Infrastructure Network Robustness and Adaptation

Work package leader: dr.ir. G.P.J. Dijkema

Content

1 Description work package

1.1 Problem definition, aim and central research questions

Problem definition

The electricity grid, ICT, transport and water networks may cease proper operation due to extreme weather and subsequent cascading failures. Due to climate change, the frequency and intensity of rain showers and (thunder)storms already is on the increase. Also in the Netherlands, local events have been disruptive to the operation of transport and electricity networks because single failures may quickly propagate and lead to system breakdown, which leads to high costs and unacceptable risks.

In this century, the average air, surface and water temperatures will increase, with more extreme temperatures in the summer. This may slowly wreck havoc on our infrastructures – sub-surface conditions will change and impact (rail)-roads, pipelines and the electricity grid. Precipitation patterns will change, so while summer electric power demand may increase (air-conditioners, refrigerators), power availability may be greatly reduced because of cooling-water restrictions and lack-of-wind. Sailing the rivers in dry summers may become impossible, with dire consequences on transit freight transport from our mainports to the European hinterland.

We have limited understanding on where and how extreme events or single-failures may escalate to severe infrastructure system deterioration or even breakdown. We simply do not know whether our infrastructure networks are robust to climate change and where and how to adapt and ameliorate them to make them resilient. These unknowns complicate development of infrastructure regulation that stipulates timely adaptation.

Central research questions

Therefore, the central research questions addressed in this work package are 1) “what are the sensitivities of transport, ICT and energy infrastructure to climate change; how may climate change affect infrastructure robustness (system integrity, operation, safety, reliability etc.)” 2) “what asset management and design of infrastructure networks provide short term robustness and long-term resilience to climate change,” and 3) “under what (policy, regulatory) conditions and incentives may such systems emerge.”

Aim and scope

Adopting a socio-technical perspective (Dijkema and Basson, 2009), the impact assessment of climate change (WP1 and WP2) will be used to develop network models to analyze and design network robustness and test short-term adaptation strategies for the hotspots (Snelder, Tavasszy, Immers, vZuylen 2008). Quantitative Agent-Based models (ABM) will be developed to simulate the infrastructure development over 50 years. Therein infrastructure assets are modeled as technical objects; the stakeholders are represented by social agents (Nikolić et al. 2009). The networks grown will be assessed for resilience to network failure using a failure mode propagation model (Nikolić, 2009). Building on asset management and risk knowledge, it will be explored how we can incorporate robustness and resilience to climate change into the (re)design of our (physical) infrastructures while maintaining the reliability and quality of operation of current infrastructure (Herder et al., 2008). The ABM's can then be used to explore the combined effect of policy, strategy, innovation and climate change and to test institutional arrangements and possible transition strategies towards climate change (Chappin et al., 2009, 2010).

1.2 Interdisciplinarity and coherence between the projects

A socio-technical system approach ensures the interdisciplinarity and coherence between the projects. The operation and evolution of the technical system, physical infrastructure, however involves decision-making by the actors involved – the social network. Each of the projects involve these technical and social network aspects, bringing together technology, system design and human decision-making.

More specifically, *project 2* focuses on modeling day-to-day operation and network failure – what external conditions and events will cause a physical infrastructure link to fail; how to model the consequence and determine when this propagates to network failure, and what measures will increase robustness? In *project 3* agent-based models of long-term infrastructure network evolution will be augmented to include climate risks – both on the physical infrastructure as on the decision-making. These models can already represent physical networks, their operation, ecologic and economic characteristics and the decision-making by various stakeholders involved in investments, strategy and policy. *Project 4* addresses robustness and resilience by ensuring infrastructure component and system integrity through asset management. Where, when and how to incorporate adaptation to climate change in deciding on maintenance, replacement, or renewal of the assets that make-up the system?

Project 1, finally, brings insights and models from project 2, 3 and 4 together to derive design principles for more climate proof infrastructure and networks.

1.3 Stakeholders

In this work package active involvement of the stakeholders is foreseen, both as "clients" and as "decision-makers", whose perceptions, behavior, management will be modeled. Thus, each and every stakeholder may eventually be allowed "to play around" with our models to see how her decisions affect the overall robustness and resilience of the infrastructure networks.

