■ Research Paper

Operational Closure and Self-Reference: On the Logic of Organizational Change

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The concept of *autopoiesis* introduced by Maturana and Varela has, in the last four decades, triggered intellectual efforts for the understanding of phenomena of self-organization in general. This contribution aims at conceptualizing and applying two aspects of autopoiesis—*operational closure* and *self-reference*—in respect of social organizations. We formalize these concepts and demonstrate their power to explain change processes. This is achieved by means of a qualitative case study and a quantitative simulation model, which lead to counterintuitive insights about the dynamics of organizational transformation. Copyright © 2012 John Wiley & Sons, Ltd.

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INTRODUCTION

The introduction of the concept of *autopoiesis* into scientific discourse (Varela *et al.*, 1974) has triggered much discussion over the last decades. If autopoiesis, from the Greek roots *autos* (self) and *poieō* (to make), means self-production, it carries a connotation of self-organization, a concept which has been at the core of the efforts of cyberneticians to reconstruct their science: first, to expand cybernetics from the domain of mechanical systems to the realm of organismic systems, and later, to the domain of human and

social organizations. The cybernetics of mechanical systems and organisms was termed *First-Order Cybernetics*, and the cybernetics of human and social systems *Second-Order Cybernetics*, also called ‘the New Cybernetics’. The difference was essentially because of the introduction of the observer: Heinz von Foerster (1984) labeled the former ‘the cybernetics of observed systems’ and the latter ‘the cybernetics of observing systems’. Whereas in the first case, the emphasis of description, explanation and design falls on information, feedback and adaptation, the new cybernetics has developed its own language, making use of concepts such as autopoiesis, self-organization, operational closure and self-reference. We return to these concepts shortly.

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This contribution is in the ambit of Second-Order Cybernetics. Our aim is to conceptualize the notions of *operational closure* and *self-reference* for organizational contexts. This endeavour is primarily a theoretical one. Beyond that, we also demonstrate the relevance of our work for the realm of concrete social organizations. The existing literature treats the two concepts in such a way that they remain difficult to grasp, that is, they are not presented in a compact, accessible form. This motivates us to develop a parsimonious formulation of both concepts and to clarify them in terms of organizational change. Our research effort is stimulated by the following questions: What is the meaning of operational closure and self-reference in organizational contexts? How can these concepts be expressed formally? Finally, are these concepts insightful descriptors of processes of organizational change?

We examine if and to what extent the concepts of operational closure and self-reference are helpful in illuminating phenomena of organizational change, concepts which may differ from most established organization theories¹ by highlighting aspects, which existing theories cannot conceptualize. Why do we concentrate on these two concepts and not others? The writings of both Humberto Maturana and Francisco Varela, including those co-authored by both men, revolve mainly around autopoiesis and operational closure. Other authors who have engaged in similar discussions, as well as having complemented and continued the work of Maturana and Varela, have also included *self-organization* and *self-reference*. We use a synthetic approach, focusing on operational closure and self-reference as a *pars pro toto*, which accounts for all four concepts enumerated above. Such a synthesis is essential; it yields understanding (Ackoff, 1981: 17).

In the following section, the crucial concepts are presented. Thereafter, we discuss these concepts in the context of the organizational domain and proceed to their formalization. Based on that formulation, a qualitative case study is presented as an exemplar to be built on in the rest of the paper. Thereafter, in the largest section, we

elaborate a computer model, which expands on the formulation developed earlier. By means of simulations, the general ideas of the paper are implemented and used in the interpretation of the case study. The discussion of the simulation experiments leads to insights, which are condensed in the conclusion.

CONCEPTS

With the concept of autopoiesis, Maturana and Varela 'wanted a word that would by itself convey the central feature of the organization of the living, which is autonomy' (1980: XVII). In their seminal paper, they 'claim that the notion of *autopoiesis* is necessary and sufficient to characterize the organization of living systems' (Maturana and Varela, 1980: 82). Reproduction and evolution occur in living systems, and the phenomena derived from them 'arise as secondary processes subordinated to their existence and operation as autopoietic unities' (1980: 112). System theory has viewed the concept of living systems in different ways. In the work of Maturana and Varela, the notion of a living system is essentially confined to biological organisms. They do not claim that their propositions concerning autopoiesis would apply to the domain of social systems (Maturana and Varela, 1980).² In General System Theory, the notion of living systems pervades all kinds of systems, for example, Miller's (1978) *scheme of living systems* subsumes the system levels from cell to organ, organism, group, organization, community, society, to supranational systems. He corroborates his claim by identifying empirically an isomorphic structure of 20 subsystems,³ which is applicable to each one of these levels. Miller uses terms such as 'auto-regulation' (also 'self-regulation') and 'self-organization' as relevant on all levels of living systems (Miller, 1978: 346, 486) but does not deal with organizational closure or self-reference. In the wake of Maturana and

¹ We are referring here to 'mainstream' organization theories, as most of the ones related in compendia such as Bullinger *et al.* (2009).

² According to Varela, social systems are not autopoietic, but they are operationally closed. Luhmann, on the other hand, conceptualizes societies as autopoietic (Mingers, 1995: 211).

³ Nineteen subsystems are described in Miller (1978). The last subsystem, the timer, is added by his wife Jessie Miller at a later stage.

