Complex dynamics in a transactional model of societal transitions

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Abstract

Transitions are structural innovations of societal systems in reaction to wicked problems threatening development. In this paper we develop a transactional model of transitions based on Coleman's linear system of action. The model implemented has the characteristics of a dissipative system. A variation and selection algorithm favoring the selection of relatively dependent actors into the social system forces the system away from equilibrium. Exchange of control, according to Coleman the driving force behind social action, accounts for dissipation and brings the social system back to equilibrium. We expect the Transactional Model of Transitions to show complex dynamics. Power law behavior and punctuated equilibrium are of special interest, as these are closely connected to hypotheses on social dynamics developed in the literature on societal transitions and system innovations. We present simulation results for various variation and selection procedures, interpret their meaning in the light of societal transitions and system innovations and discuss their conformity with actual social processes. Our results show that the Transactional Model of Transitions indeed shows complex dynamics, mirrors some of the characteristics of transition dynamics and is promising for further research on Transition Management. We did not yet find conclusive evidence of evolution to the edge of chaos, self-organized criticality and/or power law behavior.

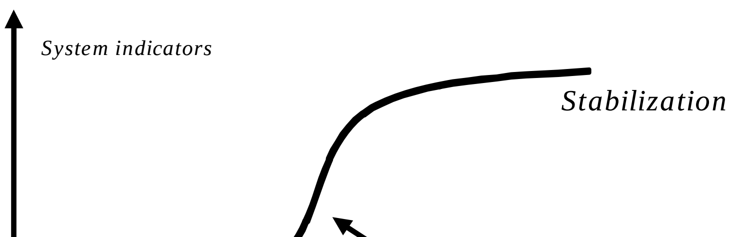
Text

1. Introduction

Transitions are structural innovations of societal systems in reaction to wicked problems threatening development (Rotmans 2005, 2001; Van der Brugge et al., 2005). Transition Management (Rotmans, 2005; Rotmans et al., 2001; Van der Brugge et al., 2005) is developed as a mode of governance aiming to deliberately guide transitions towards sustainable development (Bruggink, 2005). In this paper we present the first outlines of a transactional model (Timmermans, 2004; Timmermans and Beroggi, 2000) of the social dynamics involved in transitions. The model is developed as a tool to evaluate existing instruments and design new instruments and approaches in Transition Management and is rooted in Coleman's Social Theory and the Linear System of Action (Coleman, 1990).
Rotmans et al., have introduced the concepts of transition theory and Transition Management as a new integrative approach in the field of sustainability and governance in order to deal with persistent problems (Rotmans, 2005; Rotmans et al., 2000; Van der Brugge et al., 2005, Kemp et al., 1998). The transition framework offers analytical tools for structuring and explaining the dynamic behavior of societal systems, such as transport, energy supply, agriculture and water management. Transition management attempts to influence, facilitate, stimulate, organize and guide processes that contribute to the transition.
Transitions are often illustrated with S-shaped curves (Figure 1). Although this is a simple aggregated curve, the underlying transition dynamics are complex interaction processes between markets, networks, institutions, technologies, policies, individual behavior and autonomous trends in the economic, ecological, socio-cultural and institutional domain. From a complex adaptive systems (CAS) perspective, transitions are system transformations between two temporal (dynamic) equilibrium states (attractors). In between there is a period of rapid change during which the system undergoes irreversible re-organization (Rotmans, 1994).
According to Rotmans (Rotmans et al., 2000) the general pattern of evolution during the four phases is the following. In the pre-development phase, the system dynamics do not change visibly. In the take-off phase, the structure of the system begins to change as the result of (1) the emergence of innovations and (2) destabilization of the existing regime. In the acceleration phase, structural transformation of the system takes place. In the stabilization phase the new pattern of system dynamics reaches a new dynamic equilibrium.
The transition framework is rooted in CAS theory (Holland, 1995; Kauffman, 1995; Prigogine & Stengers, 1984) post-normal science (Ravetz, 1999), while integrating concepts from governance (Sabatier & Jenkins-Smith, 1999), evolutionary economics (Arthur, 1988; Nelson & Winter, 1982), innovation studies (Smits & Kuhlmann, 2004) and technological transitions (Geels & Kemp, 2000). In this paper we are especially interested in the CAS characteristics of social transitions. Concepts like punctuated equilibrium and self-organized criticality (Bak and Sneppen, 1993) operating in a social system carry the promise for an explanation of the unpredictable behavior and occurrence of societal transitions and the proposed S-shape dynamics of transitions. Power law behavior is congruent with the observation that in societal systems small changes happen all the time, while changes with a big impact, transitions, are rare.
We aim to develop a model of social dynamics showing complex behavior and the characteristics of CAS described above including regime formation and S-curve dynamics as postulated by transition theory (Rotmans, 2005; Rotmans et al., 2000; Van der Brugge et al., 2005). Our starting point is Coleman's Social Theory and the LSA (Coleman, 1990). This theory seems promising for this purpose, both from a theoretical as from a modeling perspective.

Figure 1 **Typical development and stages in a transition**

A transition is the shift between two dynamic equilibriums that can be described by a set of system indicators. In the transition process, four phases can be distinguished. In the predevelopment these indicators change only marginally. In the take-off and acceleration phase the indicators change with increasing speed. In the stabilization a new equilibrium is reached (Rotmans et al., 2002).