Stakeholders involved /addressed include the network operators (Gasunie, TenneT, Enexis etc.), electric power producers, Regional Development Authorities (Havenbedrijven), Rijkswaterstaat, Min. V&W and Min. EZ.

2 Project 3.1 Towards Design principles and development of climate proof infrastructure and networks

Project leader: dr.ir. Gerard P.J. Dijkema / prof.dr. L. Tavasszy

2.1 Problem definition, aim and central research questions

Problem definition

Climate change may lead to extreme events and slow but steady change of the conditions wherein infrastructures must continue to function:

- The electricity grid, ICT, transport and water networks may cease proper operation due to extreme weather and subsequent cascading failure of interconnected systems (electricity → ICT → road transport; electricity → ICT and gas transport etc.).
- Slowly increasing average air, surface and water temperatures may slowly wreck havoc on our infrastructures – sub-surface conditions will change and impact (rail)-roads, pipelines and the electricity grid. Electric power availability may be greatly reduced because of cooling-water restrictions and lack-of-wind.
- While disruptive events or degraded operation may be the initial consequence of climate change, in many a case deteriorated operation of infrastructure instigates user responses that collectively may lead to crisis or system collapse.

Road networks in urbanized areas, for example, are vulnerable for disturbances like incidents and rain. A small incident may cause congestion that cascades to many roads, a systemic congestion that takes hours to dissolve. Extreme weather reduces road capacity and congestion in peak hours. When tunnels are flooded, system breakdown may be complete.

We continuously adapt and extend our transport and energy infrastructure systems. Must we prevent such scenarios to unfold by design and management of infrastructure systems that anticipates undesired situations and prevents cascading and system breakdown?

We can only begin to address these questions, because of the lack-of-knowledge on these issues:

- We do not have a complete picture of what consequences of climate change will affect infrastructures, in what way and to what extent.
- We have limited understanding on where and how extreme events or single-failures may escalate to severe system deterioration or even breakdown.
- We simply do not know whether our infrastructure networks are robust to climate change and where.
- The development of suitable network failure mode models only has recently begun (e.g. Nikolić, 2009).
- To combine representation of infrastructure operation and long-term evolution into meaningful models presents formidable research challenges (Lukszo and Dijkema, 2009)

- While design guidelines or principles for making robust infrastructure elements do exist – e.g. solid dikes, heat-resistant road surfaces) – design principles for resilient infrastructure systems if not networks are largely lacking.
- Although there must be experience with practitioners, formalized knowledge on “no-regret” decision-making in the continued development of infrastructures is lacking.
- The body-of-knowledge on asset management for infrastructures is relatively small; formalized knowledge in asset management anticipating climate change effects is largely lacking

Aim and scope

The aim of this project therefore is to bring together knowledge on climate-change-robust infrastructure development and design and to develop a coherent framework for understanding and modeling infrastructure adaptation to climate change. Therein the focus is on the design and management of infrastructure systems and networks.

This project aims to develop network models to analyze and design network robustness and test adaptation strategies for the hotspots. The project will address at least two cases: one on a road transport network around a hotspot and one on energy infrastructure, while in both cases ICT infrastructure will be addressed. The specific case scope definition will be aligned with the work done in WP2 and WP4.

Central research questions

The central research questions addressed in this work package and project are 1) “what are the sensitivities of transport, ICT and energy infrastructure to climate change; how may climate change affect infrastructure robustness (system integrity, operation, safety, reliability etc.)” 2) “what management and design of infrastructure networks provide short term robustness and long-term resilience to climate change,” and 3) “under what (policy, regulatory) conditions and incentives may such systems emerge.”

2.2 Approach and methodology

This project is setup as a synthesis project. To address the three central questions, a systemic, integrative and connecting framework will be developed for the analysis, understanding and modeling of infrastructure network adaptation to climate change. To this end, a socio-technical systems perspective will be adopted and adhered to.