Varela, later authors, especially Luhmann, have applied the concepts of autopoiesis and operational closure to social systems as well (Jantsch, 1980; Luhmann, 1995, 2003; Bailey, 1997).⁴

Autopoiesis signifies the reproduction of the elements of a system by the system itself or, more generally, the self-generation and self-production of the system. The environment has no direct influence on an autopoietic system, except its destruction. Therefore, autopoietic systems are denoted as *operationally closed*. A system is considered a system only if it is operationally closed, that is, if the system produces and sustains itself on the basis of its elementary operations (Krause, 2001: 121). An example of this is the brain of a higher-order organism that is thermodynamically open but organizationally closed (Varela *et al.*, 1974). Hence, it is open for the exchange of energy and information, but at the same time, it is operationally closed in the sense that its processes are self-activating and recursive and do not start or stop anywhere (Thompson *et al.*, 2005: 44). Closure is about the circularity of operations producing operations and must not be confounded with closedness, which implies isolation. An organism keeps all, or a certain part, of the relations between its elements invariant, despite perturbations, which stem from the organism's internal dynamics as well as from its relationships with other systems (Maturana and Varela, 2009: 180). Changes of the system are triggered by internal structures and dynamics, not by changes in external factors. However, the perturbations (which include 'interventions') coming from outside can trigger major change indirectly and, therefore, necessarily only via self-reference. For instance, the rise of a new technology does not determine the reaction of a company. That reaction is the result of processes within the organization, which may lead to adaptation. Only in the case of the destruction of a system is the impact direct.

Self-reference 'denotes a statement which refers to itself or its own referent' (Bolander, 2009: 1). This definition stems from linguistics. It can be

elevated to a more general level by claiming that self-reference denotes any act that refers to itself or its own referent. In computer science, for instance, self-reference is important to instantiate reflection, which enables a program to read or change the instructions that govern it. Similarly, reflection is a basic capability of social systems; it enables them to decipher, ponder, describe, criticize and change the rules that govern their behaviour. A respective analysis follows in the next section.

OPERATIONAL CLOSURE AND SELF-REFERENCE IN SOCIAL SYSTEMS

Let us first revert to operational closure in the context of social organizations, a context which can be conceptualized in different ways. Many of the existing concepts of social organizations are focused on the physical manifestations of these systems, for example, organizations as mechanisms or organizations as organisms (for details, see Morgan, 1997). Others constitute social systems as psychic or socio-psychic phenomena (*ibid.*). Some conceive of such organizations as textures of symbols or concepts (e.g., Umpleby, 1986). Furthermore, system theory and cybernetics have brought to the fore theories in which communications are the constitutive elements of social organizations (mainly Luhmann, 1995). Broekstra (1998) has introduced the notion that 'an organization is a conversation' based on which one can state that social organizations are networks of conversations. Luhmann, who was profoundly inspired by the ideas of Maturana and Varela, is the main proponent of the new view of organizations, which centers on communication as the core of social systems (Luhmann, 1995, 1997). For Luhmann, the operations of social systems are communications. The closure of the system is produced by communication in a circular manner: Communications trigger communications trigger communications and so forth (Luhmann, 1997).

The operations of a system then are determined by a specific logic, which is embodied in codes that establish goals as orientators—or attractors—for the agents in the system. For example, in private firms, the goals are codified

⁴ For a critical discussion concerning the transfer of the concept of autopoiesis to social systems, see especially Mingers (1995, 2002) and King and Thornhill (2003).

on a scale between profit and loss or, within a larger time horizon, between viability and decrepitude (Schwaninger, 2009). The respective logic of the system then materializes in operations aimed at attaining these goals. In other words, the emerging operations revolve around goal attainment. In principle, the system is unable to change its orientation and has to function along one and the same trajectory. In case it is irritated by alternative orientators, it may vacillate, but the system is still bound to relapse into following the given trajectory. Transition to a different orientator occurs only if the perturbations are strong enough and enduring over a sufficient time.

A popular fallacy attributes the dynamics of a system mainly to external forces (Richardson, 2011; Sterman, 2000). Examples from the business context: when sales are down, the weather is blamed for this situation. When an undesired event occurs, random forces are held responsible. When the emotional climate in the organization is unstable, it tends to be considered the management's fault. Systems science conveys a different view: extensive studies in system dynamics demonstrate that the dynamics of systems are generated most often within the system (Sterman, 2000; Richardson, 2011). When puzzling dynamics or difficulties occur in a system, it is well worth studying the logic that generates the respective behaviour. The issue then is reflection.

Reflection is a deliberation at a higher logical level of an event or process that goes on at an object level. In the context of operationally closed, autopoietic systems, a reflection is an instance of self-reference, that is, it is about a system pointing to itself. Luhmann (1995) distinguishes three levels of self-reference: first, *basal self-reference*, which is at the level of system elements that are both cause and effect in a chain of events; second, *reflexivity*, which denotes the reference of one communication to another communication; and third, *reflection* at the level of the system, which is the system observing what it does. In the following, we are going to limit our discussion of self-reference to the third level—reflection—which is the most powerful lever of self-reference regarding inducements for change. Reflection is a mirror image if it consists merely in reflecting an object, but it can become

a major force to change the evolution of the system once the system thinks about itself and its relationship with its environment. Reflection has the potential of leading a system onto a new orientator. Autocatalytic, self-referential processes play a major role where perturbations lead to a new state of order (Jantsch, 1975; Prigogine, 1976). In the next sections, we present a formalism for the description of organizational processes in terms of operational closure and self-reference and then apply that formalism to a concrete case of organizational change. From there, we construct a simulation study to gain further insights into the workings of autopoietic systems.

FORMAL EXPRESSION

The basic diagram in Figure 1 depicts, in a classical representation mode, an operation closing in on itself, which constitutes the epitome of operational closure.

