semantic and syntactic transfer of fitness landscape models to the analysis of collective and public decision making processes

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Semantic and Syntactic Transfer of Fitness Landscape Models to the Analysis of Collective and Public Decision-Making Processes

Semantische en syntactische overdracht van fitness landschapsmodellen naar de analyse van collectieve en publieke besluitvormingsprocessen

Thesis

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Introduction to this thesis

Collective decision making is a central tenet of political, administrative and planning processes. Many of the aspects of collective decision making, such as bargaining, asymmetric power distribution, the possibility and effects of threatening, reciprocity and cooperation, have since long been studied, systematized and can be said to be widely understood. However, there exists a knowledge gap that is often recognized but rarely addressed properly. This gap consists of three aspects.

The first aspect concerns the different ways in which collective decision making processes are researched. A crude division can be made between those researchers who work with formal models and those who focus on in-situ observations. The first strand deploys tools of game theory and related modeling techniques; the second utilizes case-based methods. The advantages and disadvantages of both approaches are well-known. While game-theoretical models work quite well in structuring situations and outcomes, they rest on the contestable assumptions of the rational choice paradigm; and while case-based observations are more realistic – literally – they often fail to transcend the single-case (n = 1) observation, i.e. results often seem anecdotal. Unsurprisingly, both ways deploy entirely different analytical languages. The differences between these two approaches are so large that few scholars can bridge them successfully.

The second aspect concerns the dissimilar ways in which the research results are understood and communicated. As we will detail later on in this thesis, the differences range from causal statements to metaphors. Given the wildly diverse nature of sciences it is to be expected that many differences and inferences are made in understanding research results and the way it is communicated. Even though this wild variety may seem to hinder understanding collective decision-making, the different types of statements have their merit. While a better causal understanding of collective decision making will be appreciated by scholars interested in the structure underlying such processes, we expect metaphors to fare better in the sense of appealing to the practitioner's ability to comprehend the situation he or she is in. The simple reason is that any realistic causal statement – beyond the trivial, that is – is a complex affair of conditional and probabilistic terms. A metaphor is transferred much more easily, even though it may be more imprecise. Again, very few scholars can bridge the differences between the various ways of understanding the analytical results.

The third aspect concerns the long-term view on collective decision making processes. Real-world decision making rarely is a single-shot game. Actors interact repeatedly. This aspect is not ignored altogether but the ways in which it is understood can be improved. From the perspective of rational choice, it can be modelled as a series of repeated games. This is functional but falls short of incorporating the effects of time itself, i.e. the occurrence of novel but not random events that can change the game altogether. The rational choice paradigm also has difficulties in dealing with the vagaries of actors changing minds or even developing conflicting preferences over time. The naturalistic approach can be said to be more time-sensitive but, as mentioned before, has difficulties in providing a more structural understanding of such processes across studies and across longer time-spans. This is particular an issue in terms of the antecedents and precedents, i.e. the things that happened before the researcher entered the field and after he or she has left. It is recognized that there is merit in understanding the more time-sensitive decision-making as well as understanding the structural understanding over longer time spans. However, a real synergy between the two strands seems to be missing.

These three aspects form the main motivation behind the current thesis. Not being contended with the contemporary state of analysis, we set out to develop a method and technique that would enable us to bridge the gaps mentioned here. We turned to evolutionary biology because the theories and models seem to have the puzzling-solving capacity to deal with longitudinal interaction processes of the social kind, something that has been noted before in e.g. the works of Schelling and Axelrod. We selected a class of models called fitness landscapes from that field as the starting point for our research. Fitness landscapes provide a scalable, integrated modeling structure in which the relationships between the system's elements are deemed to be equally important for the outcome as are the elements themselves. The elements are better or worse fit in specific settings and as such will be selected for or against by this environmental setting; hence the name fitness landscape. The fitness landscapes provide a template to structure the elements in specific settings that constantly adjusts its mapping as time moves on and the condition of the environment change. This, we believed, would be a promising template to reshape our understanding of collective decision making while addressing the concerns we mentioned above. In other words: the model would provide us with a neutral structure upon which we could project all the elements we thought necessary to paint a more realistic understanding of how actors interact in order to get things their way for each specific setting in the longer time frame. For example, it is well-known that politics and policy is about who gets what, and about who is related to whom, and that when time progresses this game can change around completly. Yet, most existing models seem to focus on either aspect without uniting them in a structural fashion. The overall aim of this thesis, then, is to present an evolutionary model of collective decision making, rooted in a naturalistic understanding of empirical studies. We hope that the use of fitness landscapes will render some persistent insights into collective decision making processes. This expectation leads to the following research question:

> Are fitness landscapes capable of identifying the evolutionary properties of collective decision-making?

Obviously, this research question requires that we use fitness landscape models from biology for our specific purpose. Such a step will require us to consider the nature of the social in contrast to biology, which subsequently will force us to adapt such models for the analysis of social processes. We will demonstrate that this is not a straightforward matter. As such, the first sub-question is as follows:

1. What are fitness landscape models and in what ways should they be modified to suit the present purpose?

We will show that, contrary to existing accounts in literature, the model can't be used without any further considerations about what it measures and what kind of statements can be derived from those measurements. This automatically implies that we have to consider the implications of how we position ourselves, both ontological and epistemological, towards social reality. This means that we will have to engage in theory transfer from biology (source domain) to the social sciences (target domain). We will demonstrate that the target domain has some specific properties that need to be taken into account. In short, the nature of the social realm means that the syntactic structure of the model can be used, but not the semantic structure. Considering that we will use the syntactic structure to develop a tailor-made model, we will need to answer the second sub-question:

2. How do we transform and apply our fitness landscape model to the social reality of collective decision-making?

Answering the first two sub-questions will leave us with a tailor-made model and a suite of methods to deploy the model for the analysis of studies. We will present 4 studies in total. The first, and by far most extended one, concerns the 25 years of decision making over the HSL Zuid high speed railway line between Amsterdam in the Netherlands and Brussels in Belgium. This extensive reconstruction will demonstrate the main characteristics of the model. The other case studies will target various aspects of collective decision making. The Gotthard study will highlight the dynamics of short term search processes; the 'sports in the city' study will highlight long-term search processes and reciprocity between actors; the Bangkok study will highlight couplings between two decision making processes that were previously uncoupled. The analysis of the studies should answer the third sub-question:

3. Under what conditions do actors engaged in collective decision making processes reach goal-attainment?

We will use the results obtained from the empirical investigation to develop persistent structural understanding of the evolutionary nature of collective decision making. We will do this in the shape of six archetypes, three of which that focus on actors, and three that focus on interaction – as such exploiting the potential of fitness landscapes to pay equal attention to the properties of the system's elements as well as the interaction of said elements. The actor archetypes concern 'the buoy', i.e. actors that hold considerable sway over the arena but can't get everything their way; 'the jumper' i.e. actors that act pragmatically, thereby risking winning or losing everything; and 'the inflexible', i.e. actors that stick to their guns at an overall lower chance of goal attainment. The interaction archetypes concern 'force to fit', i.e. interactions aimed at escaping a deadlock; 'self-organized entrapment', i.e. unintentional interactions as a result of a specific composition of the arena; and 'diversity breeds diversity', i.e. interactions where diversity in connections and contents leads to more diversity with regard to both aspects.

Taking these findings together will answer the main question of the thesis. The application of the transformed model demonstrates its ability to uncover the structural features of evolutionary collective decision-making. The model presents a novelty in that it combines network elements with substantive elements, to analyze longitudinal processes, in order to ask open questions about the conditions under which actors achieve their goals, i.e. obtain fitness. As such, we believe that we have come a step closer to the ideal with sketched out at the beginning of this introduction. But we will be the first to admit that the approach isn't perfect and that more work needs to be done. We would like to invite the reader to play around with the model and, most importantly, to develop improvements and alternatives.

Although currently presented as a monograph, this thesis derives from number of scientific publications that cover several parts of the work such as theory transfer and empirical studies. They are listed here, sorted by year of publication:

Gerrits, L.M, & Marks, P.K. (2014). How fitness landscapes help further the social and behavioral sciences. *Emergence: Complexity and Organization*, 16(3), 1–17

Gerrits, L.M., Marks, P.K. (2014). Vastgeklonken aan de Fyra: Een pad-afhankelijkheidsanalyse van de onvermijdelijke keuze voor de falende flitstrein. *Bestuurskunde*, 23(1), 55-64

Gerrits, L., Marks, P.K., Ongkittikul, S. & Synnott, M (2014). Assessing high-speed railway projects: a comparison of the Netherlands and the United Kingdom. *TDRI Quarterly Review*, 16-24.

Gerrits, L.M., Marks, P.K. (2015). The evolution of Wright's (1932) adaptive field to contemporary interpretations and uses of fitness landscapes in the social sciences. *Biology and Philosophy*, 30(4), 459-479

Gerrits, L. & Marks, P.K. (2015). De opkomst en ondergang van de HSL als politiek en bestuurlijk mainportconcept. In D.M. Koppenol (Ed.), *Mainport: verleden, heden en toekomst?* (pp. 27-37).