Integrating and the projects in WP3

Adopting a socio-technical systems perspective, in the project the impact assessment of climate change the insights and results from (WP1 and WP2) will be used as a starting point for the analysis and development of network models to analyze and design network robustness and test short-term adaptation strategies for the hotspots (Snelder, Tavasszy, Immers, vZuylen 2008). An inventory and comparison of suitable modeling approaches will be made, and it will be explored where combination of modeling approaches is worthwhile and feasible.

Approach to foster integration between projects 1-4

The project will be executed in three steps each consisting of: analysis, framework development, modeling and simulation and formulating of design principles and policy advice. In each step, the topic of study and aim will be the development of a robust transport network viz. energy network for one of the hotspots.

- In the first step, the objectives are to get an overall, integrative overview of the “state-of-the-art” on the three research questions; to identify and define suitable case studies and the scope and objectives of WP3 projects in interaction with the stakeholders and hotspots. An initial setup for the framework, modeling and simulation will be compiled to explore directions for robust network design and facilitate the case studies.
- The second step builds upon the available body-of-knowledge. Using case study results and interacting with projects 2-4, we will develop a program of requirements for the models and formulate a first set of design guidelines for climate-robust infrastructure development.
- In the third step, the project results will be used to test and ameliorate the framework, to compare modeling approaches and to derive infrastructure design principles for adaptation to climate change.

Literature review on the effects of climate changes in relation to energy infrastructure and transport networks.

A literature review will be carried out in order to determine how climate changes affect the occurrence and severity of disruptions on energy and transport networks.

Social process to create shared and formalized vocabulary

The project will network the stakeholders and researchers and involve them in a socially inclusive System Decomposition Method (Nikolić 2009). This process will yield a shared vocabulary and a formal ontology of the system elements, their operation and possible failure modes of diverse infrastructure systems, together with a formal description of extreme climate events and their possible impacts.

Connecting models

Using the shared ontology it will be investigated whether the physical network models, the agent-based models and network failure models can be connected.

Complex, Large-Scale Socio-Technical Systems (adapted from Dijkema and Basson, 2009)

Infrastructures can be viewed as dynamic socio-technical systems that interact with a continuously changing world. The technical networks for transport, for example, consists of hubs (airports, ports, train stations and their facilities), links (air and sea lanes, canals, railroads and roads) and objects that move on them (airplanes, ships, trains and vehicles). The owners, operators, users, consumers and governments together form a social network that develops, operates and maintains the technical network. In the social network policies and strategies are developed and employed, regulations and operating practice develop and existing assets or new investments are decided upon. Together form an interconnected complex network.”

This complex, large-scale socio-technical systems perspective will be used as the foundation of our analysis, modelling framework and enables us to link systems design, technology, policy and management.

2.3 Scientific deliverables and results

The main scientific deliverables are a systemic framework if not theory on the analysis, understanding and modeling of infrastructure network adaptation to climate change built on a shared ontology linked to infrastructure design and management principles.

The two case studies will deliver a description of current state of particular infrastructure systems, a model-based assessment of their vulnerabilities and options to increase robustness against extreme climate events and resilience against slow degradation.

The work will yield working papers, reports, conference and journal papers, workshops and conference sessions

2.4 Integration of general research questions with hotspot-specific questions

The approach and system decomposition methodology are particularly suited to involve relevant stakeholders in all phases of the project, to define and delineate case studies, and to develop a shared understanding, vocabulary and prioritization of issues. Thus, not only will hotspot questions be articulated, but also be explored and described such that models and simulations can be developed to explore the sensitivities of transport, ICT and energy infrastructure to climate change. Wherever possible, tests will be defined to explore “under what (policy, regulatory) conditions and incentives such systems may emerge.

2.5 Societal deliverables and results

The aim and scope of this project and WP is to bring together knowledge on climate-change-robust infrastructure development and design and to develop a coherent framework for understanding and modeling infrastructure adaptation to climate change.

Addressing the central research questions provides highly relevant deliverables and results on the effects of climate change on infrastructures, how to anticipate these effects by design and by exploring policy and regulation to make the required changes happen. Specific outcomes include involvement of a network of stakeholders, a shared understanding and vocabulary (ontology), a wiki, models and databases and general awareness on the vulnerability of our infrastructure systems.