An expansion of this scheme is provided by the inclusion of self-reference. The pictogram in Figure 2 expresses the combination of organizational closure and self-reference in a parsimonious manner. In the scheme, *O* stands for operation, *R* for reflection. When addressing self-reference, as already mentioned, we focus our perspective on reflection. Arrows that transcend the bounds of the circles symbolize transformative instances. On the one hand, reflection is apt to trigger a change in the modus operandi of the system, by expanding the

Figure 1 A symbol of operational closure

Figure 2 Pictogram for a self-referential system (*O* = operation, *R* = reflection)

space of potential behaviours. On the other hand, the *modus operandi* can trigger changes in reflection, for example, by showing deficits in the adaptation of the operations to environmental needs. In both cases, a change of the system results. On the basis of a mono-causal view or a deterministic ontology, the implication would be that change is caused. A multi-causal view or a non-deterministic ontology, to which we adhere, suggests that change can only be influenced or triggered, not caused.

The process of change of the system is symbolized in Figure 3 with time on the horizontal axis. Here, *S* stands for the state of the system at different times *t*. It is possible that qualitative changes transform a system significantly, eventually leading to a new system,⁵ which is indicated by *S*, *S'*, and *S''*. *R*³ denotes reflection, which is the third level of self-reference. The changes of system state are brought about synergetically by both the endogenous dynamics of the system operations and the reflexive process. Both also influence themselves, as the horizontal arrows in Figure 3 show (see also the circular nature of *O* and *R* depicted in Figure 2). The respective mode of reflection leading to system change from *S* to *S'* (Figure 3) is introduced in the simulation study carried out later.

The simulation model will demonstrate that the reflexive strand is often more influential than the internal dynamics of the operations strand. Self-reference, including aspects such as self-observation and self-description coming together in a process of reflection, are apt to trigger substantial change of the system and even to bring about a new system. We can now proceed to the case study, which forms the basis for the rest of the paper.

APPLICATION TO PROCESSES OF ORGANIZATIONAL CHANGE

The case study is described in the language we have developed above. The case informs the

⁵ A new system could be, for example, a system dominated by a new paradigm. *Paradigm* denotes a pattern of thoughts, mindset, practices or convictions shared by a scientific community (after Kuhn 1996), a concept which can be transferred to organizations in general.

conceptualizing of the ensuing computer simulation model and the pertinent analysis. The case is about an organizational transformation accomplished in an insurance company with which one of the authors (M.S.) cooperated in his function as external facilitator. At the time, the organization, which we call INCO, had about 4000 employees. It was part of a larger corporation but had a high degree of autonomy. We found that this autonomy was, to some extent, devolved 'from above', but it came to a large degree 'from inside' as the consequence of a powerful identity that had stabilized over the years as a product of operational closure. In the following, the organizational transformation will be described in five stages. Figures 4 and 5 depict the process using the notation developed in the prior section. In Figure 4, iconic language is used; in Figure 5, the representation is a graph. Finally, the formulaic representation is applied to the case.

Stage 1: Steady State

INCO ran its distinct operations and also had the competence to define and implement its strategy, although strategy was not a topic of relevance to the managers. The company was highly profitable and efficient, so much that there seemed no need for working on its strategies. The whole firm quasi-'automatically' followed a set of proven rules, which governed recurrent, essentially 'closed', operational processes following a cogent logic. The imperatives were to increase sales, improve efficiency and achieve high profits, all in a setting of high-quality services, attractive workplaces and a well-motivated, cohesive workforce. Apparently, there was no need for changing this well-established, operationally closed system.

Stage 2: Incipient Change

This placid situation was suddenly disturbed when the market, which had grown sturdily for decades, stagnated and competition jumped up. This was first perceived by the marketing and sales people who were more aware of the immediate sales figures than about the fundamental

Figure 3 A system changes as a product of operational dynamics and reflection

Figure 4 The transformation process at INCO

Figure 5 The transformation process at INCO represented as a graph. *P* stands for a perturbation or irritation

changes in the markets that began to show on the horizon: A demand for customized solutions instead of merely standardized products, individualization, fragmentation, specialization and internationalization of the market, just to name a few. That on the market front was a crucial perturbation. It was actually perceived by many, but it took time until it triggered a reaction from the company, given significant perception

delays. The catalytic function, which induced a process of change rested with the chief executive officer (CEO) and his head of corporate development. These leading figures were aware of the emerging imbalance between the status quo and necessary change. They monitored the signals but were not very successful in transferring some of the new awareness to the high-level managers. There was too little channel capacity—that is,

the upper limit of the information that can be transmitted reliably through a communication channel (Shannon and Weaver, 1949)—for raising the awareness of the need for change, and everyone was too busy anyway to counter the organizational inertia. Meanwhile, the operational logic followed its path as ever. Over time, the need for a strategic approach to conceptualize what occurred was discussed occasionally and informally between the head of corporate development and some of the managers. Then, the two catalysts, who were perfectly aware of the need for change, pushed a corporate development project. Together with the management team, they embarked upon a strategic positioning and, if indicated, reorientation of the company. A project team of 15 top and high-level managers was formed, and a small external team of consultants hired to support the project. The key facilitators in this venture were the internal head of the corporate development unit and, externally, one author (M. S.) as the project leader on behalf of the consulting firm. This way, a discourse about strategy, its underlying principles, and values was brought to life. Reflections at the level of the organization as a whole became possible.