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Gerrits, L.M., Marks, P.K. (2017). Understanding Collective Decision Making: a fitness landscape model approach. Cheltenham, UK: Edward Elgar

Marks, P.K. & Gerrits, L. (2017). Association between decisions: experiments with coupled two-person games. *Public Management Review* (online), 1-20. doi: dx.doi.org/10.1080/14719037.2017.1364413

Marks, P.K. & Gerrits, L. (2017). Evaluating technological progress in public policies: the case of the high-speed railways in the Netherlands. *Complexity, Governance & Networks*, 48-62

Marks, P.K., Gerrits, L. & Marx, J. (provisionally accepted 2018). From a biological fitness landscape model to understanding collective decision-making: A matter of semantics? *Biology & Philosophy*

Chapter 8 This cannot be the end

8.1 Introduction

The archetypes presented in the previous chapter are proven to hold true for our empirical studies. Formulated as rules-of-thumb they offer researchers the opportunity to test them in order to tease out the exact conditions under which they emerge and operate. Naturally, the number of case studies behind these findings is limited so it one can imagine that other studies would throw up other kinds of findings. Context matters, after all. However, we will make the counter-argument that, while the number of studies are low, the amount of data driving these findings isn't. As such, the findings are still robust. We have maintained coherence throughout the whole research cycle from epistemology to research findings to ensure that there is a direct link between any empirical statement and the way in which we understand the coming-about of that empirical reality. This was all done with the original purpose in mind: to assess to what extent fitness landscapes are capable of identifying the evolutionary properties of collective decision-making. We will present our answer in this chapter.

8.2 The explanatory power generated by the model

Evolution – in the broadest sense of the word – has many aspects and very few people would dare to describe it in its entirety. This is not different from the way we see our own findings. The evolution of collective decision-making has many aspects and we haven't covered every bit of it. For example, our focus on organizations as acting units prohibits researching into the psychological dimension of the individual decision-makers. However, this is not meant to be an escape from the task to answer the main question. If anything, it is a disclaimer that the story below is going to show us some of the aspects of the evolutionary nature of collective decision making. Still firmly rooted in heaps of empirical data, of course.

We took inspiration from a class of models in evolutionary biology in order to map and analyze the evolution of collective decision-making. As knowledge transfer proceeds by providing reasons to believe that the phenomena in the target domain are adequately represented because of a high similarity between the targets. In doing the research for this thesis, we discovered that this wouldn't suffice. The differences between the source and target domain are too large to allow for an expansion of the applications without modification of the model. In other words, we had to make certain modifications in order to suit the target domain.

As described in Chapter 4, we retained the syntactic structure but had to let go of the semantic structure. We use these terms to differentiate between syntactic elements of a model, referring to the structural relations between the variables, and the intended interpretation of the model's variables. However, the original interpretation of the variables corresponded no longer to phenomena in the target domain and was modified accordingly. This is to be expected given the major differences between biological and social systems. Mäki (2010: 33) argued that models can have epistemic and non-epistemic functions. Originally, fitness landscapes have the epistemic function to represent phenomena in biology. In principle, there are two different ways how knowledge transfer between the (biological) source and target (social science) domain could happen: an existing model can be used to explain the collective decision-making phenomena, or the model is transformed to a new model in order to do the structuring and explaining. Of course, a justification is needed why the revised model is an adequate representation for the new target domain.

The most fundamental and important aspect of evolutionary collective decision-making concerns variation, selection, and retention, as a consequence of selection pressure. Here, our transformed fitness landscape model performed strongly in highlighting *which* problem and solution definitions survive the selection process (or not), to turn into decisions that matter materially; and in explaining *why* this is the case. As already outlined in introduction of this thesis, the decision making process is essentially an ongoing series of minor decisions in conjunction with chance events that, at a certain point, leads to an outcome (as in line with our first and second focal points, see sections 3.4.1 & 3.4.2) e.g. to build a high-speed railway link. To be clear, the model shows both the substantive survival (in terms of PSD's) as well as the short-term and long-term success of actors (in terms of fitness as goal attainment). The model gives us a concrete framework to process a considerable amount of data in such a way that these properties come to the fore. Without the model, we could have a hunch about how these processes evolve, if only on the basis of theoretical expectations. However, the model processes data in such a structured way that recurring actor behavior and interaction patterns can be detected and mapped in a persistent fashion. This contributes to the robustness of the findings described in the previous chapters and summarized in Section 7.2 and Section 7.3.

The second aspect of the model is that it integrates the network structure of actors tied in a decision-making process with the substantive dimension of decision-making in order to map how the conjunction of both dimensions plays out in the decision-making process. The intertwined nature of social relationships and substance has been acknowledged before (e.g. Sabatier, 1988). The starting position of actors in our model is not a tabula rasa as in most other approaches, but based on the connections actors have due to their shared history. Stronger, our model has put the two dimensions of substance and relations together in a way that does justice to the configurational nature of decision-making, and that allows us – again – to map how these conjunctions produce certain outcomes (as in line with our third and fourth focal point, see section 3.4.3 & 3.4.4). It is in this way that we could prove and not just imply, for instance, that more similar problem and solution definitions relate to a higher degree of connectedness, in turn raising the fitness of actors that manage to maneuver themselves in such a position. This, again, moves us from having a hunch about this, to robust findings that can be submitted as evidence. We have presented this evidence in the preceding chapters and summarized them in Section 7.5and Section 7.6.

The third aspect concerns the visualizations. They provide a quick and convenient access to the main evolutionary dynamics in a field. While they were obviously inspired by the original visualizations, they stand on their own in their representation of the evolution of collective decision-making process. The final graphical representation deviates considerably from the visuals found in the literature on fitness landscapes applied to evolutionary biology. The main reason has been mentioned elsewhere: a fully occupied grid can only be achieved with a data point for every coordinate on the *xy*-grid. This can be achieved in simulations but not when adhering to the prerequisites we have followed throughout. However, that should not stop us from using the graphs as convenient entry points to the findings. Strictly speaking, the visualizations are not necessary for the representation of the dynamics within and across fields (a theme that is also current in biology, see Petkov, 2014). However, they are welcome as a way to access the evolution of decision-making without having to shift through all the empirical data underneath it. At the very least, we expect the visualization to be used as another way to probe into collective decision-making.

Since much of the theoretical knowledge about the original model depends on its syntactic structure only, this knowledge is easily transferable to the new model. As the two models are isomorphic, it is possible to learn about the target domain by manipulating and analyzing the original model in the modeler-mode. This opens the window for profiting from the whole existing strand of theoretical literature about fitness landscape models and the various possible patterns and relations therein to learn in an indirect way about the target domain. These modifications are entirely justified in the face of social reality. Does this modified model give us access to the evolution of decision-making? In other words: does it reach the goals we set out? We follow Weisberg here: "Models are considered good, if they are "similar to a real-world phenomenon in certain appropriate respects" (Weisberg 2007: 218). Returning to our main research question, we can therefore confirm that, yes, the model provides a powerful tool to process varied data in order to get to a deeper understanding of the evolution in collective decision-making.

8.3 Further testing of the model

The model has been applied to a limited set of studies using, predominantly, qualitative data. An argument can be made that the best way to strengthen the models and to analyse collective decision-making processes is through quantitative methods. As Morçöl (2012; 194-195) so clearly argues, many in the social sciences believe that quantification is the only way for sciences to mature and to be able to make generalizations about objective phenomena, as mathematics is the language that is more precise than ordinary language (even though there are various interpretations of what quantitative and qualitative methods exactly mean). While our present study relies on qualitative data that is converted into quantitative measures, we see no reason to stick to either type of data. Quantitative methods can strengthen models as one has to be very clear and concise about the causal relations and the operationalisation, while at the same time qualitative research methods are needed to complement the simplified picture of the complex reality with contextual, qualitative understandings of systems and their actors (cf. Morçöl, 2012: 195).

Based on the taxonomy of different research methods provided by Morçöl (2012) our model fits in with the methods of understanding the relations between micro agents/actors and the structural properties that emerge from their interactions. The other methods, 1) macro methods – e.g. regressions models fractal geometry, Lyapunov exponents, system dynamics modelling – are used to detecting structural patterns or macro level processes, and 2) micro methods – e.g. laboratory experiments, cognitive mapping, Q methodology – are used to study the human mind and behaviour in particular settings. Micro methods can thus provide data for the generalizations used as input in micro-macro methods. Using the model, we derived six archetypes within collective decision-making, each of which offering testable hypotheses. The archetypes draw from a considerable amount of data, yet one can be concerned about the width of such data since it was based on a specific and limited amount of studies. For the archetypes to gain more explanatory strength and perhaps even have prescriptive value, it is necessary to test them on a broader spectrum. This can be achieved in multiple ways in correspondence with the micro-macro methods of qualitative case studies, social network analyses, and agent-based modelling.

Naturally, we don't need to say much about qualitative studies because that is the prime source of the empirical work presented in this thesis. However, the number of studies is relatively small, even though the data therein is considerable and covering a considerable timespan. The easiest and most obvious way to strengthen the model is to simply expand the number and diversity of studies. Do the findings work when we vary the countries or the types of studies? We believe that this way of testing is very relatively simple because all the steps needed for that are described in the previous chapters. On top of that, we developed the online app un-code.org, which is freely available to any researcher wishing to build fitness fields from case-based data. Using the app, one can use the measures to identify the occurrence of the archetypes in the data. The visual output of the app will help in the identification process.

But there are other ways of testing, and exploring the strength of the fitness field model (SNA) or the robustness of the archetypes in a simulated environment (ABM). In particular, one can try out different scenarios in quick succession and adjust parameters to identify their effects on the outcome. There are several modelling approaches that are useful to uncover complex causality. Our fitness field model applies an adapted form of technique from social network analyses (SNA). There is for instance a similarity between the density component and the weight adjustment of SNA and the calculation of the *c_score*. Different techniques from SNA could contribute to getting a more precise operationalisation of these connections between actors; that is, SNA offers techniques to study patterns of relationships between actors. The similarities of elements in the respective PSD's can be studied by multidimensional scaling which can provide raw scores of similarities. Then various techniques (for instance the Jaccard coefficient) can create a space in which all actors are located at a distance from each other that is proportional to their dissimilarities in terms of problems and solution definitions. To study the movements of actors across time (across different fields in a lineage), we can (1) make a comparison of the networks associated with the different fields, and (2) make a comparison of the pairwise distances between actors in the different fields. This serves as one example of the many techniques that SNA, combined with other techniques, can contribute to strengthening the values of at least one of the components in the configuration of the fitness field model.