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3 Project 3.2 Modeling infrastructure robustness and network failure – assessing climate risks

Project leader: dr.ir. I. Nikolic

3.1 Problem definition, aim and central research questions

Problem definition

Climate change induces a gradual process of infrastructure deterioration and induces extreme weather, which jeopardize infrastructure operation. Deterioration ultimately lets infrastructure links or hubs fail at higher than expected frequency.

Adapting to climate change to ensure acceptable operation and maintaining the function of our transport and energy networks therefore requires us to anticipate and deal with extreme weather events and physical infrastructure failures.

But how to reliably identify failure prone network components and assess the consequences of their failure? How to determine network capacity and operation under extreme weather conditions, how to determine what happens if components fail? And what options do we have or must we develop, and how to select between them to make infrastructure networks more robust and let them continue to operate them under stress at what capacity? What links and hubs should be redesigned, duplicated, expanded etc.?

Aims and scope

1. We need to identify the parts of existing infrastructures that are most sensitive to these severe climate events, in order to focus our attention and energy into securing them in advance. Identification must be done at a component level of these infrastructures, taking onto consideration local geographical and climate conditions.
2. Once we understand the current state of the network, we need to explore the likely development scenarios, and evaluate how these developments will perform under (worsening) stress. We need to understand how learning that results from operation and adaptation of these infrastructures at the local level can be used to evolve more robust system overall.
3. Many measures (related to network design, infrastructure design, information provision, routing and route guidance, incident management etc.) can be taken to make road and energy networks more resistant against disturbances. In this project, apart from road or power plant design, we address the network design question – which network structures provide additional robustness and resilience against single or multiple node or hub failures?

Central research question

The central research questions addressed in this project therefore are 1) is how road and energy networks can be made more robust against the effects of climate changes.

1. What are currently the most vulnerable components of transport and energy networks with respect to failure caused by extreme climate events?

2. Given the models of network evolution, described in project 3, how can we model systematic climate events driven network failure over time, taking learning by stakeholders and improved network design into consideration?

3.2 Approach and methodology

Modeling socio-technical networks

The focus will be on developing and using suitable network models: models that incorporate sufficient content and offer sufficient resolution, while being computationally feasible. We will start by inventorying suitable technical and social network modeling paradigms, platforms and implementations. Existing models will be assessed whether they offer required functionality – e.g. do they adequately simulate traffic conditions in case of disturbances.

Currently such models are largely lacking. In transport research, there exist some dynamic traffic assignment models that can be used to determine the effects of incidents. However, direct impact modeling and cascading failure caused by short-term disturbances like rain, snow and changes in demand need to be improved. Models of electricity grids also exist, but models that predict how failure modes propagate in electric networks are currently at the frontier of international research.

Simulate the effects of climate change on socio-technical networks.

We anticipate to build on both the work on “generic” network failure models and domain specific models, e.g. for transport or energy grids. Can the functionality of both types be incorporated in a single model, e.g. by refining network failure models by including or linking to technical and social specific models?

What we are aiming is to explicitly link climate models with models of infrastructure operation and models of infrastructure evolution. We will examine these systems as they are disturbed and account for learning during the simulated process of adaption to climate change. This learning occurs fastest at the operational level, as decision makers learn to operate the networks under stressed conditions. We will examine how this learning percolates towards higher system level learning, where the entire social network learns how to cope with climate-induced infrastructure disturbance.

Case studies

The work will involve two case studies, one on a relevant transport network and one on a relevant energy network (see description in Project 1, Approach and Methodology.

Concepts and data

Data will be collected about disturbances and their effects on the road (expressed in travel time, queue length, flows, speeds etc.) viz. electric power lines (power transmission, phase shift, modulation etc.). The collected data form a base for creating and calibrating an Agent Based Model, built on the infrastructure ontology and ABM simulation engine (described in Project 3). Seeded with a representation of an existing network (transport viz. energy), eventually the model enables simulation of the coupled infrastructure systems as a network, situated in a spatially explicit world, experiencing extreme climate events, as the network slowly evolves over time.

Network failure

Using the model we will systematically examine the effects that node or edge failure occurring as a result of extreme climate events propagates through the network, and how it affects other systems. The model will consider learning of stakeholders that operate the failed nodes and edges and incorporate this learning into the future evolution of these systems. This way, we can explore the full design space of infrastructures as they evolve over time while constantly being affected by and responding and adapting to extreme climate events.