Stage 3: Analysis, Reframing and Design

The reflection process gained momentum fast. First, the concepts of strategy, which had been largely ignored before, were introduced to the project group and assimilated by its members eagerly. The discourse gained a new dimension: A new logic and a new language gained ground; long-term perspective, strategic positioning and viability of the firm were the new imperatives. That reframing led to a sequence of fluctuations, which ultimately entailed a new order (Prigogine, 1976). To diagnose the strategic position, the project team carried out thorough analyses. Several workshops with the whole project team, including the external consultants were held, in which results were reviewed and the next steps defined. After a few months, it had become evident that the core competencies of the company lay in business transactions with corporate clients as well as in dealing with complex insurance and risk

management issues. In addition, several important insights into different aspects of the business—competitive posture, marketing and organizational processes—had emerged. The project headed towards the design phase. Several teams were formed to pursue key issues such as human resources, organizational re-design and the configuration of distribution channels. More people from these teams were mobilized for these tasks. Also, team members started to diffuse intermediate results among their own staff, thus involving them in the knowledge-building and decision-making process. The far-reaching decisions taken were as follows:

- (1) to build the company around customer problems rather than products,
- (2) to strengthen the business with corporate clients, and
- (3) to expand the international business.

These decisions implied that a fundamental organizational transformation had to result. The compass pointed to a re-design of the organization conceptually, based on the viable system model, which has been described elsewhere (Beer, 1979, 1985; Schwaninger, 2009). The emphasis of the intervention was on the structuring of the basic units and their management. The reorientation was fundamental: it is no exaggeration to speak of a paradigm shift. The radical change to which the strategy team aspired, and which was eventually accomplished, is schematically visualized in Figure 6.

The traditional organizational structure was aligned to functions. The main organizational units, apart from staff units (i.e., human resources, finance, controlling, administration, corporate development), were four large departments: marketing, underwriting, claims and sales. The first three were centralized in the capital, the last had about 80 branches across the country, grouped regionally. The first three were sub-structured according to product groups, of which, automotive insurance was the largest. The new structure was to group the company activities around two basic customer problems, that is, the needs of two major customer groups, namely, individual and corporate clients. Before the decision to restructure was taken, its multifarious aspects

Figure 6 Structuring of basic units

and implications were thoroughly examined from a variety of perspectives. The approach appeared to be robust in that the new plan was both desirable and feasible (Checkland, 1981). The structural change was at the core of the paradigm shift because it expressed a different worldview and a new organizational culture; the company was heading at a fast pace toward a culture in which the customer was the most important stakeholder, not the employees or the shareholders. The self-referential processes triggered by the catalysts of the change was the "engine" of that development.

The delineation of the new borders of the basic units was likely to be highly durable. The units were designed to be clearly identifiable businesses in their own right and viable organizations within the whole—relatively autonomous divisions equipped to maintain a separate existence (Beer, 1979, 1985). The redesign went beyond a mere outline of a new strategy and organizational structure. First, it included a detailed plan for the transition to the new state. Second, an intensive

communication process between the managers and the people in the organization provided that not only the implementation plans became highly concrete but also the people in the organization were ready to move. Indeed, culturally, it had already started to move (Schwaninger, 2006). The task ahead was also to move the organization's structure.

Stage 4: Transition

The cultural transformation was already in full advancement. After the conclusion of the consulting mandate, INCO executed the new plan. Almost every employee in the company was affected, most people to a large extent. The speed of the transformation was astonishing. The structural transition of the organization was accomplished within six months. People were transferred, locations were transmuted, equipment had to be moved and 300 computer applications were completely changed or overhauled. After these six

months, about 85 per cent of the staff had new superiors, and most employees had to think along different lines.

At first, the transition did not comprehend all the changes as mapped out. In the first phase, the subunits in the new divisions were structured along traditional product lines. Later on, a grouping into business units according to more specific customer problems or client groups would be relatively easy. There were some questions of demarcation, although of secondary importance: 'Should small business be part of the first or of the second division?', 'Should farmers be attended to by a separate business unit, and where should this be located?' and 'Is a new division that attends large multinationals necessary?'

As far as the sales organization was concerned, it maintained its regional structure. However, in all regions, a specialization between individual and corporate clients was pursued. The claims department was re-organized in the first phase by means of an internal differentiation between individual and corporate business.

It was surprising how fluent the organization had become in taking on the new rules and language. Certainly, the facilitators had contributed greatly—less through direct intervention than through the design of communication and diffusion processes, which catalysed reflexive processes into the subunits. After all, that was their function as the epitome of the corporate reflection function. By the end of the fourth stage, the operations within the new structure were already on the verge of perpetuating the new logic. A new paradigm, that is, collective mindset, and a new *modus operandi* had taken effect.

Stage 5: Further Evolution

After the change project, the new logic consolidated and eventually dominated the organization. Over the following years, INCO evolved unceasingly without any great transition. Some of the changes initiated in the transition phase were continued. To take two examples, first, the international business was developed into a separate, autonomous division. This step was taken within about two years after the project. Furthermore,

the component subsystems of the sales organizations were integrated into the individual and corporate divisions, respectively. In the following two decades, INCO went through three major reorganizations, one every seven or eight years. These all were cases in which path-breaking self-reference had led to a new paradigm. The company has not changed its basic strategy, that is, being an overall insurer with a leading position in the corporate insurance market and international business. As a whole, it has shown a great deal of adaptiveness, being grounded in self-referential processes. In the phases between the reorganizations, the new structures were stabilized by efficient processes of organizational closure.

Follow-up interviews conducted after a reasonable five-year interlude following our project showed surprising results. The whole transformation had been realized smoothly and without noteworthy resistance. Practically, all members of the company had embraced the new orientation and adapted to it quite easily. In terms of strategy, the intended strengthening of the positions in the corporate and international domains was a complete success. This had led the top management at the group level to adopt a similar organizational model. A reorganization of the corporation had taken place at two levels of recursion, company and group.

