transitie naar een duurzame mobiliteit belemmeren*. Retrieved January 5, 2011, from http://www.infrasite.nl/images/railpedia/attachments/80282671/80445490.pdf.

Harms, L., Olde Kalter, M.-J. & Jorritsma, P. (2010). *Krimp en Mobiliteit. Gevolgen van demografische veranderingen voor mobiliteit.* Retrieved May 9, 2011, from http://ikregeer.nl/document/blg-64361.

Hupkes, G. (1977). *Gasgeven of afremmen. Toekomstscenario's voor ons vervoerssysteem.* Deventer: Kluwer.

Inspectie Verkeer en Waterstaat (2011a). Europees en international. Retrieved January 27, 2011, from http://www.ivw.nl/onderwerpen/rail/spoorwegen/wet_en_regelgeving/europees_en_internationaal/.

Inspectie Verkeer en Waterstaat (2011b). Organisatie. Retrieved January 26, 2011, from http://www.ivw.nl/organisatie/.

Karaçali, E. (2007). *Het spoor van verwachting. De zoektocht naar verwachtingen van het tractie-energievoorziening systeem.* Retrieved January 5, 2011, from http://www.uu.nl/uupublish/content/Karaali_Ekrem_eindverslag.pdf.

Lejour, A. (2003). *Quantifying Four Scenarios for Europe.* The Hague: Centraal Plan Bureau.

Magnien, A., Lis, S., & Tavola, G. (2008). *Trans-European conventional rail system. Subsystem energy.* Retrieved January 26, 2011, from http://www.era.europa.eu/Document-Register/Documents/IU-ENE-Final%20Report%20on%20ENE%20TSI%20081219-1.pdf.

Ministerie van Financiën (2011, September 21). *Samenvatting Miljoenennota 2011*. Retrieved March 16, 2011, from http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/publicaties-pb51/samenvatting-miljoenennota-2011/09po2010g204.pdf.

Ministerie van Verkeer en Waterstaat (2007). *Landelijke Markt- en Capaciteitanalyse Spoor*. Retrieved May 6, 2011, from http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/rapporten/2007/11/19/eindrapport-landelijke-markt-en-capaciteitsanalyse-spoor/landelijke-markt-en-capaciteitsanalyse-spoor.pdf.

Ministerie van Verkeer en Waterstaat (2009). *Programma Hoogfrequent Spoorvervoer: Plan van Aanpak tot projectbesluiten in juni 2010*. Retrieved November 26, 2010, from http://www.gelderlander.nl/multimedia/archive/01574/Download_het__Prog_1574448a.pdf.

Ministerie van Verkeer en Waterstaat (2011). *MIRT Projectenboek 2011. Priotaire opgaven*. Retrieved May 6, 2011, from http://mirt2011.mirtprojectenboek.nl/mirt_2011/1_nationaal/prioritaire_opgaven/.

Ministerie van Verkeer en Waterstaat, & VROM (2004). *Nota Mobiliteit. Naar een betrouwbare en voorspelbare bereikbaarheid.* Retrieved March 16, 2011, from http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/notas/2004/09/25/nota-mobiliteit/notamobiliteit-compleet.pdf.

Mohajerani, K. (2003). *Haalbaarheidsonderzoek: Het verhogen van de tractiespanning van 1500 VDC naar 3000 VDC.* Utrecht: Strukton Railinfra Development & Technology B.V.

Movares (2009). *Investeringsanalyse Business Case 3000V DC*. Utrecht: Movares.

Movares (2010). *Business Case 3000 Volt op de bovenleiding. Hoogwaardig openbaarvervoer* énenergiebesparing!. Utrecht: Movares.

Nederlandse Spoorwegen (2011). *Over NS*. Retrieved January 31, 2011, from http://ns.nl/cs/Satellite/over-ns.

NedTrain Consulting (2004). *Haalbaarheid van 3kV tractie-energievoorziening op het NS-net*. Utrecht: NedTrain Consulting B.V.

NS (2010). *Jaarverslag 2010.* Retrieved April 30, 2011, from http://www.ns.nl/binaries/content/assets/NS/over-ns/jaarverslag-2010/928_274_ns_jaarverslag_2010.pdf.

NS & ProRail (2006). *NETWERKANALYSE SPOOR. Markt- en capaciteitsanalyse van de rol van de trein in de mobiliteit van Nederland.* Retrieved May 6, 2011, from www.rijksoverheid.nl/...netwerkanalyse-spoor/netwerkanalyse-spoor.pdf.

NS, ProRail, Railion, & Ministerie van Verkeer en Waterstaat (2003). *Benutten en bouwen. Het plan van de spoorsector.* Retrieved March 22, 2011 from http://www.fnvspoor.nl/index.php/downloads/finish/7/23.