This information in combination with the behavioral effects found literature in case of disturbances will be used to expand or construct suitable models to simulate non-regular situations. Therein, attention will be given to structural validation and verification of the models, and where possible the models or parts thereof will be calibrated.

Indicate measures to make the networks more robust

Since a few years, road and energy network robustness received a lot of attention. While several types of measures have been identified by which these networks can be made more robust, these measures have been developed to adapt to all kinds of disturbances, not specifically climate change related disturbances. Furthermore, many measures focus on long term network design, whereas also short term measures like dynamic traffic/load management and incident management are good options.

Using the data, simulation results and expertise, climate-specific measures will be explored that can be used by the hotspots either short term or long term. Therein, intense discussion and use of results from WP4 is foreseen to arrive at a first cost-benefit analysis of measures.

3.3 Scientific deliverables and results

Scientific deliverables consist of a :

1. Formal ontology of infrastructure systems, their operation and climate event effects.
2. Description of the current state of the infrastructure systems and their most vulnerable parts
3. Models and simulations of the networks response to extreme climate events.
4. Provide insights into learning and adaptation at the operational level that can be incorporated in Project 1, 3 and 4
5. Overview of measures with a indication of cost and benefits (in conjunction with WP4)
6. Design and management principles

The scientific deliverables consists of papers and reports and participation in conferences.

3.4 Integration of general research questions with hotspot-specific questions

Integration of this project will be through project 1 (synthesis) of WP3, by using information and knowledge generated from the other work packages and projects and by working on the two case studies:

- The effects of climate changes on the performance of energy and transport physical infrastructure links (WP2)

- Measures that can be taken to reduce the local effects of those disturbances on the functioning and performance of these infrastructures (WP2)
- The direct and indirect costs and benefits of those measures? (WP4)

3.5 Societal deliverables and results

The models developed focus on transport and energy networks and eventually will help addressing questions such as:

- What are the effects of climate changes on the performance of energy and transport infrastructure network
- How can the cascading if not disruptive effects of climate change related disturbances in infrastructure networks be determined with models?
- Where on which location in the network can what measure best be taken?
- When should measures be taken?
- Is it possible to point out critical infrastructure links (roads, power lines) or hubs (ports, switching stations) that should maintain their function under (almost) all circumstances?
- What is the level at which a road network or energy network should function under different circumstances? Or, in other words, how robust should these networks be against the effects of climate change?

Other relevant outcomes are a network of stakeholders, interacting and haring knowledge about the system, its operation and its potential failures and a wiki / databases / website where the model results. These help to promote the insights and incite a public debate on the vulnerability of our infrastructure systems.

For one of the hotspots a robust network design will be made. This is a combination of network design and traffic/incident management. The strategy can also be applied to other regions. This will result in less unexpected travel time losses and a better accessibility of locations in emergency situations.

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4 Project 3.3 Agend-Based Modeling of long-term development of transport and energy infrastructure networks

Project leader: dr.ir. Gerard P.J. Dijkema

4.1 Problem definition, aim and central research questions

Problem definition

In our industrial society, transport and energy infrastructures each are large-scale systems, networks comprised of hubs and links. Over time, these systems have become interconnected. The network structure, scale and scope of infrastructures evolve over decades – an evolutionary process of shaping the network through a series of decisions by a variety of actors that respond to their external world, which comprises the physical and societal environment.

While no single actor has authority or span of control over the entire system, the social network of actors that shape these systems is subject to policy, regulatory regimes, market conditions and culture. Most actors would prefer 'resilient' systems, or at least their system to be resilient – the infrastructure network should have the capacity to respond to and recover from (extreme) external stress. Only the government may assume responsibility for infrastructure system resiliency at large, however.

Climate change represents a modified if not changed environmental driver or stressor to infrastructure systems. While making each and every component robust to climate change and its effects is an obvious adaptation strategy, there exist also possibilities for creating system robustness by growing resilient network structures.