Social theories are theories that aim to explain social developments. The Social Theory of James S. Coleman explains social development as the result of exchange of control over issues between actors and belongs to the group of social theories that apply exchange theorizing and rational choice theory. Coleman's Social Theory and similar or adapted theories have been widely applied in policy analysis (Timmermans 2004, Timmermans and Beroggi 2005, Schouten et al., 2000; Stokman and Berveling, 1998; Stokman and Zeggelink 1996; Pappi and Knoke, 1991).

In Coleman's Social Theory, profitable transactions between purposive actors are the primary explanatory factors. According to Coleman, in the minimal social systems there are two kinds of elements and two ways in which they are related. The elements are actors, and *issues* over which they have control and in which they have some interest. Social development is perceived of as a negotiation process in which agreements are reached on the exchange of control between actors in a social system. The quantitative implementation of this theory, the Linear System of Action (LSA), captures this exchange process in a micro-economic model. We use the LSA as the basis for the Transactional Model of the social dynamics involved in transitions.

The LSA is an equilibrium model and only covers part of social dynamics. It covers normal social development in the pre-development and stabilization phases of the S-curve. It does however, not cover the rapid and fundamental change observed in societal transitions. In terms of the LSA, transitions involve a fundamental shift in the distributions of control and interest defining the LSA.

In the next section first the LSA will be presented in more detail. Next the model will be extended to cover the radical changes and related dynamics of transitions observed in real social systems and described in transition theory.

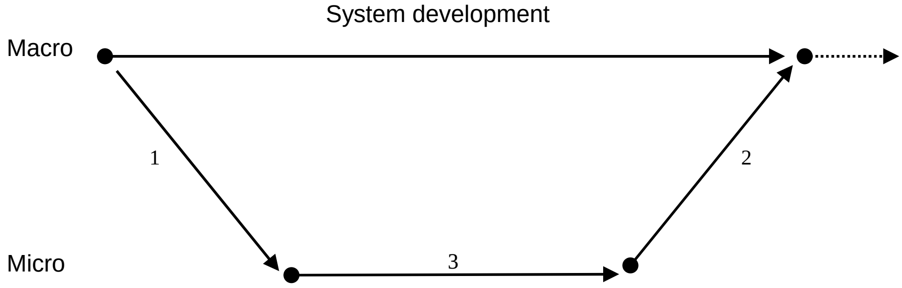
2. The Linear System of Action

Coleman's Social Theory uses a systems approach to social explanation and incorporates three components. Two of these involve the relation between the system and the system units. These relations are called respectively the micro-to-macro and the macro-to-micro transition. The third component is called the individual-level theory of action and covers the actions of the individual actors (Figure 1).

Figure 2 **Systems approach to social explanation (after Coleman, 1990)**

Arrow one is the macro-to-micro transition and depicts the influence of action determining the decisions of individual. In turn arrow two depicts the micro-to-macro transition and resembles the influence of the actions of individual actors on system development. Arrow three is the individual level theory of action.

In the minimal social systems there are two kinds of elements and two ways in which they are related.



The elements are actors, and things over which they have control and in which they have some interest (Coleman, 1990). These things can be called resources, issues or events, depending on their character. It is each actor's interest in resources, issues or events under another's control that lead purposive actors (Weber, 1958 [1904]) to engage in interactions involving exchanges of control. In these transactions actors maximize their realization of interests. Exchanges of control continue until the system of action reaches equilibrium, at which point all actors control those issues that most interest them, subject to the power of their initial resources.

The Linear System of Action (LSA) is the formal implementation of this theory and is based on micro-economic theory and its use of utility theory and the more rigid notion of rationality, as developed in economics.

In micro-economic theory, the utility U_i of actor *i* can be specified algebraically as a function of the amount of each good *m* held by actor *i*:

$$U_i = U_i(c_{i1}, c_{i2} \ldots c_{im}) \qquad (1)$$

The development of the LSA deviates from micro-economic theory in its prescription of a specific form of the utility function U_i:

$$U_i = c_{i1}^{x_{1i}} c_{i2}^{x_{2i}} \ldots c_{im}^{x_{mi}} \qquad (2)$$

Where U_i is the total utility of actor *i*, c_{ij} is the amount of good *j* held by actor *i* and where x_{ji} expresses the contribution that good *j* makes towards the utility of individual *i*

while $x_{ji} \geq 0$ and $\sum_i x_{ji} = 1$. The first constraint implies that each good contributes positively, if at all, to individual *i*'s utility. The second constraint implies declining marginal utility. This multiplicative form of a utility function is known in economics as a Cobb-Douglas-type utility function.[1] In the formulas above the quantities *cij* correspond directly to control of actor *i* over issue *j* and the quantities x_{ji} correspond directly to interest of actor *i* in issue *j*. Furthermore, c_{ij} and x_{ji} are scaled arbitrarily to 1:

$$\sum_{i=1}^{n} c_{ij} = 1 \quad \text{and} \quad \sum_{i=1}^{m} x_{ji} = 1 \qquad (3)$$

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1 In fact the Cobb-Douglas function is a production function, relating production to the input of capital and labor. The utility function used by Coleman in the LSA has the same shape as the Cobb-Douglas production function.