Early on in the new millennium, 20 years after the project, one of the authors (M. S.) approached the CEO of the group for a second follow-up. The interviewee commented that the original project had been the bedrock upon which the foundations for a new orientation had been laid. The company and its management had learned a new approach to strategy and organization, which was the key factor in the rise of the group and its international projection as a financial service organization. Self-reference was the key to evolution, operational closure the mode of implementation. Viability and prosperity have been the consequence.

To summarize, the transformation process observed in this case comes close to the ideal type of a 'teleological' change process—a process in which a problem or opportunity is perceived and acted upon purposefully (Poole *et al.*, 2004), with the special feature of a participative, cooperative

mode developing the unifying goals and strategies. However, it also carries characteristics of the 'evolutionary' process type, with variation, selection and retention as the drivers of change (ibid.). This latter aspect has not been analysed here in great detail, but it consistently underlay the pattern of change from an extant to a new paradigm.

SIMULATION MODEL OF ORGANIZATIONAL CHANGE VIA SELF-REFERENCE

In the following, we develop a simulation model that operationalizes the logic of a self-referential system. For this, we use a higher-order, differential equation model, which we simulate to obtain insights about the basic properties of operational closure and its interplay with self-reference. The model will function as an insightful descriptor of organizational change processes. It has been developed to demonstrate under what conditions an established paradigm can be displaced by an entrant paradigm. The simulation model is a causal process theory about paradigm change based on self-reference as laid out in the first part of the paper and the subsequent case study. We use system structure diagrams to detail the parts of an organization that generate operational closure, paradigm evolution and paradigm consolidation as well as to estimate the impact that self-reference can have on paradigm transition. Thereafter, we simulate the system model and analyse its behaviour. Finally, we derive insights based on experimentation using the simulation. We develop the structure of the system model in four parts by unfolding the main dynamic that exists with relation to our operational closure and self-reference paradigm in the light of evolution and paradigm transition. The simulation methodology used is system dynamics.⁶ The following graphs show 'system structure diagrams' or 'hybrid

diagrams' (Groesser & Schaffernicht, 2012; Sterman, 2000), that is, slightly simplified stock-and-flow diagrams, where rectangles denote stocks (also: 'levels') and valves denote rates (also: 'flows'). Parameters are written out in capitals, auxiliary variables with small initial letters.

Structure Part 1: Basic Operations in the Existing Paradigm (Figure 7)

The day-to-day activities of an organization can be represented by *tasks*. *Tasks required* is a stock variable, that is, an accumulation or buffer of activities, which have to be fulfilled to achieve the purpose of the organization. These tasks are, for instance, development of new products, formation of new affiliates, or hiring and training of employees. The stock is changed by its rate variables. The one that adds to *Task required* is the rate *new tasks*. This demonstrates that new activities are required every period to sustain the current level of the organization. The level of *Tasks required* is reduced by task execution. In case the tasks are executed successfully, that is, to a satisfying degree relative to the requirements of the environment, they move from *Tasks required* to the level *Tasks successfully fulfilled*. This is the normal process ongoing every day in organizations. The stock *Tasks successfully fulfilled* is depleted by *discarding tasks*, for example, customers who discontinue the relation with the organization or research efforts about mature technology, which become obsolete. To sustain the self-production of the organization, these tasks have to be renewed, for example, new products have to be designed, customers acquired, and employees hired. This process operationalizes the concept of *operational closure* as defined in the first section of this paper; here, we capture it in the loop *Operational Closure (R)*.

The successful execution of tasks depends on the available competencies of the organization. The higher the level of *Competency in the established paradigm (EsP)*, the more efficient is the execution of the tasks that are completed successfully. In addition, the more tasks are successfully executed, the more proficient the organization

⁶ System dynamics (SD) is a methodology for the modeling and simulation of complex systems, developed by Prof. Jay Forrester at MIT, and grounded in Control Theory as well as in the modern Theory of Nonlinear Dynamics (see: Forrester 1961; Sterman 2000). The focus of SD is on issues, which are modeled as systems made up essentially of stock and flow variables forming closed feedback loops and simulated as continuous processes. The mathematics of the models is based on differential equations.

Figure 7 Operational closure (R) ensures the self-production of the organization. This is operationalized by a simple task completion chain with successfully and unsuccessfully executed tasks within an established paradigm

becomes regarding this competency base in the established paradigm. This execution and learning process forms a virtuous circle of success (R1). To complete the picture, the competencies are also lost over time by organizational forgetting—represented by the rate *forgetting*. Besides completing the tasks successfully, they can also be completed unsuccessfully. These tasks then accumulate in the stock *Tasks not fulfilled and latent*. They are latent and hence not known to the organization. With significant time delays, it is likely that these unsuccessfully executed tasks are discovered and are then *Tasks not fulfilled and known*. This difference between the statuses of unfulfilled tasks—latent and known—is of crucial relevance for understanding the counterproductive dynamics that unfold in an operationally closed system. The degree to which operations are executed successfully in the first place is largely determined by the requirements of the environment with regard to the established paradigm. If there is a strong correspondence of the established paradigm to the external requirements, the adequacy is high and leads to a successful completion of the tasks, leaving only a few of them as completed unsuccessfully. However, as the environment evolves over time, the requirements on the operational level change, for example, the requirements change from product innovations to process innovations to service innovations (Utterback, 1994). The case study in the previous section has described an

exemplar of how an existing organizational paradigm can become obsolete. The more inadequate the existing paradigm becomes for executing the tasks required, the lower is the share of the successfully completed ones and the higher is the share of unsuccessfully executed tasks, leading to unfulfilled tasks—both latent and known (Figure 7).