Peijs, K (2005, October 18). *Motie Slob cs. (29800 XII, nr. 31).* Retreived March 17, 2011, from http://www.rijksoverheid.nl/bestanden/documenten-en-

publicaties/kamerstukken/2005/10/18/motie-slob-cs-29800-xii-nr-31/motie-slob-cs-29800-xii-nr-31-www-verkeerenwaterstaat-nl-cend-bsg-brieven-data-1129640294.pdf.
Planbureau voor de Leefomgeving (2011, March 31). *Sterke daling beroepsbevolking verwacht in grote delen van Europa.* Retrieved March 5, 2011, from http://www.pbl.nl/publications/2011/sterke-daling-beroepsbevolking-verwacht-in-grote-delen-van-europa.
ProRail (2011). *Wettelijk kader*. Retrieved March 21, 2011, from http://www.prorail.nl/Vervoerders/Wettelijk%20kader/Pages/default.aspx.
ProRail Projectteam Hanzelijn (2003). *Tracébesluit Hanzelijn. Algemene Toelichting. Bepalingen.* Retrieved February 2, 2011, from http://www.prorail.nl/SiteCollectionDocuments/Publiek/Doc/Projecten/Hanzelijn/1_tracebesluit.pdf.
ProRail, Nederlandse Spoorwegen, & Belangenvereniging rail goederenvervoerders (2008). *Ruimte op de Rails.* Retrieved January 4, 2011, from http://www.prorail.nl/ruimteopderails/Documents/ruimteopderails_opgemaakt.pdf.
Raganato, P. (2010). *Measures in rail transport.* Retrieved May 6, 2011, from http://www.ghg-transpord.eu/ghg-transpord/downloads/WP6-workshop1/reduction-mesures-road-rail/road-technologies/18_TRT_RaganatoP_Rail_Measures.pdf.
Railway Mobility (2011). *Check your CO^2 emissions.* Retrieved January 4, 2011, from http://www.railway-mobility.org/links.html.

Recagno, V. (2010). *Railenergy Project.* Retrieved May 6, 2011, from http://www.ghg-transpord.eu/ghg-transpord/downloads/WP6-workshop1/reduction-mesures-road-rail/road-technologies/20_Stakeholder_RecagnoV_RailEnergy_Project_Potentaisl.pdf.
Regus (2009, October). *Regus Business Tracker 1*. Retrieved May 5, 2011, from http://www.regus.com/futureofwork.
Rijksoverheid (2009). *Economische visie op de langetermijnontwikkeling van Mainport Rotterdam. Op weg naar een Mainport Netwerk Nederland.* Retrieved May 8, 2011, from http://www.rijksoverheid.nl/bestanden/documenten-en-publicaties/rapporten/2009/06/01/economische-visie-op-de-langetermijnontwikkeling-van-mainport-rotterdam-op-weg-naar-een-mainport-netwerk-nederland/economische-visie-ontwikkeling-mainport-rotterdam.pdf.
Rijksoverheid (2011a). *Concessies voor vervoer en beheer.* Retrieved January 31, 2011, from http://www.rijksoverheid.nl/onderwerpen/spoorvervoer/wie-doet-wat-op-het-spoor/concessies-voor-vervoer-en-beheer.
Rijksoverheid (2011b). *Groei op het spoor*. Retrieved January 31, 2011, from http://www.rijksoverheid.nl/onderwerpen/spoorvervoer/groei-op-het-spoor.
Rijksoverheid (2011c). *Wie doet wat op het spoor.* Retrieved January 31, 2011, from http://www.rijksoverheid.nl/onderwerpen/spoorvervoer/wie-doet-wat-op-het-spoor.
Rijksoverheid (2011d). *Ministerie van Infrastructuur en Milieu.* Retrieved March 16, 2011, from http://www.rijksoverheid.nl/ministeries/ienm.
Smokers, R. T. M., Boer, L.C. den, & Faber, J.F. (2007, July). *State-of-the-Art CO_2 en Mobiliteit.* Delft: CE Delft.
UIC, & CER (2008). *Rail Transport & Environment. Facts and Figures.* Retrieved November 26, 2010, from http://www.uic.org/homepage/railways&environment_facts&figures.pdf.
Union Internationale des Chemins de fer (2011a). *Sustainable mobility.* Retrieved January 4, 2011, from http://www.uic.org/spip.php?article1543.

Union Internationale des Chemins de fer (2011b). *Welcome to the Website for Energy Efficiency Technologies for Railways.* Retrieved January 4, 2011, from http://www.railway-energy.org/tfee/index.php.

Wee, B. van, Rietveld, P., Meurs, H. (2006). Is average daily travel time expenditure constant? In search of explanations for an increase in average travel time. *Journal of Transport Geography*, 109-122.

Wesdorp, J. (2010). *Eindrapportage PHS capaciteitsanalyse*. Retrieved January 4, 2011, from www.rijksoverheid.nl/.../2010/...programma-hoogfrequent-spoor.../6bc4e392-a7d1-423a-990e-00f89bcf5ad4.pdf.