In matrix notation the matrix C denotes the control of actor *i* over good *j*, while the matrix X depicts the interest of actor j in good i:

$$C = \|c_{ij}\| \quad \text{and} \quad X = \|x_{ij}\| \qquad (4)$$

In a competitive equilibrium, each issue has a single price, v_j, the rate at which it is exchanged in all transactions. Consequently all actors have a fixed amount of power, which is equal to the sum of the value of their resources:

$$r_i = \sum_{i=1}^{m} c_{ij} v_j \qquad (5)$$

Combining the values of all *j* issues and the power of all *i* actors in the system results in the value vector *v* and the power vector *r*:

$$v = \|v_j\| \quad \text{and} \quad r = \|r_i\| \qquad (6)$$

In the LSA, all actors engage in exchanges of control in order to maximize their utility. This exchange process leads to an equilibrium distribution of control, the competitive equilibrium. The competitive equilibrium for the LSA with initial control distribution *C* and distribution of interest *X* is reached at the equilibrium distribution of control, C^*, which is calculated as:

$$C^* = D_r X' D_v^{-1} \qquad (7)$$

Where D_r is an n x m matrix with diagonal elements r_i and D_v is an m x m matrix with diagonal elements v_j. Depending on the available data, *C* and *X* or C^* and *X*, the missing parameters of the model can be derived from the matrix equation by substituting:

$$r = CXr \quad \text{or} \quad v = XCv \qquad (8)$$

where the power vector r or the value vector v can be calculated as:

$$r = (I - CX + E_n)^{-1} e_{n1} \quad \text{and} \quad v = (I - XC + E_m)^{-1} e_{m1} \qquad (9)$$

With E_n a square matrix with elements $^1/_n$ and E_m a square matrix with elements $^1/_m$, both e_{n1} and e_{m1} are defined as n x 1 and m x 1 column from these matrices; *I* is the identity matrix. Figure 2 presents a general layout of the LSA.

Figure 3 Matrices X and C of the Linear System of Action

The matrices of interest *X* and initial control *C* define the LSA. *X* is an m x n matrix with row-wise m issues and column-wise n actors. *C* is an n x m matrix, with row-wise n actors and column- wise m issues.

$$\begin{bmatrix} x_{ji} & x_{j(i+1)} & \Lambda & \Lambda & x_{jn} \\ x_{(j+1)i} & \Lambda & \Lambda & \Lambda & x_{(j+1)n} \\ \Lambda & \Lambda & \Lambda & \Lambda & \Lambda \\ \Lambda & \Lambda & \Lambda & \Lambda & \Lambda \\ x_{mi} & x_{m(i+1)} & \Lambda & \Lambda & x_{mn} \end{bmatrix} \qquad \begin{bmatrix} c_{ij} & c_{i(j+1)} & \Lambda & \Lambda & c_{im} \\ c_{(i+1)j} & \Lambda & \Lambda & \Lambda & c_{(i+1)m} \\ \Lambda & \Lambda & \Lambda & \Lambda & \Lambda \\ \Lambda & \Lambda & \Lambda & \Lambda & \Lambda \\ c_{nj} & c_{n(j+1)} & \Lambda & \Lambda & c_{nm} \end{bmatrix}$$

3. A Transactional Model of Transitions

The LSA presented above is an equilibrium model. In the LSA there are no changes in the equilibrium values of issues, or in the distribution of power over actors. Societal transitions however exactly involve such changes or shifts from one dynamic equilibrium to another.

According to Coleman three sources of such a shift in equilibrium exist (Coleman, 1990). First, issues can enter or leave the system. Second, new actors can enter the system, and third actors and issues can simultaneously enter or leave the social system (Coleman, 1990: p. 895-896). All three developments result in a shift in the distribution of interest and control within the LSA and consequently a new equilibrium. Coleman does elaborate on the reasons for actors or issues to enter or leave the system for the specific case of single- and double-contingency panics (Coleman, 1990:p. 899-931) but does not present a more general explanation.

To describe the social dynamics involved in transitions, a more general explanatory theory of equilibrium shifts in the LSA is required. To model the dynamics of social transitions, we propose a variation and selection procedure based on a rational approach at the system level. For individual actors in the social system is seems rational to select actors into the social system that increase their own opportunities for exchange of control and thus realizations of their individual interest while excluding actors that do not contribute. At the system level this rational maximizing behavior process of individual actors leads to a collective outcome in which actors adding opportunities for exchange, and thus forcing the system away from equilibrium, are selected into the social system.

Whether we define this mechanism as a pure selection mechanism operating on existing actors outside the social system studied or as a mutation selection procedure which forces less favored actor to mutate by changing their interests in order to continue to be a member of the social system, is an interesting point of debate but not relevant for the dynamics of the model proposed. We favor the mutation selection procedure as it links to the idea that an important difference between the social dynamics in equilibrium conditions and during transitions is the shift in equilibrium of the LSA caused by changing interests of actors under transition conditions. This choice is further bolstered by the observation of the two prominent authors on rational choice theories. Michael Hechter (Hechter, 1987, 1988) and James S. Coleman (1986) in their theories of group solidarity. These theories explain the emergence of groups from the rational self-interested behavior of individual actors. Coleman's line of thinking develops around the need for actors to interact in order to produce joined goods contributing to the realization of the interests of the individual actor.

To implement the mutation selection procedure and the link to the LSA, numerous procedures can be developed. Each of these procedures uses different criteria to answer the two relevant questions: which actor is replaced, mutated or changed? And to what extend and in accordance to which procedure are the characteristics of the selected actor mutated or changed? A wide range of selection and mutation procedures is available and many of them were tried to get an overview and increased insight in the characteristics of the model. In this paper we present three alternative selection mutation procedures.