If we identify government policy and company strategy as the main handles to anticipate and adapt to climate change in infrastructure design, a new problem results: how to determine ex-ante which (combination of) policy and strategy results in resilient infrastructure networks? Or, in other words, the problem addressed in this project is: ‘how to provide quantitative model-based assessment of infrastructure climate adaptation policy with respect to infrastructure system resilience’.

Aim
The aim of this project is to develop agent-based models that enable exploring the effect of climate change and adaptation by simulation of the long-term development of transport and energy infrastructure networks subject to a variety of scenarios.

Central research questions
While we know we can construct agent-based models of infrastructure evolution (Nikolic, 2009; Chappin et al. 2009), it remains unknown whether these provide sufficient resolution and reliability to represent the effect of climate change. In addition, it is unknown how to suitably represent the behavior of actors and link these to climate change behavior. Furthermore, we need a suitable representation of adaptation strategies to allow the comparative simulation.

These will be the central questions addressed: we will elucidate the dominant factors that shape infrastructure networks, how climate change as a stressor relates to these and develop an approach to explore the possible effect adaptation strategy.

4.2 Approach and methodology

Approach
Each infrastructure system can be viewed as a dynamic socio-technical system that lives in a continuously changing world (Dijkema and Basson, 2009). The technical network and the actors and bodies of rules that are involved – the social network – together form an interconnected complex network. Infrastructure also must be considered complex, layered and dynamic systems that interact with their environment. Much like natural ecosystems, this socio-technical system can be seen to constantly evolve because individuals, organizations and governments decide on, for example, development, restructuring, demolition, (dis)investment, prefer certain transport modalities over others, strive for CO_2 reduction or sustainability etc.

A plethora of decisions is made in response to and in interaction with the system's environments, and with time the infrastructure evolves and complex structures emerge that are characterized by diversity, multiple interactions both within and between layers, feedback loops and emergence – all characteristics that lead us to consider them as "complex".

Methodology: Evolutionary, Agent-Based Models

We use Agent-Based modelling, as according to Axelrod, "the simulation of an agent-based model is often the only viable way to study populations of agents who are adaptive rather than fully rational." We need a modeling paradigm where we can model technical objects, social actors and there interaction: Agent-Based Modeling.

An agent has been defined as "an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives." Jennings (2000).

In Agent-Based Models of socio-technical systems, agents are reactive, proactive, autonomous software entities that represent actors, technologies or combinations thereof. These agents exist in an external world. Depending on their state, inputs received and decision rules or transformation rules, they will generate output – material, energy, information.

Agents interact by exchanging material or goods, energy or information – decisions – over interfaces. In our framework, both actors and technical objects are modeled as agents – the former employ decision rules, the latter are represented as input/output transformation or transfer functions. The simulation setup may include social agents that are born or die – organizations are setup and may go bankrupt, and that decide on the creation or decommissioning of technical facilities.

Agent Based Models thus may be set up to reflect the evolution of Socio-Technical Systems such as mainport-hinterland transport infrastructure. Therein, – as in natural ecosystems - , the agents must survive, interacting, competing, cooperating with other agents, subject to conditions imposed from an external world.

E&I Modular ABM Simulation Engine, Scenario approach and High Performance Computing

A main objective of the work is to quantitatively assess transition policy using simulation and modelling. As stated, this presents an enormous challenge, which is being addressed for some time in the context of the Next Generation Infrastructures subprogram Understanding Complex Networks (http://www.nginfra.nl).

The work of Nikolić et al. (2009) has resulted in a modular simulation engine, wherein evolutionary Agent-Based models can be implemented and executed. The engine currently includes Agent Modules of contract negotiation and bidding, (dis)investment decision in response to market developments, operational management and various "Agent-styles". The engine interfaces to a database of technical objects that are specified by input-output relations; in the simulation mass balances are correct and a prototype LCA module has been implemented to enable life-cycle CO_2 calculation (Davis et. al. 2009). Currently, the software represents a some 10 man years of coding

Apart from an increasing number of models that have been completed, the simulation engine has been used to explore large scenario-spaces – instead of completing simulations for a few scenarios, relevant future developments are mathematically presented and parameterized. A scenario is thus a set of parameters passed to the simulation. The scenario-space that thus results can be sampled using a variety of techniques to return a number of samples that can be computed in time.