The principal loop *Operational Closure* (R) will be crucial throughout our following discussion; without it, the organization would cease to exist. Because the purpose of our elaboration is to detail the dynamics of paradigm evolution, paradigm transition, and the effects of self-reference, we can safely exclude the flows *new tasks* and *discarding tasks* in the following Figures 8–10 without losing generality.

Structure Part 2: Evolution of an Entrant Paradigm (Figure 8)

Besides the established paradigm, entrant paradigms (EnP) evolve. Here, we consider only one of them, which is capable of addressing the whole range of requirements of the environment. Hence, this entrant paradigm is more powerful than the established one. It fulfills the tasks required and can, in addition, solve the remaining unfulfilled tasks. In principle, the entrant paradigm evolves by the same self-reinforcing learning mechanism (R2) as described before (R1). However, at the

is new and immature. However, once the entrant paradigm would gain experience and become powerful, it would substitute for the established

Figure 10 Self-reference as a catalyst of change and balance in an organization. The feedback mechanism R7 and B1 can help to overcome Organizational lock-in (R3) and Blindfolding (R4)

paradigm. Then, the flow *successfully executed tasks EsP* would disappear, and the *successfully executed tasks EnP* would complete the tasks without a significant number of failures. However, as we have pointed out in the first part of the paper, the transition of an organization's paradigm is an undertaking that causes friction and resistance. An organization's core competencies⁷ are the basis for its adaptiveness, and they must be developed over time (Utterback, 1994). Hence, we could not explain the transition of paradigms if we were unable to account for the resistance dynamics of the established paradigm, which perseveres to prevent its displacement by the entrant paradigm. In the following, we detail those behavioural aspects that result in policy resistance and thereby answer the question: Why is the new paradigm not embraced, although it is more capable of coping with the requirements of the changing environment?

⁷ Core competencies are those factors, which enable an organization to create value for customers and achieve sustained competitive (and collaborative) strength or advantage (see also: Prahalad *et al.*, 1990).

Structure Part 3: Resistance Dynamics of the Established Paradigm (Figure 9)

The resistance to change of the established paradigm can be explained by a multi-loop feedback system. An increasing base of competencies in the established paradigm, coupled with an increase in the number of successfully fulfilled tasks, leads to the perception that the paradigm is adequate to the environment's requirement. Only a significant number of unfulfilled and known tasks could invert this perception. Initially, however, the related stock *Tasks not fulfilled and known* is virtually zero. Consequently, the task-executing organization learns and develops competencies (R1) and, because of the absence of any other indications, also retains confidence in its established paradigm. The evolution of confidence could be influenced by a powerful entrant paradigm, which, in the beginning, does not exist. Hence, increasing levels of confidence limit the organizational possibilities to perceive the true benefits of other paradigms; the dominant mode is one of organizational (self)-confirmation and not one of experimental reinvention (Nelson &

Winter, 1982; Sastry, 1997). This perception bias fuels two powerful mechanisms: *Organizational Lock-in* (R3) and *Blindfolding* (R4).

Because the perception bias devalues the true economic and social benefits of the entrant paradigm, the organizational members are discouraged from learning about this paradigm hindering the creation of competencies. As a result, the entrant paradigm cannot build up strength and cannot be applied to solve tasks. Consequently, the only way to fulfill the required tasks is by means of the established paradigm. This feedback mechanism is active from the beginning of the development and cements the status quo, with the side effect of preventing competing paradigms from arising (R3). When only the established paradigm is utilized, the continuous development of its competency base (R1) leads to the effect of organizational lock-in, that is, 'allocations gradually rigidify' (Arthur, 2000: 28). Put differently, the hurdles for an entrant paradigm to enter the organization increase exponentially (R3). Let us now assume that the adequacy of the established paradigm becomes smaller as time progresses.⁸ The efficiency with which it fulfills the tasks is then reduced; it still results in successfully executed tasks but, at the same time, also in a growing number of unsuccessfully executed tasks, which are latent at first.

The second powerful impact of the perception bias is that it reduces the organizational capabilities for detecting latent unfulfilled tasks (R4), by diminishing the rate at which they are discovered. Consequently, R4 renders ineffective the only structural measure, which the organization has for countering an inadequate development of its paradigmatic direction, resulting in higher confidence in the established paradigm and even stronger misperceptions of others.⁹ Both reinforcing cycles decouple the organizational perception from reality, predetermining a strong and severe drawback if this aberration is not corrected. Given the described evolution, no countervailing

paradigm can gain enough strength to balance the over-confidence in the established paradigm. Moreover, the evaluation of a new paradigm's adequacy is performed within the perspective of the established paradigm. This flaw results in a rigid organizational outlook, which is unable to navigate into beneficial futures. The *Blindfolding* loop (R4) is especially powerful because it fosters a situation in which organizational members do not know that they do not know ('double-blindness'). The feedback loop R5 acts as an additional virtuous cycle, which boosts confidence in the established paradigms exponentially to overly high levels; it reinforces the already ongoing development.

Let us assume that the environment has changed slowly but steadily within a significant time horizon. At such a point in the organization's future, the established paradigm is not adequate anymore. Given steady behaviour by the environment, even the obvious inadequacy of the paradigm does not lead to a paradigm change because, first, no alternative paradigm has survived and had enough strength to substitute for the established one. Second, the inefficiency of the established paradigm is not perceived by the organization itself because the stock of *tasks unfulfilled and latent*, although large, goes undiscovered. In such cases, incremental changes in what the environment requires leave the adequacy of the paradigm unchallenged.