The point of departure for the modelling of the archetypes equals those present in emergence-driven, spatially-situated modelling approaches in the complexity sciences: agent-based modelling (ABM). ABM functions on the basis of programmable units, i.e. the agents that can change location on the grid the moment their attributes change. These agents can represent anything, from individuals to institutions (as in line with our definition in Chapter 4). They interact according to a restricted set of rules and environmental constraints. The aggregation of all behaviors within the constraints forms a higher-level output that can be seen as emergent from the interactions. Injecting a degree of randomness in the simulation means that each iteration of the model leads to a (somewhat) unique outcome (e.g. Pagliarin & Gerrits, 2017; for a more detailed discussion). One typically does multiple runs of the simulation and then performs a regression analysis on the results to derive the archetypal behavior of the agents given the set of parameters and constraints. As such, ABM represents the emergent-type of modelling where local interactions leads to non-linear aggregated outcomes, i.e. emergence (Holland, 1995, 2012). It will be clear that emergence-driven modelling suits the testing of the archetypes. The behavioral rules can be found in the rules of thumb defined in boxes 7.1 to 7.5. These are directly transferable to the parameters of the agent-based model. The environmental constraints can be attributed freely. By playing around with the parameters, for instance by changing values for PSD and/or *c_score* one can see where the boundaries for the archetypes occur, or how well connected the archetype needs to be to remain for instance the buoy. An important parameter here is the number of ticks, i.e. the iterations of the model. While it could be argued that each tick should represent a step in time, e.g. a month or a year, we think it would be more useful to treat each event as a tick. After all, it is the events upon which the lineages are structured and those events are distributed unevenly across time stamps, as per e.g. Abbott (2001). The aggregated behavior across the lineage of events, then, forms the emergence we're after.

ABM's, and other types of simulations, serve as heuristic devices with which one can explore different ideas. The outcomes matter in the sense that they give clues as to the directions one could probe empirically, but they don't constitute empirical outcomes. Above all, modelling and simulations provide a boxed environment where one can explore the effects of changing parameters at an accelerated pace – after all, the results can come in a matter of minutes instead of years. Of course, we are not the first to do this – see e.g. Lansing's work on the irrigation network of Bali – we simply wanted to demonstrate how one can convert the archetypes into simulations. As mentioned before we believe that quantitative approaches and methods like SNA and ABM would be a suitable method to supplement, but not replace, qualitative (empirical) case studies.

The approach presented in this thesis combines some modelling and high-level theories with a common-sense, strongly data-driven understanding of collective decision-making. We hope that our modest attempt will help furthering this avenue of inquiry.

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Appendix A – Data processing and www.un-code.org

We will explain the details of the un-code.org application that we used to store, structure, analyze and visualize the empirical data in this appendix. We tried many different software programs with which the data could be visualized, such as Mathlab, R, and Rhino in combination Grasshopper. The software we were looking for should (1) not contravene the five requisites explained in Chapter 2; (2) provide a database function to store and retrieve raw qualitative data in a structured way; (3) allow the researcher to code and recode raw data for analytical purposes; (4) visualize the coded data in a three-dimensional fitness landscape; (5) highlight specific dynamics in the landscape such as the adaptive walk. Not surprisingly, such software didn't exist so we developed our own web-based application called www.un-code.org (where un-code stands for Understanding Collective Decisions). The practical coding was done by Julian Stieg.

A.1 www.un-code.org application description

A.1.1 Software architecture

www.un-code.org is open-source web-based software. It can be accessed online from anywhere on the world. To run it locally, the installation of a standard web service (such as the Open Source program XAMPP) is needed beforehand. The software's backend is written in PHP5 and uses MySQL as database system for storing user and case data in two separate databases. The front end of HTML5, JQuery and JavaScript utilizes the AJAX method – asynchronous server-interactions – to achieve a fluid user experience. 3D visualization from within the browser is done using the Three.JS library utilizing the WebGL interface – thus enabling the software to use real 3D graphic acceleration from within any modern browser, such as Google Chrome, Mozilla Firefox, Apple Safari, Microsoft Edge or Internet Explorer 11. This approach allows a dynamical and on-the-fly data visualization in a scalable environment. Although a dedicated video card is recommended for improved performance, graphics chips supporting OpenGL 2.1 or higher can also work.

The www.un-code.org software also provides the possibility of storing case study sources, such as documents or images up to the size of 32 Mbytes per file in any format, online on the server. The files are uploaded via the browser and stored in the MySQL database only accessible from within a personal account, offering always-online availability and data protection at the same time.

A.1.2 Data Input

Before using the software, the user has to create a password-protected (stored encrypted in the database) user-account. All entered data is only accessible to the user. In this section, we outline the core possibilities of inputting data within a case study. The overview assumes that the data for each component is readily available.

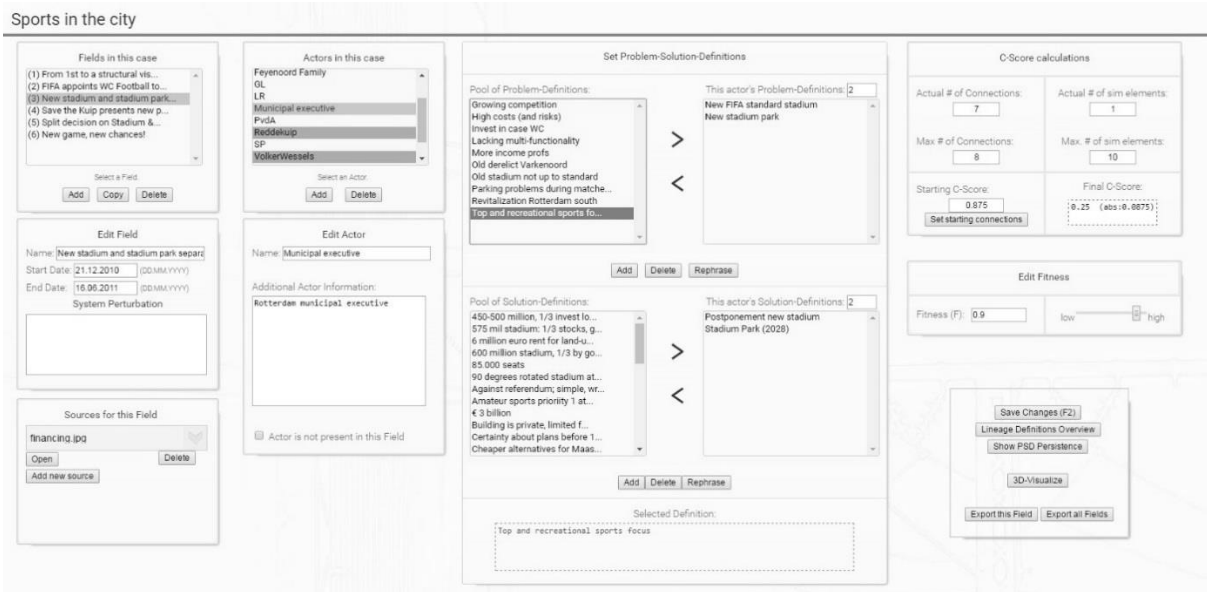

Figure A-1 – www.un-code.org's main data input mask. From left to right: fields/sources, sources, actors, problem/solution definitions, c_score calculation/fitness. AJAX is used for every input.

- Fields: The researcher defines the time span for each field, ranging from days to years per field. The time span cannot overlap with another field of the same lineage.
- Actors: The researcher can assign actors by entering information for every field. A checkbox can be used to indicate if an existing actor is present or not in the subsequent fields. If it is present, it is included in the calculation and visualization.
- PSD's: The researcher first defines the pool of problem and solution definitions for each lineage. Specific definitions can be assigned to each actor for every field – as of course definitions change throughout time. This data is then used to calculate the *PSD score* (see 2.3) and is eventually utilized in the 3D-visualization and persistence visualization features (see 2.4). The software can also generate a complete definitions overview as an excel sheet.
- Connectedness: We differentiate between "starting connections" forming the *starting c_score* and the qualified *weighted c_score*. To set the starting connections, the application creates a table of active actors for each field. One can then define a starting connection between two or more actors in a field by simply clicking checkboxes within that table. The more refined *final c_score* is created by taking into account the similarities in elements of *PSD's* (see. 2.3).
- Fitness: You can enter the fitness value by either typing the numerical value or by using the slider. The fitness score per actor is represented on the z-axis of the 3D visualization (see 2.4.1).

A.1.3 Calculations

www.un-code.org will automatically calculate values for *PSD* and *c_score*. These scores are calculated for every actor in every field. Any changes made to the case data updates the calculation. This facilitates case study work where such changes are often made during the research process. All score calculations will lead to results between 0 and 1 in order to facilitate comparability and scalability.

- PSD score

The *PSD score* for each actors per field is calculated by the application as follows:

every actor *i* has $PSD_i = \frac{actual\ \#\ elements\ PSD_i}{maximum\ \#\ elements\ \ PSD}$, where $PSD_i \in \{0, 1\}$

Actual # elements PSD is amount of elements in a PSD of an actor in the field. *Maximum # elements PSD* is the sum of all elements in all *PSD's* in the field. Inactive elements in *PSD's* that are present in the pool but not used, are ignored by the application.