First we present a procedure, 'replace' in which the most self-dependent actor in the system is selected and is completely replaced by a new actor with randomly generated distributions of interest and control according to a random permutation of the (preference) order of interests and control. In fact this procedures simulates a situation where a new actor is selected into the system from outside and no relation between the actors inside and outside the social system exists. The procedure does not conserve the total power of the actor, which means a sudden change in the distribution of power over the actors in the social system is possible. The procedure is not rational at system level, because it seems unlikely that powerful actors within the system will select a more powerful actor into the system.

Second we use a procedure, 'mutate' in which the most self-dependent actor in the system is selected and is mutated by exchanging interest and control for the most self-dependent issue and a randomly chosen second issue. This procedure is a mutation procedure that establishes a feedback between the social system, the selected actor and the mutation itself. From the viewpoint of an individual actor this mutation procedure is rational, because it minimizes change as it only involves the swap of two preferences in the order of interest and control over the issues.

In the third procedure, 'change' interest and control of the most self-dependent actor for the most self-dependent issue are replaced by a random number within the range c_{nj}^{min} to c_{nj}^{max} and x_{jn}^{min} to x_{jn}^{max} where n is the most self-dependent actor. 'Mutate' and 'change' both conserve the total power of selected actors and the total interest in the selected issue. This makes the procedure rational from the perspective of the social system modeled, as no sudden change in the distribution of power over the actor can occur. ‘Change’ is similar to ‘mutate’ but increases the range and magnitude of possible changes. In short the three procedure implemented are:

1. ‘replace’: replaces the interest and control distributions of the most self-dependent actor
2. ‘mutate’: mutates the interest and control of the most self-dependent actor for the most self-dependent issue
3. ‘change’: changes the interest and control of the most self dependent actor for the most self-dependent issue

All three procedures proposed, require the selection of the most self-dependent actor and for ‘mutate’ and 'change’ also the most self-dependent issue. When the matrices *X* and *C* of the LSA are known the matrix of inter actor dependencies, D_{act}, can be calculated as:

$$D_{act} = C*X \qquad (10)$$

The main diagonal of matrix D_{act} gives the self-dependency of actors (Timmermans, 2004), that indicates to which extend actors are independent of the other actors in realizing their interests. It follows logically that the most self-dependent actor is also the most independent actor in the social system and consequently offers the minimum contribution in terms of potential exchange of control. This actor, with index *n*, is selected for mutation. In addition for ‘mutate’ and ‘change’ the most self-dependent issue is selected. The matrix of dependency of issues, D_{iss} is calculated as:

$$D_{iss} = X*C \qquad (11)$$

Again the main diagonal gives us the self-dependence of issues, indicating that developments in this issue are relatively independent of the development on other issues (Timmermans, 2004). On this diagonal the most self-dependent issue, *m*, can be selected. The interest of the most independent actor *n* in the most independent issue *m* contributes least to the potential for exchange of control in the LSA and therefore is the most logical spot for the mutation or change to occur.
In case of ‘mutate’ the mutation is implemented by exchanging the values x_{mn} in the matrix *X* and c_{nm} in matix *C* of for the two most self-dependent issues, while keeping total control of the mutated actor unchanged by normalizing the vector to its original length. In case of ‘change’ the mutation procedure continues by replacing x_{mn} in the matrix *X* and c_{nm} in matrix *C* of the LSA with a random number smaller or equal to the maximum x_{mi} of the matrix *X* and the maximum c_{nj} of the matrix *C*, while keeping the total control of the mutated actor unchanged by normalizing the vector to its original length.
Next we present simulation results of the model using the three procedures described and their reference cases in which selection of the mutated actor is based on a random procedure. For each model we calculated the development of the distance from equilibrium, with and without exchange and the distribution of the exchanges. All simulations are made using a randomly generated LSA with 9 actors and 15 issues. The matrices *X* and *C* are generated by random permutation of the vector (1.. 9) for the actors and (1 .. 15) for the issues and normalizing the resulting matrices column wise. This procedure resembles the ability of human actors to derive their preferences up to a strong preference order through paired comparisons (Beroggi, 2000, 1999; Timmermans, 2004). All simulations are continued for 25.000 iterations. The model is implemented in the Matlab environment. Matlab is also used for data processing and presentation.

4. Simulation results of three alternative models

To present and evaluate the alternative procedures, we use three characteristic parameters:

- distance from equilibrium
- maximum bilateral exchange
- frequency distribution of maximum bilateral exchange

Distance from equilibrium, ${}^r c^{\phi}$, indicates the amount of exchange of control required to reach equilibrium from the current state of the current model and is calculated as:

$$ {}^r c^{\phi} = \sum_{ij} \left| {}^r c^{*}_{ij} - {}^r c_{ij} \right| \qquad (11) $$

where ${}^r c_{ij}$ is the actual control of decision maker *i* over issue *j*, ${}^r c^{*}_{ij}$ is the equilibrium control of decision maker *i* over issue *j* and *r* is the number of the iteration.