Recently, a High Performance Computing Facility has been acquired by TPM to allow rapid completion of large-number of simulation runs. This enables completion of very large-numbers of scenario's (e.g. Chappin and Dijkema, 2009) and extensive, rigorous study of possible energy transitions.

4.3 Scientific deliverables and results

This project will advance our knowledge and on the (im)possibilities of long-term infrastructure network evolution.

The past decade, complex systems theory, network theory and associated modeling paradigms (multi-agent systems, agent-based modeling, physical networks, social networks) have become a rapid expanding if not exploding fields. Work on *applications*, modeling large-scale systems such as infrastructures, as complex socio-technical systems is fairly limited to date (cf. Nikolic, 2009; Dijkema and Basson 2009 and papers cited therein from the Special Issue on Complexity and Industrial Ecology). Knowledge, applications and real case studies where the simulation of technical and social network co-evolution is combined are sparse.

Only one of the unknowns is whether simulation of long-term evolution can provide sufficient resolution and reliability to represent the effect of climate change. This, for example would require combining models of evolution – spanning decades - with models of operation – providing resolution at or below the timescale of hours or possibly minutes (Lukszo and Dijkema, 2009). Another issue is how to suitably represent the behavior of actors and their response to extreme events, infrastructure failure etc. to enable socio-technical systems modeling of infrastructure evolution.

4.4 Integration of general research questions with hotspot-specific questions

Integration will be through project WP3-1 (synthesis) and by using information and knowledge generated from the other work packages and by working on the transport and energy case studies. The project will take in:

- The effects of climate changes on the performance of energy and transport physical infrastructure links (WP2)
- Measures that can be taken to reduce the local effects of those disturbances on the functioning and performance of these infrastructures (WP2)
- The direct and indirect costs and benefits of those measures? (WP4)

- The project will bring to the other projects and WP's:
- The dominant factors that shape infrastructure networks, how climate change as a stressor relates to these and develop an approach to explore the possible effect adaptation strategy.
- Interfacing with projects 1, 2 and 4, the setup will allow for inclusion of insights from the network failure models and asset management considerations.

4.5 Societal deliverables and results

Models to visualize potential long-term evolution of transport and energy networks will be developed. These will allow us to explore a variety of scenario's, which may span behavior of infrastructure users, investors, companies; different types and severity of gradual and extreme climate change effects, different robustness and quality of individual infrastructure components etc.

Societal deliverables and results will be generated by defining the case study scope and model capabilities in interaction with the stakeholders (see also project 1, Approach and Methodology)

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5 Project 3.4 Asset management for adaptation to climate change

Project leader: dr.ir. P.M. Herder

5.1 Problem definition, aim and central research questions

Problem definition

Infrastructure systems are an assemblage of tangible (physical) and intangible (knowledge) assets that must be created maintained and renewed. With climate change imminent, preferably its effects should be anticipated in the management of the infrastructure assets – the asset management. Asset management is different from the day to day maintenance management, because its objective is to translate long-term goals into operational practice. Regarding climate change, this implies that the required changes in the future appearance of the infrastructures should incorporated presenting the management decisions taken today with regard to these infrastructures. This (re)design of our (physical) infrastructures needs to take place while maintaining the reliability and quality of operation of our current infrastructure (Herder et al., 2008)

Infrastructure assets are expensive and have a long life time. For example, one can not replace all copper telephone lines with fiberglass in a single year. First, this would be too costly. Second it would be impossible as the required workforce would not be available and third, one is confronted with many unknowns when deciding on interventions to adapt the physical appearance of infrastructures to adapt to climate change. For example: present and future costs of infrastructure adaptation are unknown, as are the risks for assets and of assets breaking down.

In long-term infrastructure asset management, preferably a life cycle perspective is used to at least allow some ‘no-regret’ decision-making, to determine life-cycle environmental impact, life-cycle cost, life-cycle performance and its robustness and possible adaptation to climate change.

The aim of this project

Asset management is a scientific (management) domain in development. Presently, it is both art and science. The aim of this project is to bring to the table asset managers expertise and questions related to climate change, its effect and possible responses. The objective is to improve our understanding of and somehow incorporate climate change adaptation into asset management, and develop first models to elucidate the drawbacks and benefits of such approaches.