- c_score

The *starting c_score* is calculated as follows:

$$c\_score_i(t_0) = \frac{actual\ connections_i}{maximum\ \#\ connections}, \text{ where } c\_score_i \in \{0, 1\}$$

Actual connections are the number of connections of the actor to the other actors in this field. *Maximum # connections* are the maximum number of connections an actor can have; i.e. connection with all active actors in this field. The weighted factor (w) is added as follows to the *final c_score*:

$$c\_score_i(t) = w_i \times \frac{actual\ connections_i}{maximum\ \#\ connections}\ ;$$

$$\text{where } w_i = \frac{\#\ actual\ similar\ elements\ PSD_i}{maximum\ \#\ similar\ elements\ PSD}, \text{ and } w_i \wedge c\_score_i \in \{0, 1\}$$

 # Actual similar elements PSD is the number of elements in the *PSD* of the actor that are shared with at least one other active actor in this field. *Maximum # similar elements PSD* is the maximum number of elements in the PSD that could be shared with at least one other active actor in this field.

A.1.4 Output Methods

Besides being a case management and calculation tool, www.un-code.org can also visualize the data. There are two main methods of results output in the application: 3D-Visualization and Persistence Mapping.

3D-Visualization

The application offers the possibility of real-time 3D-visualization within the browser. The data is rendered on three axes: *PSD* on one axis, *CON* (i.e. final *c_score*) on another axis and *FIT* on the z-axis. Moreover, to increase the clarity of the visualization, www.un-code.org presents the results of *PSD* and *CON* in a relative way with the highest value of the lineage being the ceiling of *1*. For the *PSD* score, it can be selected in the options whether the ceiling should be relative to the whole lineage or only to the chosen field(s).

The user can select which combination of fields and actors he or she wishes to visualize. This allows the observation of a specific configuration at a specific point in time. Or, if multiple fields are selected, it allows monitoring the movement of one or multiple actors throughout the lineage. The movement can also be emphasized by the software using arrows to connect actors' positions in time. Different time positions are labelled with *t1…tn*. Earlier positions can be rendered transparent.

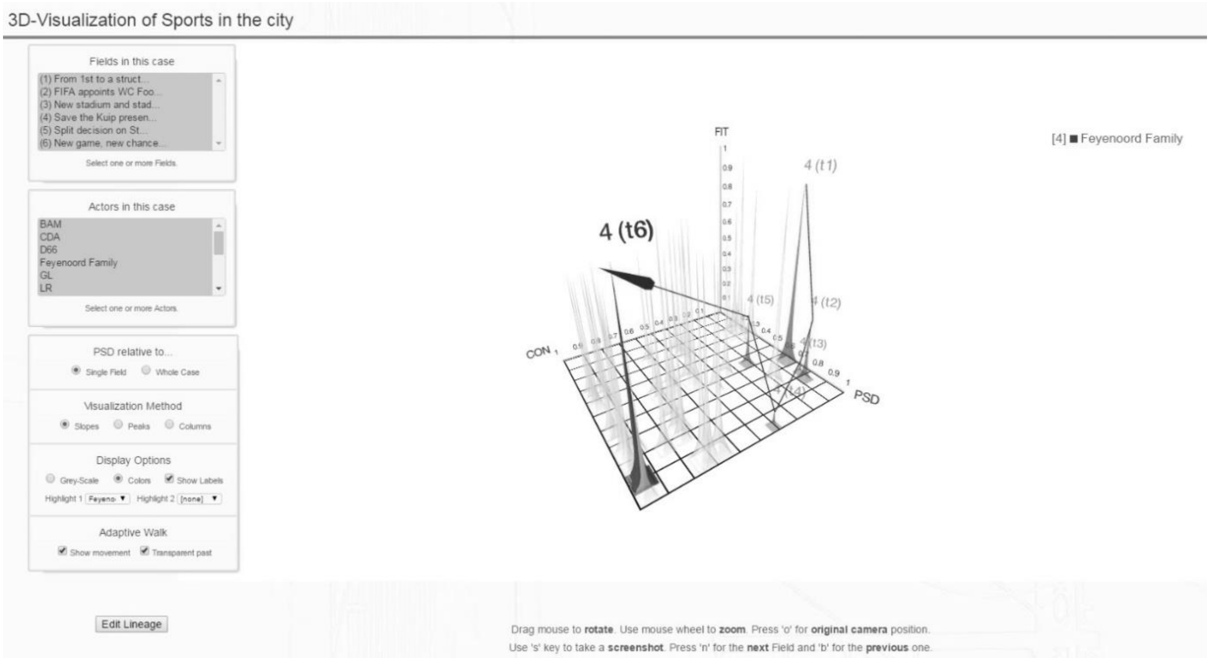

Figure A-2 – www.un-code.org's 3D-Visualization: A typical case examination, highlighting the movement of an actor throughout multiple fields in relation to other actors.

To allow for detailed examinations and view small iterations within the visualization, the camera view allows for free 3D-rotation by holding the left mouse button or for zooming using the mouse wheel. 3D-labels for actors and grid will rotate always facing the camera. The tool has a function to return to a standard original camera position, offering comparability. It also has the function to take screenshots. Options in the visualization are (1) colored or gray scale output, (2) highlighting one or more specific actors in the field, and (3) sloped, peaked and columned fitness representation. Whenever selecting any option, changes to the visualization are applied instantly and no reload of the web page is required due to the utilization of AJAX and WebGL-abilities.

A1.5 Persistence Mapping

Over time, the interaction and alignment between actors in search for fitness produces a number of evolutionary substantive outcomes. Tracing the evolution of PSD's over time, and the positions and actions of actors tied to those PSD's will give a thorough understanding of the mechanisms of variation, selection and retention at work. For this reason, www.un-code.org offers the possibility of mapping the persistence of *PSD's* throughout a lineage. The output is done per lineage as an automatically created *.xlsx sheet (using the library PHPExcel).

un-code.org: PSD persistence of lineage "Sports in the city"	From 1st to a structural vision	FIFA appoints WC Football to Russia	New stadium and stadium park separated	Save the Kuip presents new plan	Split decision on Stadium & Stadium Park	New game, new chances!	Total Shared	Persistence
Problem Definitions								
Growing competition	11% (1/9)						1	1
High costs (and risks)			89% (8/9)	36% (4/11)	73% (8/11)		20	3
Invest in case WC							0	0
Lacking multi-functionality	11% (1/9)						1	1
More income profs						20% (1/5)	1	1
New FIFA standard stadium		89% (8/9)	100% (9/9)	100% (11/11)	100% (11/11)	100% (5/5)	44	5
New stadium park		11% (1/9)	11% (1/9)	9% (1/11)			3	3
Old derelict Varkenoord				9% (1/11)			1	1
Old stadium not up to standard	100% (9/9)						9	1
Parking problems during matches		11% (1/9)					1	1
Revitalization Rotterdam south	89% (8/9)						8	1
Top and recreational sports focus	89% (8/9)						8	1
Solution Definitions								
450-500 million, 1/3 invest loc gov		11% (1/9)					1	1
575 mil stadium: 1/3 stocks, gov							0	0
6 million euro rent for land-use		11% (1/9)					1	1
600 million stadium, 1/3 by government	11% (1/9)						1	1
85.000 seats		22% (2/9)					2	1
90 degrees rotated stadium at Maas				9% (1/11)			1	1
Against referendum; simple, wrong quest		78% (7/9)					7	1
Amateur sports prioriity 1 at Varkenoord				9% (1/11)	18% (2/11)		3	2
€ 3 billion	11% (1/9)						1	1
Building is private, limited funding gov	67% (6/9)						6	1
Certainty about plans before 1-1-2014				9% (1/11)			1	1
Cheaper alternatives for Maas variant			44% (4/9)	9% (1/11)	9% (1/11)		6	3
Financing of metro line by city region	44% (4/9)						4	1
Gov. finance under very strict condition				18% (2/11)			2	1
Independent fin, risk assessment stadium		11% (1/9)					1	1
Independent research risk, fin perspecti		78% (7/9)					7	1
Invest in case WC, nat gov coinvest		11% (1/9)					1	1

Figure A-3 – www.un-code.org's Persistance Mapping: Helping to see which definitions survived over time.

The fields of the selected lineage form the x-axis, the definitions used anywhere in the lineage are presented on the y-axis, group-separated by problems and solutions. Each cell shows the percentage of actors that share this definition within this very field. Next to the percentage, the exact number of actors sharing it and the total number of actors active during this field are made visible. The strength of shared definitions is highlighted by different colors - with green representing non-shared or weakly-shared definitions and red representing broadly-shared definitions.

The columns on the right side show the number of total shares of this definition throughout the lineage, and the persistence score. The latter expresses in how many fields of the lineage a definition was active, i.e. shared by at least one actor. This presentation allows the researcher to keep track of definitions getting weaker or stronger at specific points in time and helps pointing out possible explanation approaches why some definitions ended up being successful.

A1.6 Coding and interpretation

The one thing the application can't do is collect and code data. This has to be done by the researcher. It is also up to the researcher to assign certain values to certain data, i.e. the coding of data. This implies that data has to be interpreted, which, in turn, means that validity and reliability is at stake. We took the following measures: (1) both authors coded all data and compared differences and similarities, which often lead to changes; (2) data sources were triangulated in order to identify suspect sources and to inform the coding process; (3) data sources and coding have been made public in Appendix B and Appendix C. This enables the reader to check our interpretation. As always when working with qualitative data: one can disagree about an interpretation but such disagreement should not concern the procedure.

Appendix B – Data collection

This appendix provides an overview of the data sources used for the empirical studies presented in Chapters 5 and 6. The full list of references includes about 1800 sources and can't be published here because of practical limitations. This list is available from the authors upon request.

B1 – Data collection HSL-Zuid

For the HSL-Zuid study, we collected both newspaper articles and policy documents to trace the lineages of the study, the movements of the actors and their considerations for undertaking certain actions. Dutch newspaper articles published by Algemeen Dagblad, Financieele Dagblad, NRC Handelsblad, Reformatorisch Dagblad, Telegraaf, Trouw and Volkskrant were retrieved from the Lexis-Nexis database. We started the search with five different generic themes that covered the whole decision-making process. This resulted in the following overview of articles.