Maximum bilateral exchange potential is the highest exchange of control for a pair of decision makers and corresponding pair of issues, available in the model. For all pairs of decision makers *i* and *k* and pairs of issues *j* and *l*, the maximum bilateral exchange potential,

c^{ϕ}_{ikjl}, is calculated as:

$$ {}^r c^{\phi}_{ikjl} = \max\left[\min\left(\left| {}^r c^{\phi}_{ij} \right|, \left| {}^r c^{\phi}_{kl} \right| \right) \right] \quad \forall \quad \left| {}^r c^{\phi}_{ij} + {}^r c^{\phi}_{kl} \right| \neq \left| {}^r c^{\phi}_{ij} \right| + \left| {}^r c^{\phi}_{kl} \right| \qquad (12) $$

and:

$$ {}^r c^{\phi}_{ikjl} = o \quad \forall \quad \left| {}^r c^{\phi}_{ij} + {}^r c^{\phi}_{kl} \right| = \left| {}^r c^{\phi}_{ij} \right| + \left| {}^r c^{\phi}_{kl} \right| \qquad (13) $$

where:

$$ {}^r c^{\phi}_{ik} = {}^r c_{ik} - {}^r c^{*}_{ik} \qquad (14) $$

and:

$$ {}^r c^{\phi}_{jl} = {}^r c_{jl} - {}^r c^{*}_{jl} \qquad (15) $$

The expressions behind the ‘for all sign’, ∀, in Equations 12 and 13 shows the existence or non-existence of a double coincidence of wants. Last we use the frequency distribut-

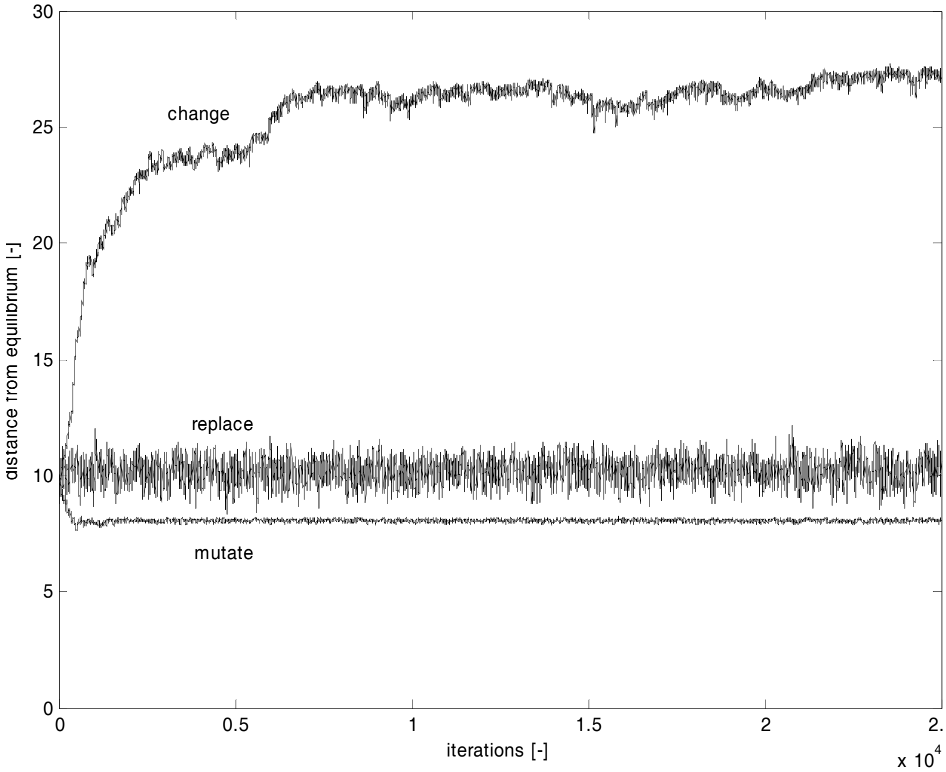
ion of c^{ϕ}_{ikjl} to characterize the results of the simulations.

In the following some characteristic results are presented and used to conclude on the characteristics and applicability of the resulting transactional model for simulating societal transitions.

Figure 4 presents the distance from equilibrium or potential for exchange of control for the three procedures. For ‘replace’ and ‘change’ the variations in ${}^r c^{\phi}$ are limited and remain close to their value at the start of the simulation. These mutation procedures don’t show a clear benefit in terms of potential for exchange at system level and in case of ‘mutate’ the potential for exchange even declines at the start of the simulation. Further inspection of the date shows that in ‘replace’ mutated actors manage to enter and survive in the system. However, the mutation procedure does not produce actors strong enough to move the social system further from equilibrium and ${}^r c^{\phi}$ remains close to the average value of 10. This is caused by the fact that the random permutation procedure to generate the new actor is similar to the procedure used to generate the initial model and overrules the effect of selecting the most self-dependent actor for mutation. This conclusion is supported by the frequency distribution of exchanges generated by replace procedure, which is approximately a normal distribution (Figure 5).

The frequency distribution of maximum bilateral exchanges for ‘change’, as presented in Figure 6b, is very irregular. Numerous local maxima exist. The frequency distribution seems to be the result of an addition of numerous frequency distributions, each with its own mean and standard deviation. The plot of the maximum bilateral exchanges of Figure 6a supports this conclusion. This plot shows more or less punctuated pattern where extended periods of average exchanges alternate with periods of relatively high exchanges of considerable duration. As can be inferred from both Figure 4 and Figure 6b, this behavior becomes apparent after circa 7500 iterations.