However, if change in the environment is radical and comes relatively early in the development of the organization's life, then a disruptive burst destabilizes the organization's fitness landscape significantly. The established paradigm becomes suddenly inadequate; a large number of tasks cannot be fulfilled satisfactorily anymore. Because the competencies in the established paradigm and the tasks successfully fulfilled have lower levels, confidence in the current paradigm goes down, with lower perception biases. In such a setting, the mechanisms R3, R4 and R5 would be rather weak. Hence, tasks which are not fulfilled would be discovered much faster. Then, it would become obvious that the adequacy of the established paradigm is questionable. In this case, learning with a new paradigm would be possible and would result in successful task execution and problem

⁸ This is implemented by a gradient over time, in the values of *Actual Adequacy of Established Paradigm*.

⁹ See the following causal loop: *perception bias* → (−) *discover* → (+) *Tasks not fulfilled and known* → (−) *Perceived adequacy to environment* → (+) *confidence in established paradigm* → (+) *perception bias*. The product of all polarities is (+).

solving. The learning process (*R2*) would fuel the competencies in the entrant paradigm, leading to a successful displacement of the established paradigm.

Both of these developments can be summarized as the *boiling-frog syndrome*—the organization will remain in a paradigmatic steady state when the environment's rate of change is below a certain threshold; beyond the threshold, the organization will adapt its paradigm to the environment's requirements. Here is where the concept of self-reference provides an important lever. Self-reference is an organization's second receptor for the current state of the system. It should enable the organization to overcome the organizational lock-in dynamics as described before. The next section will detail the respective mechanisms by which this can happen.

Structure Part 4: Enabling the Organizational Paradigm Transition (Figure 10)

Self-reference is, as has been detailed in this paper, a competency in deciphering, criticizing and changing the rules that influence the behaviour of the system. In Figure 10, self-reference is a meta-level measure, a meta-competence, for controlling the organizational reality. The level of self-reference of an organization is improved by external perturbations, internal perceptions, or a reflection process (*R6*). It is stimulated when the organization realizes that tasks are not fulfilled adequately. Self-reference is learned, which then results in improvements in the rate at which unsuccessful tasks are discovered (*R7*). In addition, increments in the level of self-reference also stimulate learning effects in the competencies of an entrant paradigm and increase the rate of successful task solving. To summarize, the concept of self-reference acts as a meta-level control loop (*B1*) to align the organization with its environment—with the side effect of developing competency in the entrant paradigm (*R2*).

Now that we have detailed the system structure, we also want to point to some of its limitations. We have concentrated solely on competing paradigms (Senge, 1990; Sterman & Wittenberg, 1999). In reality, there are also paradigms, which

coexist in symmetrical-symbiotic or unsymmetrical predator–prey relationships (Pistorius & Utterback, 1997). These forms of interaction would best be discussed in future research. In addition, we detail in this model the transition between two paradigms; future research might generalize it to *n*-interacting paradigms, which is assumed to be a demanding task (also Sterman and Wittenberg (1999) use only a limited number of paradigms for explicatory purposes).

Simulating the Model

Having detailed the structure of the system under study, we are now going to simulate it in the following. First, we show the case of an organization, which is locked in the established paradigm, and demonstrate that a short-term external perturbation is not sufficient to break the existing paradigm. The second case demonstrates a successful displacement of the established paradigm by means of a sufficient perturbation. Based on these first two cases, we are motivated to experiment with the mathematical model to understand its tipping point dynamics and the sensitivity of the tipping point. The model is simulated over two years (720 days).

Case 1: Dominance of the Established Paradigm—Entrant Paradigm Fails

In this case, the organization has a low level of self-reference (*R6*, *R7* and *B1* are not significant). Given this situation and based on the established paradigm, tasks are executed successfully, competencies are accumulated (*R1*), and confidence in the established paradigm arises, leading to strong perception biases, which confirm the established paradigm (*R3*, *R4*, *R5*) and thwart evidence of mismatches from becoming obvious. An entrant paradigm cannot gain strength by itself—*R2* is not active (Figure 11). The evolution of the state of the system is smooth and continuous. As indicated in Figure 11 (right hand side), the organization is locked-in; hence, the system changes only within the same paradigm *S'*.

Intentions to change the established paradigm in such a situation require an external perturbation.

Figure 11 The established paradigm dominates the system; an entrant paradigm cannot gain strength. The state of the system evolves incrementally towards equilibrium, which indicates a complete organizational lock-in

This might be achieved by the application of external self-reference capabilities. The intensive perturbation begins at $t = 150$ [days] with a duration of 20 days. Thereupon, the competencies in the entrant paradigm can gain strength (Figure 12). When the perturbation ceases, the paradigm has to prosper based on its own momentum (R_2). However, this momentum is not strong in relation to the forces suppressing it (R_3 , R_4 , R_5). Consequently, the competencies that have been built up dissolve over time—the organizational lock-in of the established paradigm could not be overcome; the state of the system (Figure 12) follows the same trajectory as in Figure 11.

Case 2: Displacement of the Established Paradigm—the Entrant Dominates

Given enough resources to sustain an external perturbation for a longer period, what might be

the result on the changes in paradigms? To answer this question, we simulate an external perturbation with duration of 60 days, three times as long as the perturbation in the first case.

The perturbation (60 days, Figure 13) starts at $t = 150$ here as well. Figure 13 shows that until $t = 210$, the competency level of the entrant paradigm is pressed to a level of nearly 50. Then the perturbation levels off. However, this external support has been sufficient to create a momentum in the organization that can now be self-sustained. R_2 continues to improve the competencies in the entrant paradigm; higher levels of self-reference lead to a discovery of more unfulfilled tasks, which are subsequently completed in view of the entrant paradigm. In addition, R_6 and R_7 are active in improving the level of self-reference, transforming the organization into a highly self-referential system. After $t = 230$, the established paradigm is displaced by the entrant paradigm,

Figure 12 The external perturbation results in a short-term improvement of the competencies for the entrant paradigm. This intervention, however, cannot gain enough strength internally to challenge the established paradigm. The system remains on the same trajectory

Figure 13 A perturbation of 60 days is sufficient to break the organizational lock-in and change the trajectory of the organization from S' to S'' . The established paradigm loses its superior position and fades in the long-term

at first gradually, later abruptly. This is also indicated by the transition of the system state from S' to S'' (Figure 13). The external perturbation has successfully enlivened the self-referential process of the system with a subsequent paradigm change. The system has become a different one.