Generic search	Specific strand	Period	# articles
HSL Zuid	Building, construction, etc.	28/04/1994 – 23/12/2009	321
	Tender, infrastructure, etc.	17/02/1995 – 02/07/2004	183
	Concession, operation, etc.	10/07/2001 – 04/04/2007	67
	Fyra, high-speed train, etc.	12/07/2005 – 22/11/2008	38
	Operation, V250, Fyra, etc.	08/09/2009 – 05/03/2013	577
			1186

In addition to the newspaper articles, we retrieved six in-depth articles about the HSL and / or V250 from (technical) railway journals not covered in the LexisNexis database. The search resulted in 1192 articles. Some sources appeared multiple times because of the predefined structure in five strands. In addition, we triangulated the articles from multiple sources, which lead to the rejection of a small number of articles when we thought that they we unreliable or contradictory. The selection is skewered towards more recent years as news coverage was more intensive than during the early stages of the project. It also appeared that recent newspaper articles showed more similarities than older ones. Redundant articles have been removed, which may have corrected the skewed distribution somewhat.

The articles where then structured in an Event-Sequence Database (Spekkink, 2013; 2015) and then coded to reconstruct how different events evolved through time in the study. This made it possible to select the significant events to form the lineages presented in Chapter 5. The event sequence is a condensed presentation of the news articles, as certain events were covered by several newspapers; in total 412 events were identified as significant for the collective decision-making process. The exact dynamics of those events were fleshed out on the basis of government papers: 6 policy documents of the Ministry of Infrastructure, 27 letters of Parliament and 28 evaluation reports (from the Court of Audit, temporary evaluation committees, etc.). This enabled us to reconstruct the decisions actors took, the context of those decisions and the rationale for the decisions.

The writing of the thesis coincided with a parliamentary inquiry regarding the Fyra debacle for which we also made a minor contribution. The report was published in 2015 as 'Reiziger in de kou' (Tweede Kamer der Staten Generaal, kst-33678-10). The publication led to considerable media coverage. We have taken notice of the news coverage and the report, and used the information to cross-check our findings. It confirmed our data-analysis and as such no amendments to our study were needed.

B2 – Data collection Gotthard

Data for this case was also collected from newspaper sources, most prominently the Neue Züricher Zeitung and swissinfo.ch, and policy papers. We searched for 'future Gotthard region', 'consequences GBT' and related terms. The media coverage of the cooperation progress leading up to PREGO / San Gottardo was considerably less extensive than in the other studies, in particular in comparison to the news coverage of the Gotthard Base Tunnel. In total, we used 23 newspaper articles. Given the nature of the issue and the lack of coverage, we needed to rely on government papers: 18 policy or evaluation reports, including Bundesrat and Kanton reports as well as project reports. Since a search in Lexis Nexis didn't return the desired results, we relied primarily on Google to retrieve the documents. We were assisted by a German speaker, Julian Stieg, in searching, translating and structuring the data. The resulting lineage was checked again by the native speaker, which led to some changes.

B3 – Data collection Sports in the city

Data was collected from Dutch newspaper articles, mostly published by Algemeen Dagblad / Rotterdams Dagblad, retrieved from LexisNexis. The search terms used were 'nieuwe kuip', 'Feyenoord stadium', 'sportpark', 'stadionpark'. The search resulted in 412 articles that cover the full duration of the study. The articles where structured using the Event-Sequence Database and then coded to reconstruct the lineage. The final lineage featured 105 events. In addition to the written sources, we carried out 10 interviews with key people involved in Stadion Park and / or the stadium. The interviews were conducted by Lasse Gerrits and Iris Korthagen and are listed in the table below.

Respondent	Function	Date
Mark van den Boer	Spokesperson municipality Rotterdam	23/02/2011
Hans van Rossum	Project manager Stadium Park	15/11/2012
Marieke Gruijthuisen	Spokesperson for the alderman of sports	15/11/2012
Jan van Merwijk	Director Stadium Feyenoord	22/11/2012
Robin van Holst	Red-de-Kuip group	18/12/2012
Kirsten Verdel	Ice Skating Club Rotterdam	20/02/2013
Gert Onnink	Sports journalist Algemeen Dagblad	21/02/2013
Jan Geuskens	Former project manager Stadium Park	21/02/2013
Ard Buijsen & Erwin Pakasi	Voluntary advisors Feyenoord-family	01/03/2013
Aad van der Laan	Former president Sports Club Feyenoord	10/04/2013

We also used 3 policy documents published by the municipality Rotterdam (the Structural Vision, Masterplan Sports Campus, and the Environmental Impact Assessment), several reports (a.o. evaluation reports, master theses), and internet sites. The reconstruction method was the same as with the studies listed above.

B4 - Data collection Bangkok

Most of the written data came from English newspaper articles published in The Bangkok Post, The Nation and the Railway Gazette, and was retrieved from Lexis Nexis. The search terms used were for 'Bangkok', 'Makkasan', 'Suvarnabhumi', 'Lat Krabang', 'Hopewell' and 'Airport Railway Link'. We were limited to English sources because we couldn't engage a Thai translator, though this may not have had much impact on the results because Bangkok Post and The Nation are both reputable newspapers publishers from Bangkok in English. The search resulted in 114 useful articles. Naturally more information in Thai could possibly have given more information, but we had to limit ourselves to English as none of us can read the Thai language. In addition to the written sources, we carried out 6 interviews during a site visit that took place between January and March 2014. All interviews were conducted by Lasse Gerrits and are listed in the table below.

Respondent	Function
Dr. Sumet Ongkittikul	Researcher at Thailand Development and Research Institute
Dr. Waressara Weerawat	Researcher at Mahidol University, Logistics Innovation Center
Dr. Jirapan Liangrokapart	Researcher at Mahidol University, Logistics Innovation Center
Dr. Krit Anurakamonkul	Superintending engineer, State Railway of Thailand (2 meetings)
Dr. Chumloon Tangpaisalkit	Chairman board of directors State Railway of Thailand Electrified Train

Also several research papers (a.o. Property rights Bangkok, Built environment behavior, Railway Sector Reform Studies) and internet sites have been used to reconstruct the contextualized considerations of actors and their subsequent actions.

Appendix C - Data coding high-speed railway study

C.1 Lineage 1 – The finances of building the HSL-Zuid

Field 1 - Building starts and fraud detected

From the start all builder have had a working history and as becomes clear in the fraud have real close connections on all fronts, as such they are all connected. The ministry of Transport has working relations with all actors, while the House of Representatives only has a history with the ministry, as is shown in the table below.

Actor c_score	Ballast	Bechtel	B/K	MT	HoR	NBM	VW S
Ballast Nedam c.s.		x	x	x		x	x
Bechtel	x		x	x		x	x
Bouyges/Koop	x	x		x		x	x
Ministry of Transport	x	x	x		x	x	x
House of Representatives				x			
NBM Amstelland c.s.	x	x	x	x			x
VolkerWessels Stevin	x	x	x	x		x	

Actor PSD	Problem definition	Solution definition
Ballast Nedam c.s.	1. Building rails, etc.	1. Schiphol-Green Heart Tunnel & Rotterdam-Moerdijk (February 2000)
Bouyges/Koop	1. Building tunnel	1. Tunnel; single tube (diameter 15 meter) (February 2000)
Holzmann c.s.	1. Building rails, etc.	1. Brabant South (February 2000)
House of Representatives	1. Finances HSL	1. Astonished about agreements with builders, and rising finances (14-10-2000) 2. Investigation into finances and builders agreement (14-10-2000)
Ministry of Transport	1. Building HSL-Zuid 2. Finances HSL-Zuid	1. Tender of foundation in six separate parts (design & construct) (6-5-1999) 2. Tender rails, catenary & signal system through (DBFMO) (6-5-1999) 3. Contract with five consortia: 1.9 billion euro (14-3-2000) 4. Tendering for catenary etc. (2 consortia still in the running) (20-10-2000)→ half year later Infraspeed wins (5-5-2001) 5. Year more: Longer negotiations with builders, acquiring land (22-7-2001)
NBM Amstelland c.s.	2. Building rails, etc.	1. Green Heart – Rotterdam (February 2000)
VolkerWessels Stevin c.s.	1. Building rails, etc.	1. Brabant North (February 2000)

Solution: The Dutch Authority for Consumer and Markets have announced the fines for the building companies that made price agreements the last years; fines range from a couple of thousand euro to nineteen million (April 5th 2005). However, it is not made public which firms in the HSL-Tender are fined for what amount. This creates much change in the HSL-Zuid playing field; questions on who has to pay for what and who is to blame start to play.

C.2 Lineage 2 – Route and track decisions HSL-Zuid

Field 1: Crossing borders & a tunnel

As all actors involved in this field are political and/or administrative bodies they have many links in history that make them connected, except for the Belgian minister who has a working history only with the Dutch minister. This creates the following starting connections as input for the *c_score*.

Actor c_score	BMoT	MT	HoR
Belgium ministry of Transport		x	
Ministry of Transport	x		x
House of Representatives		x	

Actor PSD	Problem definition	Solution definition
Belgium ministry of Transport	1. Route across border	1. Route via Roosendaal (7-10-1995) 2. Route via Breda (E19) including compensation for extra cost (24-5-1996)
Ministry of Transport	1. Route HSL-Zuid	1. Route via Breda (7-10-1995) a. Compensation for Belgium (24-5-1996) 2. Tunnel through green heart (April 1996) a. Compensation villages (400 million euro)
House of Representatives	1. Route HSL-Zuid	1. Green Heart Tunnel (April 1996) a. Compensation villages

Field 2: Versions of the Green Heart Tunnel

The ministry is connected to all actors involved in this field as they are political and/or administrative bodies they have many links in history. This creates the following starting connections as input for the *c_score*.