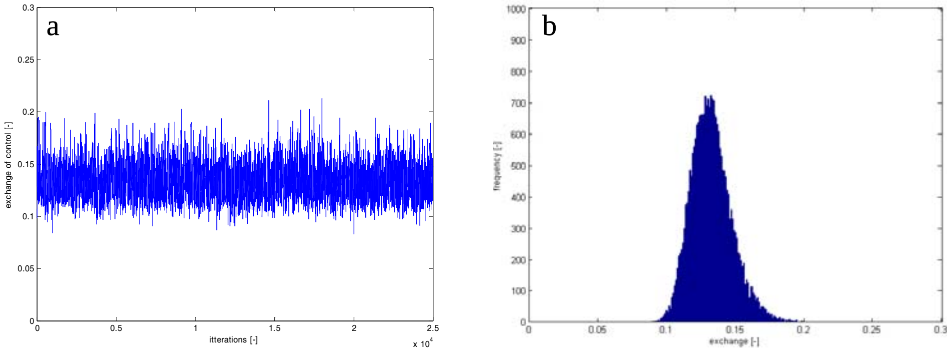
Figure 4 Distance from equilibrium for 'replace', 'mutate' and 'change'



In case of 'mutate', after an initialization period of around 1500 iterations in which ${}^{r}c^{\phi}$ declines from 9 to around 8, the mutated actors don't survive in the system anymore and the system reaches a dynamic equilibrium in which one actor is mutated infinitely.

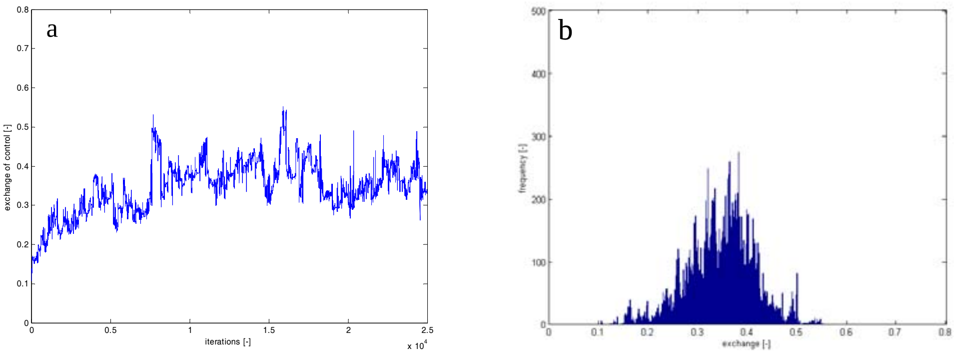
The results of 'change' are of more interest. Here the mutation procedure pushes the social system far from equilibrium. New actor move into the system all the time and survive for shorter or longer periods and move out of the system after they are ruled out by new actors adding even more potential for exchange.

Figure 5 **exchanges (a) and frequency distribution of exchanges (b) for 'replace'**



As a reference case, the selection of the actor to be replaced, mutated or changed based on self-dependency is replaced by random selection. For 'replace' and 'mutate', selection of the actor based on self-dependency or random does not influence the results of the simulations. Distance from equilibrium, maximum bilateral exchange and frequency distributions of exchanges remain similar. Also the frequency distributions of maximum bilateral exchanges are close to a normal distribution, although the influence of the initialization period spurs the results initially. Only for 'change' a clear difference between the simulations results for random selection of the actor to be mutated and selection based on self-dependence is apparent. The difference, however, is only a matter of scale; while the characteristics of the behavior are similar; selection of the actor based on self-dependence moves the social system further away from equilibrium and results in bigger maximum bilateral exchanges (Figure 6). When also the selection of the issue to be changed is replaced by a random procedure, the social system does not move away from equilibrium and the frequency distribution of the exchanges resembles a normal distribution.

Figure 6 **exchanges (a) and frequency distribution of exchanges (b) for 'change'**

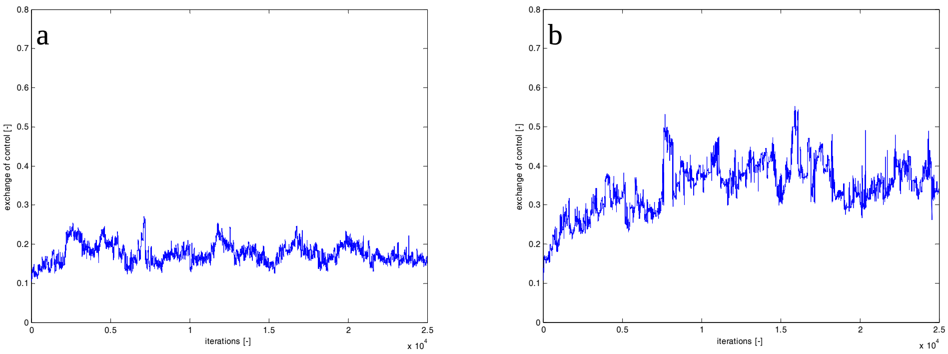


We conclude that selection of the most self-dependent actor and thus establishing a relation between the social system and the actor mutated has a decisive influence on model behavior. Only then the social system moves away from equilibrium and thus increases the opportunities of the actors included in the system to realize their interests. This proves that changing the most self-dependent actor in he social system is a rational action for the social system as a whole. This is an important conclusion in the light of the rational action theory applied in the LSA, as non-rational behavior at the system level would violate the assumption underlying the model itself.

From the above we conclude that the behavior of the TMT using 'change' is of most interest from the perspective of modeling societal transitions. The simulations show a strong push of the social system away from equilibrium while maximum bilateral exchanges are relatively large and show signs of punctuated or periodic behavior on a long time scale. Furthermore the procedure 'change' is a rational action at the system level. It remains to be seen however if and to which extend the mutation procedure satisfies the rationality assumptions for the individual actors. We leave the more detailed analysis required to answered this question for further research.

In the next paragraph the TMT incorporating procedure 3, 'change' is studied more extensively.