Central research question

How can we incorporate the required robustness of our infrastructures regarding climate change into the asset management of our (physical) infrastructures?

5.2 Approach and methodology

Research Design

In order to answer this question we will combine and add to two theoretical bodies of knowledge that address this issue.

Recently, scientific literature has reported successful efforts to integrate considerations from the operational stages into the design of complex socio-technical systems (Herder et al., 2008; Thissen and Herder, 2009). For example, the literature on Reliability, Availability and Maintainability Engineering (RAM) now delivers ways to integrate RAM performance criteria into the conceptual design stages of energy infrastructures (Goel, 2004; Ajah, 2009; Bauer and Herder, 2009). A challenge to this field thus is to translate these RAM models to useful models for infrastructure systems subject to climate change effects, while the exact nature nor magnitude or representation of these effects is yet unknown.

A second body of knowledge that we will drawn upon is the Asset Management body of knowledge. This discipline has evolved in recent years from down to earth maintenance management approaches to system-level approaches that consider the asset base as a coherent interacting system (Wijnia et al, 2008). Asset management researchers are developing approaches that address the quality of the portfolio of assets in stead of focusing on one asset's quality that would typically create suboptimal systems. Topical issues in asset management are the integration of other than economic criteria into the portfolios evaluation. Most importantly, it is considered a great challenge to incorporate sustainability, robustness and system resilience criteria into the asset management process (Wijnia, 2008). Second, there are crucial questions with regard to tradeoffs between keeping the current asset base in order versus investing in new assets in view of changing external circumstances.

Methodology

The project involves the following elements:

1. modeling the RAM characteristics of specific infrastructure networks
2. adapting contemporary RAM models to fit infrastructures in various domains
3. developing useful representation of climate change criteria for use in asset management processes
4. adapting asset management procedures to allow for risk based tradeoffs between 'maintenance' and 'robustness'
5. creating behavioral rules for agents that capture above RAM thinking in an asset management framework

Motivation and embedding

The project will combine RAM modeling and asset management strategies that would on the one hand help decision makers in practice to operate, maintain and design their assets, while on the other hand it would contribute to the scientific domain by supplying behavioral (investment and maintenance) rules for the agents in the ABM developed in project 2.

5.3 Scientific deliverables and results

Asset management has only recently emerged from practice as a scientific domain. This project will contribute to the development of a more solid scientific underpinning. Likewise, the consequences on infrastructure systems – both gradual deterioration and extreme events – are largely unknown.

To date few empirical RAM models for infrastructure systems exist that address or incorporate considerations on climate change related effects on system performance, integrity and reliability.

The project thus will deliver concepts, guidelines and first prototypes on how to deal with climate change effects in infrastructure asset management. First set of criteria and rules for risk based asset management procedures to adapt to climate change will be developed and where possible be underpinned by theory, literature, models and simulation.

5.4 Integration of general research questions with hotspot-specific questions

Integration of this project will be through project 1 (synthesis) of WP3, and by using information and knowledge generated from the other work packages and projects. The project will take in:

- The effects of climate changes on the performance of energy and transport physical infrastructure links (WP2)
- Technical measures that can be taken to reduce the local effects of those disturbances on the functioning and performance of these infrastructures (WP2)
- The direct and indirect costs and benefits of those measures? (WP4)
- The project will bring to the other projects and WP’s:
- How, where and when best to adapt and deploy asset management to adapt infrastructures to climate change
- What measures can be expected to deliver on reliability, availability and maintainability of infrastructure networks subject to climate change.
- Case study results on specific infrastructure networks relevant for the hotspots

5.5 Societal deliverables and results

The project aims to provide practical guidelines to decision makers in practice to operate maintain and design their assets, in view of climate change. It provides generic and useful RAM models for infrastructure decision makers. Finally it provides a 'climate-proof' risk-based asset management strategy, taking into account technical as well as organizational constraints.

The above will lead to more appropriate tradeoffs in design, construction and maintenance of infrastructures, which will at its turn lead to lower overall system life cycle cost.

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