Actor c_score	HoR	MT	Villages
House of Representatives		x	
Ministry of Transport	x		x
Villages (stakeholders)		x	

Actor PSD	Problem definition	Solution definition
Ministry of Transport	1. Building HSL-Zuid 2. Tunnel length	1. Tunnel 6 or 9 km (October 1996) 2. Against dug tunnel, needs adjustment Planning decision (July 22nd 1998) 3. Tender (DBFMO) for drilled tunnel of 6.4 or 2.6 kilometers (February 1999) a. Safety & comfort passengers b. 300 km/h c. No pressure waves 4. Longer tunnel option as short is harmful (20-4 1999)
CDA & VVD	1. Tunnel length	1. Tunnel dug instead of drilled (July 22nd 1998)
Villages (stakeholders)	1. Tunnel length	1. Long tunnel, i.e. 6.4 km (February 1999)

Solution: December 22nd 1999 the project bureau HSL present the new Green Heart Tunnel: a single tube with a diameter of almost 15 meter, except in the middle of the tunnel which will hold a small section of two tubes. This diameter is necessary to prevent painful ears of passengers. The Dutch/French combination Koop/Bouyges will build the tunnel for € 430 million (connection with lineage 1).

Field 3: Building & Safety

The only two actors in this field are the House of Representatives and the ministry of Transport, which are by definition connected as they have a shared political history.

Actor c_score	HoR	MT
House of Representatives		x
Minister Transport	x	

Actor PSD	Problem definition	Solution definition
House of Representatives	1. Building HSL	1. No pergola as it is in contrast with nature preservation (13-7-2000) 2. Stop building due to heavy metals (20-12-2001)
Ministry of Transport	1. Building HSL	1. Pergola a. Willing to abandon pergola if province and municipalities contribute (12-9-2000) then lower crossing is possible (3-10-2000). 2. Lowered track Bergschenhoek (20 million more) and builders receive nine months extra (22-6-2001) 3. Remove furnace slacks and place new ones (21-2-2002) 4. ERTMS is only safety system (24-5-2004), but is delayed for testing (3-5-2006) and upgraded (20-12-2006)

Solution: Except for minor incidents, e.g. dust accumulation in the tunnel, revisions to sound screens, the building continues and on the 14th of October 2008 the HSL-Zuid is ready for operation. Train shall be able to travel from Amsterdam to Brussels (212 kilometers) in 1 hour and 46 minutes with an average speed of 120 km/h including stops.

A.3 Lineage 3 – Concession for operating the HSL-Zuid

Field 1: From favored party to one of many

The House of Representatives and the ministry of Transport are by definition connected as they have a shared political history. The ministry is also connected to the NS as for instance NS used to part of the ministry, but also as they work together on many occasion.

Actor c_score	HoR	MT	NS
House of Representatives		x	
Ministry of Transport	x		x
NS		x	

Actor PSD	Problem definition	Solution definition
House of Representatives	1. Concession HSL	1. Minister is too proactive in going for exclusive right NS and should keep options open (7-4-1998) 2. Different opinions on NS as sole provider and given deadline for new proposal (13-11-1999)
Ministry of Transport	1. Concession HSL	1. Cutting up rail net into regional and central net a. HSL part of central net, hence open to other parties than NS as well (5-2-1998) 2. Exclusive right HSL to NS (23-03-1999) a. Registering NS for stock market, regional nets for tender if NS doesn't want them 3. Start tender and NS should withdraw offer (19-6-1999) a. Tender will be in favor of NS, due to reciprocity 4. Offer NS (dd. 1-9-1999) inadmissible (13-11-1999) a. Joint bid NL & international b. 360 million too low c. NS will get 1 week for renewed offer
NS	1. Concession HSL	1. Sole right to operate (22-6-1998) 2. Applying to stock market for finances 3. Do make offer for exclusive right (1-9-1999) 4. Not willing to make new offer following dictate minister (17-11-1999)

End of field: November 17th 1999 NS announces that they are willing to follow the dictate of the minister and will not provide a new offer. The same day the minister announces that the operation of HSL will now be an official public tendering process as NS has refused to provide a better offer.

Field 2: Disinformation, but still tendering

The connections are the same as in the previous field.

Actor c_score	HoR	MT	NS
House of Representatives		x	
Ministry of Transport	x		x
NS		x	

Actor PSD	Problem definition	Solution definition
House of Representatives	1. Concession HSL	1. No tender because minister misinformed house (9-12-1999)
Ministry of Transport	1. Concession HSL	1. Will wait with tender: (15-12-1999) a. Maybe NS state owned again b. NS maybe eligible monopoly c. In case tender; NS will win 2. Bid by NS consortium is admissible, but decision is that exclusive offer cannot be made (EU regulation) (4-5-2000)
NS	1. Concession HSL	1. Together with KLM & Schiphol make offer (4-4-2000)

End of slice: May 4th 2000 the cabinet decides that NS, KLM & Schiphol cannot make an exclusive offer and put the concession for HSL-Zuid up to tender.

Field 3: NS wins public tender HSL-Zuid

The ministry of Transport is connected to all actors as they are the actor putting the concession to tender. All other actors know each other but are competitors due to the tendering process, as such they are not connected in this field.

Actor c_score	HoR	MT	NS	Conn	DB	SC
House of Representatives		x				
Ministry of Transport	x		x	x	x	x
NS, KLM, National Express		x				
Connexxion, CGEA & SJ		x				
DB & Arriva NL		x				
Stagecoach		x				

Actor PSD	Problem definition	Solution definition
Connexxion, CGEA & SJ	1. Concession HSL	1. 61 million (June 2001)
DB & Arriva NL	1. Concession HSL	1. 100 million per year is too high (3-2-2001) 2. The offer for the bid is 100 (June 2001)
House of Representatives	1. Concession HSL	1. No tender, because fear for big foreign contender (5-5-2000) 2. Allows tender, but still fears big foreign contenders (29-6-2000)

Ministry of Transport	1. Concession HSL	1. Public tender; demands such that NS will win (14-6-2000): a. Dutch office, knowledge rail NL b. Level playing field (reciprocity) 2. Independent committee to evaluate bids (2-10-2000) 3. Four bids qualify and receive bid information (26-10-2000) 4. At least 100 million for concession for 15 years (in case no proper offer operate themselves) (25-1-2001) 5. NS will receive concession (16-6-2001), 2nd are Connexxion, c.s. and third DB & Arriva.
NS, KLM, National Express	1. Concession HSL	1. 148 million (June 2001)
Stagecoach	1. Concession HSL	1. Withdraw due to no Dutch partner (3-5-2001)

Solution: July 10th an agreement on the main issues for the concession of HSL-Zuid is made between the ministry and NS; concession cost is 148 million per year (established after negotiation), the contract will be valid for 15 years, 96 train rides per day.

Field 4: Price fight

The ministry of Transport is connected with NS (HSA) and the House of Representatives as in the previous fields.

Actor c_score	HoR	MT	HSA
House of Representatives		x	
Ministry of Transport	x		x
HSA		x	

Actor PSD	Problem definition	Solution definition
House of Representatives	1. Concession HSL	1. Against high price rise tickets (5-12-2001) a. Renegotiate contract with HSA for lower ticket price (29-8-2002)
Minister Transport	1. Concession HSL	1. Prices 50% higher for HSL-Zuid (5-12-2001) 2. No maximum on prices for tickets (29-8-2002), reconfirmed 4-10-2002) based on information from HSA
HSA	1. Concession HSL	1. Raise ticket price 50% to cover cost concession (5-12-2001) 2. Two bid options (29-6-2002): a. 148 million, high ticket price (60%) b. 101 million, lower ticket prices (25%)

Solution: October 4th minister De Boer (Transport) reconfirms that he will not request a maximum price based on the information provided by HSA that a lower price will raise the amount of train rides on the route so the concession could go to 101 million. In other words, it stays at 148 million with no price restriction. December 12th the House of Representatives want the minister to request more information of HSA to judge if it is really impossible to have a maximum price for the tickets. The minister promises to look into it.

Field 5: Lost time and lost connections between NL & BE

The ministry of Transport is connected with NS (HSA) as in the previous fields. They are also connected with the Belgian ministry of Transport due to having had many related issues and working history. The Belgian ministry is also connected with the Belgian train operator NMBS as they have been working together for years. NS & NMBS are connected as they jointly operate HSL-Zuid, but also as they have been servicing cities across the border together.

Actor c_score	Be MT	NS	MT	NMBS
Belgian min transport			x	x
NS			x	x
Ministry of Transport	x	x		
NMBS	x	x		

Actor PSD	Problem definition	Solution definition
Belgian minister transport	1. Servicing cities 2. Deepening Westerschelde	1. Recover lost time and service Breda & Den Haag, by different schedule to prioritize HSL (1-6-2004)
Ministry of Transport	1. Belgians not servicing cities and recovering delay	1. No renegotiation concession with NS as Belgium is responsible for lost time and no service to Breda & Den Haag (19-3-2004) a. HSA & NMBS need to find joint solution 2. Different schedule to prioritize HSL (1-6-2004) 3. No deepening Westerschelde as long as Belgian minister does not put pressure on NMBS (21-12-2004)
NS	1. Servicing cities	1. Reduction on concession cost as Belgium has made wrong time calculations (17 minutes) (19-3-2004)
NMBS	1. Servicing cities	1. No service as risk for losses (19-3-2004)

Solution: March 12th 2005 the two ministers reach an agreement on HSL-Zuid: minister Peijs accepts a loss of 8 minutes travelling time in exchange for shuttle services to Breda and Den Haag.