Figure 7 **exchange with out (a) and with selection of most self-dependent actor for 'change'**



5. Characteristics of the Transactional Model of Transition

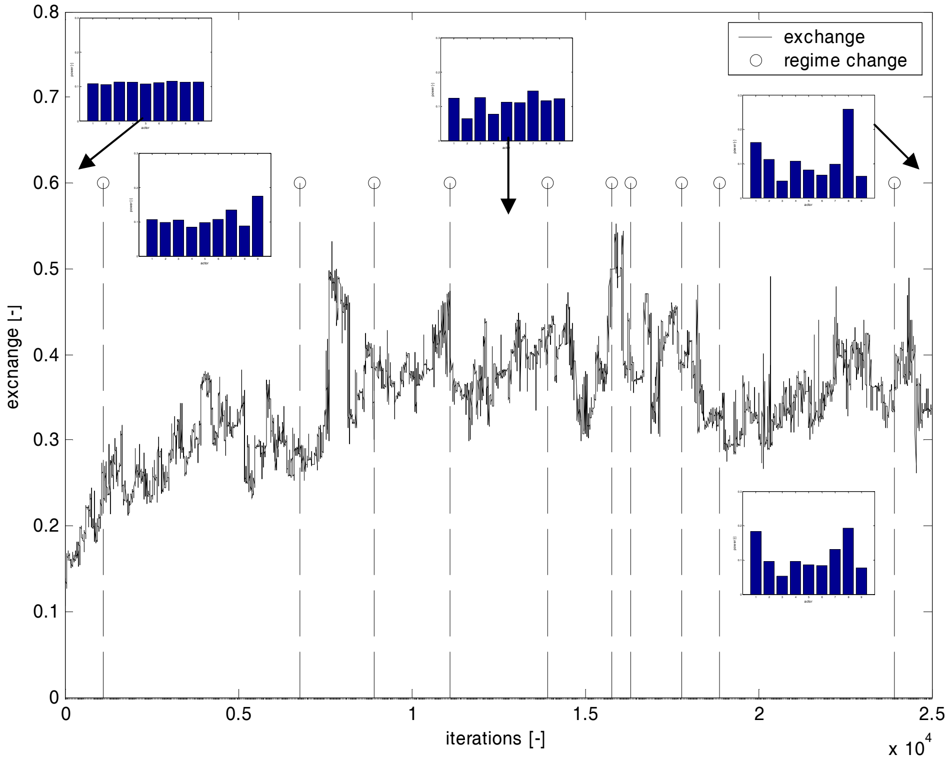
The model described in this paper is developed to model, study and evaluate tools and strategies for transition management. In this section we evaluate model behavior regarding two characteristics pertinent to societal transitions. Rotmans and Kemp state that transitions (Rotmans, 2005; Rotmans et al., 2001; Van der Brugge et al., 2005; Kemp et al., 1998):

- require a change of regime
- develop in accordance with an S-curve

In transition theory, a regime is both characterized by a 'ruling' set of actors and a 'ruling' set of substantive characteristics, like institutions, practices, structures and artifacts or infrastructure (Rotmans, 2005; Van der Brugge et al., 2005, Kemp et al., 1998). At an abstract level, these regime characteristics translate into a distribution of power of actors and value of issues in the LSA. Power of actors is a straightforward concept, both from definition of regimes in transition theory as from the LSA (equation 6). The translation of the substantive characteristics of the regime into values of issues is however less clear-cut. In the LSA, at the system level all issues obtain a value based on the interest of actors in the respective issues. If we characterize and describe the substantive elements of a regime with issues and the level up to which these issues are served by the current regime with the values, the LSA gives us a quantitative characterization of the substantive elements of the regime. For example if sustainability is one of the issues included in the LSA, a high value of the issue sustainability in the LSA indicates that the current regime highly values issues of sustainability when taking decisions. For a method to define these issues for a real world social system we refer to Timmermans (Timmermans, 2004; Schouten et al., 2001; Timmermans and Beroggi, 2000).

Figure 8 **Exchange and regime changes**

The bar graphs inserted present a representative distribution of power for the regime between the regime shifts indicated by the dotted lines.

