Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

On infrastructure network design with agent-based modelling

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Abstract—We have developed an agent-based model to optimize green-field network design in an industrial area. We aim to capture some of the deep uncertainties surrounding infrastructure design by modelling it developing specific ant colony optimizations. Hence, we propose a variety of extensions to our existing work, first ideas on how to realize them and three cases to explicate our ideas. One case is the design of a CO2 pipeline network in Rotterdam industrial area. First simulation results have shown the relevance of the approach.

Keywords—Infrastructure design, network planning, ant colony optimization, deep uncertainty, socio-technical systems

I. Introduction

IN previous work, we have shown the applicability of agent-based modelling for optimization green-field network design in an industrial area [1]. Infrastructures enable suppliers and consumers of goods and services to connect [2]. Infrastructures develop over decades and network design is an activity under deep uncertainty. How 'good' the eventual design is depends on who pays the costs, who receives the revenues and how the risks are distributed [3]. In designing infrastructure networks, computer power is only used in a late phase, for drawing detailed layouts. At the point where computers come in, most of the decisions are already made. We see a huge potential for modelling in earlier phases, in which networks are designed from scratch or in which expansion or new connections are proposed.

We have already developed an agent-based model and a geometric graph method that enable designing good networks that can transport a commodity from one source to several sinks, in which the building costs depend to a large extent on the pipeline length (e.g. due to digging costs), but also on the pipeline capacities (e.g. due to materials costs). The networks are built in areas that pose limitations on the possible routing of pipelines due to existing buildings, obstacles like rivers or mountains, or zoning rules (e.g. protected natural areas). We formulated the simplified planning problem as an optimization problem with the objective to minimize the expected building cost, taking into account the various aspects and constraints of the system. For details see Heijnen et al. [1]. We have applied the agent-based model to CO_2 pipeline design in Rotterdam industrial area (see Illustration 1)

We argue that other uncertainties, e.g. in the participating actors in the network, on potential future expansion can be done with possible extensions to the agent-based model. In this abstract we aim to explore what extensions we will explore in the near future, by introducing a variety of cases.

II. Objectives and Approach

We aim to gain more insight in the consequences of fundamental uncertainties around planning investments in networked infrastructures. We conjecture that to some extent they may be covered with an ABM.

Important aspects are:

- Connecting multiple sources to multiple sinks
- Cost differentiation in networks on a variety of bases, such as for splitting and corners and related to the area.
- Time dependencies in and uncertainties of participating of actors
- Convertor stations that are nodes that enable conversion between different 'qualities'
- The multi-actor system, such as actors owning different parts of demand or supply side of the infrastructure, which has consequences for risks, negotiation, vested interests and cooperation.
- Decentralized and centralized production and consumption
- Larger variety in the relevant time scales (operation and investment)
- Uncertainties in developments upstream and downstream.
- Interactions between (existing and new) infrastructures
- Locational aspects, such as existing infrastructure, terrain.
- Political/juridical aspects, such as permitting.

We conjecture that agent-based models, possibly in combination to other paradigms, will help to explore each of these aspects in concrete cases, which we will describe in section III. We expect it can be done for instance by making the the agents (ants) more intelligent, taking into account more properties of the terrain. In addition, the nodes and nest can be made more intelligent, therewith guiding the ants to make better designs. In an optimization (such as an ant colony optimization) time is typically not represented at all: the tick that passes by is a form of iteration, but not time. Advancements are necessary to uncertainties in the system dynamics (e.g. when will which company want o participate from the list above).

III. Cases

We illustrate possible choices based on three cases:

1. CO_2 pipeline design in Rotterdam industrial area.

In this case (illustrated in figure 1), we aim to find out what a robust design would be of a pipeline network in the industrial area of Rotterdam. Developing it in the real world would be a huge 100-500 million euro cooperative project, depending on the participating actors. We hope that the agent-based model in this case will help in the discussion amongst possibly participating actors.

2. Power cable of TenneT between the Netherlands and Denmark

A new power cable between these two countries is embedded strongly in the current international and national network. A good layout would strongly depend on expected developments in 1) production in consumption of electricity and their locations, 2) solar and wind energy and 3) energy storage. Whereas the costs of the network are close to the current application, the performance of the system in the new layout and the added value of a new line is not easy to determine.

3. Different quality gas network

Large part of the Dutch gas infrastructure is based on the so-called Groningen-gas quality standard. This standard is based on the gas from the Slochteren field in Groningen, in the Netherlands which is gradually depleting. A new role of natural gas in the Netherlands can exist in requires us to rethink what standards of gas to supply from where to where.

IV. Conclusion

Our past work has shown that an ant colony optimization can be used effectively for a good-enough first layout of a tree-shaped infrastructure network [1]. By expanding on this work, we hope to capture more of the uncertainties surrounding network infrastructure planning in the real world. We have listed many of the sources for uncertainty. By exploring cases on CO_2 pipelines in industrial areas, high capacity interconnectors between countries to more densely connect electricity grids and by looking at a variety in quality of gas networks we hope to explicate what the consequences are of such uncertainties, to contribute to infrastructure network planning and to improve the networked infrastructures that we rely on day by day.

References

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Illustration 1: Simulation of CO2 pipeline network Rotterdam design