Field 6: HSA uses monopoly power, but still needs to be saved from bankruptcy

The ministry of Transport is connected with NS (HSA) as in the previous fields.

Actor c_score	MT	NS
Ministry of Transport		x
NS	x	

Actor PSD	Problem definition	Solution definition
Ministry of Transport	1. Concession HSL	1. Bankruptcy NS vs losses new concession (31-1-2011) 2. New concession 2.2 billion (cost Min T: 390 million instead of 2.4 billion bankruptcy) (18-11-2011)

NS	1. Concession HSL	1. Lower concession fee (9-12-2010) a. Lasts for 15 years b. Cost 130 €/km

Solution: New concession 2.2 billion (cost Min T: 390 million instead of 2.4 million bankruptcy) (18-11-2011)

Field 7: Finally trains going to Breda and Den Haag

The ministry of Transport is connected with NMBS due to decisions in previous fields.

Actor c_score	MT	NMBS
Ministry of Transport		x
NMBS	x	

Actor PSD	Problem definition	Solution definition
Ministry of Transport	1. Servicing cities	1. No new schedule as NMBS should service Breda & Den Haag (19-9-2012) a. NMBS should buy new train 2. Possible legal steps against NMBS (10-10-2012) 3. Financial contribution (2.5-3.5 million) (4-12-2012) a. High speed service to Breda – Antwerp b. Intercity connection Den Haag – R'dam
NMBS	1. Servicing cities	1. No service to Breda & Den Haag (22-11-2011) a. Not profitable 2. Dutch government should financially assist (19-9-2012)

Solution: December 4th 2012 it is agreed between secretary of state Wilma Mansveld (Transport), NS & NMBS that a high speed train will ride between Breda and Antwerpen. Den Haag will be serviced with an intercity to Rotterdam where it connects with Fyra. The Dutch government will financially contribute to make this possible; estimated cost between 2.5 and 3.5 million euro. NS & NMBS are happy, but traveler organizations Rover (NL) and TreinTramBus (Be) are dissatisfied as it is compromise between nations which won't benefit citizens.

Field 8: Back to square 1

The ministry of Transport is connected with NS (HSA) as in the previous fields.

Actor c_score	MT	NS
Ministry of Transport		x
NS	x	

Actor PSD	Problem definition	Solution definition
Minister Transport	1. Servicing HSL 2. Servicing DH - Brussels	1. Alternatives for HSL, since no V250 (22-1-2013) 2. Penalties to NS & NMBS if they don't fulfill contract (22-1-2013) a. Punctuality b. Passenger satisfaction 3. Temporary intercity service Den Haag – Brussels will remain (26-2-2013)

		4. No new contracts, or new tender, for HSL-Zuid (26-2-2013)
NS (& NMBS)	1. Servicing HSL	1. New scenario's about servicing HSL-Zuid (26-2-2013)

A.4 Lineage 4 – Operating the HSL-Zuid

Field 1: Tendering rolling stock

The NS (HSA) is connected to all actors as they are the actor putting the concession to tender. All other train builders know each other but are competitors due to the tendering process, as such they are not connected in this field. The ministry of Transport is connected to HSA as per working together in several other fields and in other related issues in history.

Actor c_score	Alstom	AB	Bom	HSA	MT	Siemens
Alstom				x		
AnsaldoBreda				x		
Bombardier				x		
HSA & NMBS	x	x	X		x	x
Ministry of Transport				x		
Siemens				x		

Actor PSD	Problem definition	Solution definition
Alstom	1. Rolling stock	1. Double decker AGV pulled by two locs & price per seat 34.384 (fall 2003) 2. Withdraw (23-12-2003)
AnsaldoBreda	1. Rolling stock	1. New train, 220 km/h and 546 seats 2. V250, price per seat 34.631 (fall 2003)
Bombardier	1. Rolling stock	1. Locs 200 km/h, wagons variable 2. Withdraw (summer 2003)
HSA & NMBS	1. Rolling stock	1. 23 trains ready by October 2006 (19-4-2002) a. 220 km/h b. Price per seat should be low c. 450-550 seats 2. Only 12 trains (with option for 14 more), new offer requested of Alstom & Bombardier (23-12-2003)
Min T	1. Rolling stock	1. 250 km/h due to required service time (summer 2003)
Siemens	1. Rolling stock	1. Velaro, 300 km/h. 2. Withdraw (summer 2003)

Field 2: Troubles with ERTMS

The NS (HSA) is connected to all actors as they are the actor putting the concession to tender. All other train builders know each other but are competitors due to the tendering process, as such they are not connected in this field. The ministry of Transport is connected to HSA as per working together in several other fields and in other related issues in history.

Actor c_score	AB	HoR	HSA	MT
AnsaldoBreda			x	
House of Representatives				x

HSA	x			x
Ministry of Transport		x	x	

Actor PSD	Problem definition	Solution definition
AnsaldoBreda	1. ERTMS a. Constantly adjusted norms b. Conflicting laws NL, BE and EU	1. Train delivery will be delayed due to ERTMS issues (16-12-2005), trains will probably be more expensive
House of Representatives	1. Operating HSL	1. Do not keep NS to their contract as they may go bankrupt (2-11-2005) 2. Demands solution by minister about ERTMS and delayed delivery trains, paid by NS (11-11-2005) 3. NS should Fix late delivery, # expected passengers and ERTMS (based on report by Court Audit, 20-7-2007)
Ministry of Transport	1. Operating HSL 2. Late delivery material	1. Only ERTMS (12-10-2005) 2. NS will be held to their contract (148 mil/year) (12-10-2005) 3. NS should lease material in the meantime (12-10-2005) a. NS should pay for the leased material 4. No legal battle with and no deadline for NS, as the ministry has underestimated ERTMS (25-4-2007) 5. HSA will be compensated a. Due to late delivery ERTMS by ministry b. Unclear starting date HSL, also due to dust formation in Green Heart Tunnel (11-9-2007)
NS/HSA	1. Operating HSL 2. Later delivery material due to ERTMS	1. Besides ERTMS other safety system (12-10-2005) 2. Leasing locs (160 km/h) till V250 is delivered, means 10 minutes shorter instead of 30 (7-11-2005), i.e. 12 Bombardier-Traxx locs (27-12-2005) 3. Charge minister for leasing locs of Bombardier (27-12-2005)

Solution: In a letter to the House the minister announces that the ministry is guilty about the late delivery and will discuss with HSA about compensation (September 11th). In this letter he also writes that it is unclear whether the starting of HSL-Zuid in December will be realized. The first reason is the already mentioned ERTMS problems, but also there is excessive dust formation in the Green Heart Tunnel. Besides these building issues he is also afraid that AnsaldoBreda will not deliver the trains on time, but that the leased Traxx-locomotives are not ERTMS proof yet.

Abstract

A primary distinction made in research on collective decision-making is between formalized approaches and empirical, in-situ approaches. As we are dealing with collective decision-making *processes*, it stands to reason that they must be studied as phenomena that occur across long time-spans. Formal models may find it difficult to cope with longitudinal dynamics as they are not well-equipped to incorporate artefacts of actual reality, such as the occurrence of random events or environmental changes. Case-based observations, however, especially those derived from single-case studies, run the risk of presenting anecdotes as evidence, and of failing to render a more structural understanding.

We set out to develop a method and research technique that could unite both modelling and case-based observations in order to analyse collective decision-making processes. To this end, we transferred fitness landscapes from evolutionary biology, and applied them to concrete studies. This class of fitness landscape models provides a scalable, integrated modelling structure in which the relationships between the system's elements are deemed as important to the outcome as the actual elements. This aim leads to the following research question: *Are fitness landscapes capable of identifying the evolutionary properties of collective decision-making?*

Following Abbott's (2001) recommendation regarding social processes, we have defined collective decision-making as an uninterrupted and non-directional process that is structured in sequences or lineages of events. Each period between demarcating events can be captured in fitness fields. While non-directional, the process is limited to a bandwidth that is determined by the configuration of both substantive and relational aspects. To structure these processes, we re-modelled the basic components of Kauffman's (1993) *NK-Fitness* model for the present purpose. We converted *N* to 'problem and solution definitions' (*PSD*s) and *K* to 'connectedness' between actors (*c_score*). An important modification is that we consider *NK* to be a *configuration*; i.e., *K* entails both content and process, particularly in relationship to past experience with other actors in similar and equivalent cases. Fitness is defined as the probability of an actor achieving (elements of) its *PSD* as a result of its adaptive moves in relation to the adaptive moves of others.

'Time' is accounted for in three ways. It can be found within the various fitness fields as field-bound dynamics. These dynamics are driven by actors trying to gain and maintain higher individual fitness in response to the moves of others that alter the average fitness in the field, thereby necessitating such a move. Second, it is present in lineage-bound dynamics, i.e. as series of coupled events and their unfolding in one field affecting the events in a subsequent field. Third, it is present in the coupledness between fields in different lineages where movement or changing environmental conditions in one field influence other coupled fields in other lineages.

The model is put to the test in four different studies: i.e. (i) 20 years of decision-making in planning, building and servicing HSL-Zuid high-speed railways in the Netherlands, (ii) the strategic search process of villages and cantons in the Gotthard region of Switzerland, (iii) the redevelopment of a football stadium and the surrounding area in south Rotterdam, the Netherlands, and (iv) the rise and fall of the Airport RailLink in Bangkok, Thailand.

Actors engaged in the collective decision-making process try to gain fitness by seeking alliances with or opposition to other actors. Therefore the locus of fitness gains and losses is in the *interaction* between those actors, as each action is carried out in response to actions of others. The consequences of these interactions are manifest in two principal forms of emergence. First, the aggregated result of all those individual actions in the field concerns shifts in PSD and c_score, ultimately leading to changes in the fitness of each individual actor in the field. As such, fitness is context-dependent. This implies that it can be achieved through various strategies in response to what other actors do and that, once obtained, it will be temporal.