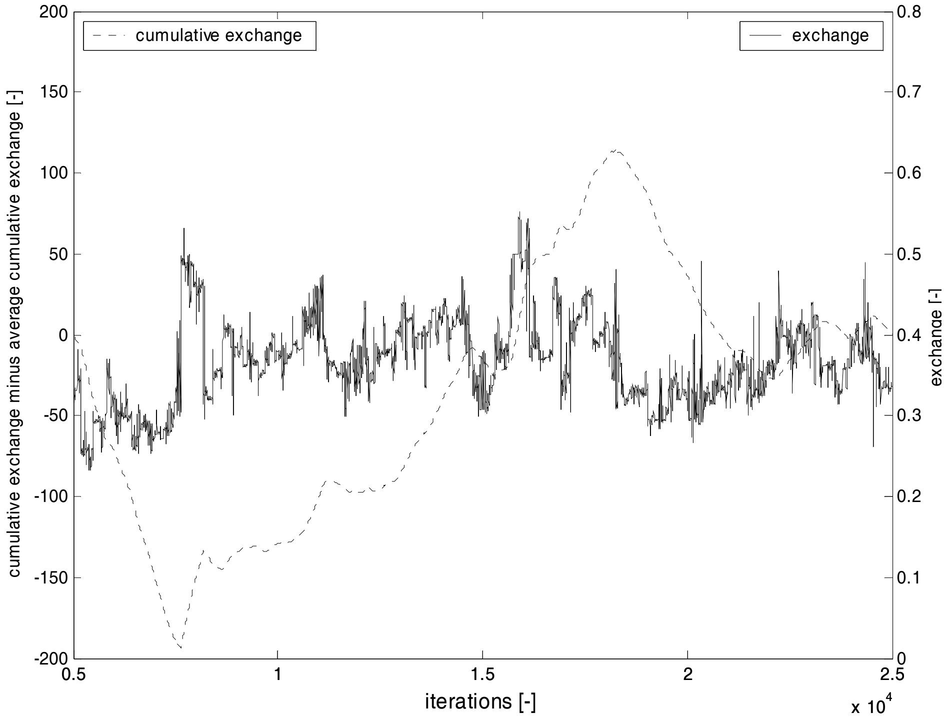


In Figure 8 the exchanges of control for the model are given and shifts in de power regime are indicated. The bar graphs give a representative distribution of power over the actors for the period between two regime changes. A regime change is defined as a persistent change of the most powerful actor. The persistence is indicated with a threshold; only if the new actor stays in power for more than 'threshold' iterations a new regime is installed. For the analysis in Figure 8 a threshold of 400 is used.
From Figure 8 it can be seen that from an almost uniform distribution of power at the start of the run after around 1000 iterations a regime emerges with actor 9 as the most powerful actor. Halfway the simulation a more even distribution emerges, while at the end, actor 8 takes over and develops into an extremely powerful actor possessing almost two times the power of actor 1, the second powerful actor. From Figure 8 it appears that the regime changes more or less coincide with changes in the average and standard deviation of the exchanges, indicating that the new regime is not only characterized by a new distribution of power, but also by a specific average and range of exchanges.
If a smaller threshold is used, far more regime changes occur. However, frequent changes of regime are limited to specific periods and long periods of stable regimes remain. The periods of frequent regime change are periods of transition, a struggle between the actors to take over the regime. Only after some time one of the actor takes over and installs a new stable regime.
The model also shows changes in the issue regime, indicated by a change in the most valuable issue. However, these are less frequent. Power and value regime changes do not normally occur at the same time. From the above we conclude that the model indeed shows the development of regimes and regime changes as expected in transition theory.
Figure 9 presents the maximum bilateral exchanges and the cumulative exchange for iteration 5000 to 25000. The first 5000 iterations are left out, because they belong to the initiation period in which the model is loaded. The accumulation is taken over the maximum bilateral exchange minus average maximum bilateral exchange. The curve thus identifies periods of above average exchange and periods of under average exchange. The most important conclusion from Figure 9 is the alternation of long periods of less than average exchange and periods of more than average exchange. Although the calculation of the cumulative exchange is sensitive to the period that is taken, it is clear that periods of fast change alternate with periods of stagnation. The changes in the slope of the cumulative exchange curve coincide with the change in characteristics of the exchanges. Without subtracting the average, the

result will be an ever-increasing curve with alternating periods of fast increase and slow increase, resembling a sequence of S-curves as hypothesized by transition theory.

Figure 9 **Exchange and cumulative exchange**

The full line presents the exchanges of control over time. The dotted line is obtained by subtracting the average exchange from the actual exchanges and cumulating the result. A descending trend in cumulative exchanges indicates periods of less than average exchange, while an ascending trend indicates periods of above average exchange or transitions. The iteration axes runs from 5000 to 25000 excluding the initialization period.



6. Discussion and further research

The first experiences with the Transactional Model of Transitions (TMT) shows that the LSA combined with a suitable variation and selection procedure, produces simulation results that mirror some of the main characteristics of transitions in a social system. Especially the emergence of regimes and the alternation of periods of high exchange of control with periods of low exchange of control are of interest. Selecting the actor to be changed, as the most self-dependent actor is an important feature of the model. The selection procedure establishes a feedback between the LSA and the new actor and causes the social system to be pushed away from equilibrium. Without selection based on self-dependence, the model shows random behavior.

When applying rational choice theory to model a social system, also selection of actors into the system should be a rational action. Replacing, mutating or changing the most self-dependent actor is rational at a system level, because the actor contributing least to the potential for exchange in the social system modeled is removed. The mutation and selection procedure implemented, however, is still a rough procedures it does not guarantee the rationality of the decision at the level of individual actors. Further research has to be committed to the exact characteristics and effect of the change mechanism. Although the procedure is rational at a system level, a more refined procedure, selecting the actor based on a rational decision on both the individual and system levels, will probably result in a more refined mechanism. It remains to be seen if such a mechanism will again mirror the characteristics of societal transitions.

The model is developed as a simulation tool for testing Transition Management. Important instruments of transition management are visioning (Rotmans 2005; Van der Brugge et al., 2005) and strategic niche management (Geels and Kemp, 1998). In terms of interest and control, visioning can be translated into a convergence of interests of actors. The result of visioning can be evaluated with the TMT.

Strategic niche management aims to develop innovative alternative solutions for a problem in niches initially protected from market influences. In term of the LSA, alternatives are the carriers of exchange of control. In a social system exchange of control between actors can only be implemented when a practical solution exists that implements the exchange of control (Timmermans, 2004; Timmermans and Beroggi, 2004). Without this solution the potential for exchange remains potential, without the possibility of implementing the exchange in practice. This aspect of exchange of control is not touched upon in this paper. However, the model developed facilitates the evaluation of the effect of more innovative with less innovative conditions on the exchange of control and thus the speed of change.

We conclude that the TMT developed is promising for its purpose of evaluating instruments and tools for transition management. The model mirrors some important characteristics of societal transitions. Also the model is flexible and allows for a connection to real world issues pertinent to Transition management.

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