From the four empirical studies, we derived six archetypical forms in collection decision-making, subdivided into actor archetypes and interaction archetypes. Each group contains three archetypes. For the actor archetypes, behavioural consistency is not just a trait for the actor but also affects the space of possibilities and/or behaviours of other actors. The first archetype is that of 'the buoy': an actor that is relatively stable and that acts as a beacon for other actors. The second

archetype is ‘the jumper’: an actor that behaves relatively erratically and can be seen moving around on the grid. The third archetype is ‘the inflexible’, an actor that against all the odds (un)knowingly or (un)willingly sticks to certain elements of its PSD. By and large, actors with a high PSD and *c_score* are likely to achieve at least some of their goals, and actors with a lower PSD and *c_score* can also be successful, provided they are flexible. Inflexibility in combination with a low PSD and *c_score* is usually, but not by definition, not rewarded with fitness gains.

The interactions of individual actors combine to produce self-propagating dynamics that drive the further evolution of the collective decision-making process. Again, we identified three principal archetypes: ‘force to fit’, ‘self-organized entrapment’, and ‘diversity breeds diversity’. In ‘force to fit’, actors try to break out of deadlocks through changes in the *c_score*. ‘Self-organized entrapment’ entails involuntary clustering due to alterations in problem and solution definitions, as expressed in the *c_score*. ‘Diversity breeds diversity’ concerns the idea that the introduction of diversity in the *c_score* and problem and solution definitions trigger more diversity. These dynamics are related to individual actions in a non-linear fashion because the actions of individual actors contribute to, but cannot exclusively cause, the said dynamics.

The fitness field model presented in this thesis enables us to investigate the various dimensions of the collective decision-making process – ranging from individual strategies and actions to variation, selection and retention of contents, from interactions to fitness gains and losses, and back again. The studies presented in the thesis confirm that the model highlights said dynamics.

Samenvatting

In het onderzoek naar collectieve besluitvormingsprocessen kan een onderscheid gemaakt worden tussen formele benaderingen en empirische, in situ benaderingen. Omdat het hier gaat om *processen* van collectieve besluitvorming, ligt het voor de hand om ze te bestuderen als fenomenen die zich over een langer tijdsbestek afspelen. Formele modellen kunnen minder goed overweg met longitudinale dynamiek omdat ze slecht zijn toegerust om artefacten van de werkelijkheid mee te nemen, zoals toevallige gebeurtenissen of veranderingen in de omgeving. Case-based waarnemingen - vooral wanneer die voortkomen uit single-case onderzoek - lopen daarentegen het risico anekdotes als bewijs te presenteren en niet te leiden tot meer structureel begrip.

We hebben ons ten doel gesteld een methode en een onderzoekstechniek te ontwikkelen die de mogelijkheid bieden modellen en case-based waarnemingen te combineren en op die manier collectieve besluitvormingsprocessen te analyseren. We hebben daartoe het begrip ‘fitness landschap’ uit de evolutionaire biologie overgenomen en dit in concreet onderzoek toegepast. De klasse van modellen van fitness landschappen voorziet ons van een schaalbare en geïntegreerde modelleringsstructuur waarbinnen de relaties tussen de elementen van het systeem net zo belangrijk zijn voor het eindresultaat als die elementen zelf. Dit brengt ons tot de volgende onderzoeksvraag: *Is het mogelijk met behulp van fitness landschappen de evolutionaire eigenschappen van collectieve besluitvorming te identificeren?*

In navolging van Abbott’s (2001) aanbeveling met betrekking tot sociale processen in het algemeen definiëren we collectieve besluitvorming als een ononderbroken en niet-directioneel proces dat is gestructureerd rond opeenvolgingen of ‘*lineages*’ van gebeurtenissen. Perioden tussen twee bepalende gebeurtenissen worden vastgelegd in fitnessvelden. Hoewel de richting van het proces niet vastligt, beweegt het zich altijd binnen een zekere bandbreedte, die wordt bepaald door de configuratie van zowel inhoudelijke als relationele aspecten. Om dergelijke processen te structureren hebben we de basiscomponenten van Kauffman’s (1993) *NK-Fitness* model op een nieuwe manier toegepast. We hebben *N* omgezet in ‘definities van problemen en oplossingen’ (DPOs) en *K* in ‘koppeling’ tussen actoren (c_score). Een belangrijke aanpassing bestaat hieruit dat we *NK* beschouwen als een *configuratie*, hetgeen wil zeggen dat *K* betrekking heeft op zowel inhoud als proces, met name waar het gaat om eerdere ervaringen met andere actoren in vergelijkbare of dezelfde situaties. Fitness definiëren we als de waarschijnlijkheid dat een actor (delen van) zijn DPO aanvaard krijgt als gevolg van zijn eigen adaptieve handelingen afgezet tegen de adaptieve handelingen van andere actoren.

‘Tijd’ wordt op drie manieren verwerkt. Ten eerste in de veldgebonden dynamiek binnen de diverse fitnessvelden. Deze dynamiek wordt aangedreven door actoren die proberen een hogere individuele fitness te verkrijgen en te behouden in reactie op de zetten van anderen, die de gemiddelde fitness in het veld immers veranderen en daarmee nieuwe zetten noodzakelijk maken. Ten tweede in lineage-gebonden dynamiek, dat wil zeggen de reeksen van gekoppelde gebeurtenissen en hun uitwerking in het ene veld die invloed hebben op de gebeurtenissen in een volgend veld. Ten derde in de koppeling tussen velden in verschillende lineages waarbij beweging of veranderende omgevingsomstandigheden in een bepaald veld een weerslag hebben op gekoppelde velden in andere lineages.

We hebben het model getest aan de hand van de volgende vier studies: (i) 20 jaar besluitvorming inzake planning, bouw en onderhoud van de Hogesnelheidslijn-Zuid in Nederland, (ii) het strategische zoekproces van dorpen en kantons in de Gotthardregio in Zwitserland ten aanzien van hun ruimtelijke en economische planning, (iii) de herontwikkeling van een voetbalstadion en het omliggende gebied in Rotterdam-Zuid en (iv) de opkomst en ondergang van de Airport Rail Link in Bangkok, Thailand.

Actoren die betrokken zijn bij collectieve besluitvormingsprocessen proberen hun fitness te verhogen door allianties aan te gaan of verzet te organiseren tegen andere actoren. De locus van toename of afname van fitness ligt daarom in de *interactie* tussen de actoren, aangezien iedere handeling wordt uitgevoerd als een reactie op de handelingen van anderen. De gevolgen

van deze interacties komen op twee manieren tevoorschijn. Het geaggregeerde resultaat van alle individuele acties in het veld draait om verschuivingen in DPO en c_score en leidt uiteindelijk tot veranderingen in de fitness van elke individuele actor in het veld. Fitness als zodanig is contextafhankelijk. Dit houdt in dat fitness kan worden bereikt door middel van uiteenlopende strategieën in reactie op de handelingen van andere actoren en dat eenmaal verkregen fitness altijd tijdelijk van aard zal zijn.

Op grond van de vier empirische studies kunnen we in collectieve besluitvorming zes archetypen onderscheiden, onderverdeeld in actor-archetypen en interactie-archetypen. Elke groep bestaat uit drie archetypen. Waar het gaat om actor-archetypen is consistent gedrag niet alleen een eigenschap van de actor maar beïnvloedt het ook het scala aan mogelijkheden en/of gedragingen van andere actoren. Het eerste archetype is dat van de 'boei': een relatief stabiele actor die fungeert als een baken voor andere actoren. Het tweede archetype is dat van de 'springer': een actor die zich betrekkelijk onvoorspelbaar gedraagt en op diverse plaatsen kan opduiken. Het derde archetype is dat van de 'onbuigzame', een actor die, ondanks alles, bewust of onbewust en al of niet met tegenzin blijft vasthouden aan bepaalde onderdelen van zijn DPO. Over het algemeen hebben actoren met een hoge DPO en *c_score* meer kans om ten minste enkele van hun doelen te bereiken, maar actoren met een lagere DPO en *c_score* kunnen eveneens succesvol zijn, op voorwaarde dat ze zich flexibel opstellen. Onbuigzaamheid in combinatie met een lage DPO en *c_score* wordt doorgaans - maar niet noodzakelijkerwijs - niet beloond met een toename in fitness.

De gecombineerde interacties van individuele actoren produceren een zichzelf voortstuwende dynamiek die de verdere evolutie van het collectieve besluitvormingsproces aandrijft. Ook hier kunnen we drie hoofdarchetypen onderscheiden: 'force to fit', 'self-organized entrapment' en 'diversity breeds diversity'. In '*force to fit*' proberen actoren patstellingen te doorbreken door middel van veranderingen in de *c_score*. '*Self-organized entrapment*' verwijst naar onvrijwillige groepsvorming als gevolg van wijzigingen in de definities van probleem en oplossing, zoals uitgedrukt in de *c_score*. '*Diversity breeds diversity*' betreft het idee dat het introduceren van diversiteit in de *c_score* en in de definities van probleem en oplossing meer diversiteit tot gevolg zal hebben. De relatie tussen dynamiek en individuele acties is non-lineair van aard aangezien de handelingen van individuele actoren weliswaar bijdragen aan de betreffende dynamiek maar daarvan niet de enige oorzaak zijn.

Het hier voorgestelde fitnessveld-model maakt het mogelijk de verschillende dimensies van het collectieve besluitvormingsproces te onderzoeken, variërend van individuele strategieën en handelingen tot variatie, selectie en behoud van inhoud en van individuele interacties tot een toename dan wel afname van fitness. De studies die hier behandeld worden bevestigen dat het model goed in staat is de beschreven dynamiek naar voren te halen.