Experimentation

The previous cases indicate that the system has emergent bifurcation properties. We analyse the simulation model using a univariate sensitivity analysis ($n=100,000$ simulations, uniform distribution, with durations $D \in [0; 720]$ [days]). Figure 14 shows an insightful subsample of this analysis. The bifurcation threshold is approximately at $D=22.8$ days after the beginning of the perturbation. Perturbations with durations shorter than

Figure 14 A sensitivity analysis uncovers a bifurcation dynamic. In the specification used for this paper, the tipping threshold is approximately at 22.8 days after the beginning of the perturbation or intervention, which occurs at $t=150$

this threshold cannot build enough strength of the entrant paradigm to self-sustain it internally in the organization.

For the sensitivity analysis in Figure 14, we have started the perturbation (or intervention) at $t=150$ for all cases. A further interesting question are as follows: how the duration, D , of the perturbation is related to the perturbation's starting point, t_i , and how both influence the bifurcation threshold? This is what we analyse next by an additional extensive Monte Carlo simulation with the following setup: $n=150,000$ simulations, $D \in [0; 720]$, $t_i \in [0; 400]$, final time of the simulation, $T=720$; $t_i \notin [400; 720]$ especially because for $t_i > 400$, the development of the entrant paradigm is not completed by the end of the simulation. From the analysis, we obtain a positive, continuous and curvy relation between the start time of the perturbation, t_i , and the required duration of the perturbation, D , required for displacing the established paradigm. The curve represents the tipping points between the areas of 'entrant paradigm dominates' and 'established paradigm dominates' contingent on start time and duration of the perturbation. From Figure 15, it becomes obvious that the earlier the perturbation occurs, the less its duration has to be for the established paradigm to be overcome. This is comprehensible, given the feedback mechanisms described previously. We can also see that the relationship is highly nonlinear. This is because of the complex interactions of accumulations, duration of perturbation, learning dynamics, and timing of perturbation as well as the adequacy of the established paradigm. Two implications can be derived. First,

Figure 15 An extensive Monte Carlo simulation exhibits that the tipping point for paradigm displacement depends significantly on the duration and the start time of the perturbation. The earlier the intervention, the more efficient it will be. A late intervention is most efficient at $t = 165$

overcoming established paradigms becomes more expensive the longer the established paradigm is reinforced, up to the point where a change in paradigm becomes virtually infeasible ($t > 300$). Second, it is beneficial from an efficiency view to pay attention to the displacement threshold. For example, from $150 < t < 180$, the effort of the intervention required to initiate a paradigm displacement remains approximately constant; hence, in this neighborhood, waiting with interventions will be beneficial. The reason is that adequacy of the existing paradigm decreases during this period, thus slowing the intensification in the tipping threshold, that is, the time required to overcome the established paradigm. During the period from 90 to 150, the effort to displace the established paradigm, although relatively high, even diminishes. This is because the learning that takes place during this period is faster, as a significant body of unfulfilled tasks has already accumulated, which is then reduced quickly, leading to a steep increase in the competencies in the entrant paradigm. The ideal point in time for a latest but by then most efficient intervention because of these dynamics would be at $t = 165$.

We notice that we have always assumed ideal perturbations, that is, perturbations of maximal strength from the start of the perturbation (a stepwise increase of 100 is introduced without significant delays, see Figures 12 and 13). Hence, with our assumptions, the effects of external perturbations on self-reference and the organizational dynamics are overestimated. To compare perturbations with more realistic assumptions regarding

delays and strengths, it is necessary to calculate the effective force of the perturbation. Expressed mathematically, it is the integral of the perturbation from t_i to t_{i+D} , with D as the duration of the perturbation. For example, an increase of D from 20 to 60 results in a threefold effective force of the perturbation or intervention.¹⁰

To summarize, it is most likely that the changes of established, locked-in paradigms are triggered by external events, for example, disruptive changes of the environment, or by interventions, which increase the level of self-reference and hence kick off paradigm-transition dynamics.

DISCUSSION AND CONCLUSIONS

We have found that the concepts of operational closure and self-reference are indeed relevant for the inquiry into organizations. Not surprisingly, our attempt to make these highly abstract concepts palpable has borne the fruit of higher conceptual clarity more at the end of our article than at its beginning. We have defined *operational closure* as fundamental property of an organization, which produces and sustains itself on the basis of its elementary operations. The concept of *self-reference* has been considered,

¹⁰ The first case: $D = 20$ [days] with 100 competence units each day, resulting in an effective force of the perturbation = 2000 competency units. The second case: $D = 60$ [days] with 100 competency units each day, resulting in an effective force of the perturbation = 6000 competency units.

in regard to the organizational context, in the sense of reflexive activities or roles, which deliberate on processes at an object level from a higher-level logical stance. We have proposed a formal conceptual framework for a parsimonious expression of these concepts and applied it to both a qualitative case study and a simulation model to capture essential properties of organizational change. Based on the case study and the simulation, we can now draw conclusions for organizational practice. These conclusions are not the product of a 'forceful syllogism' (as Aristotle would call it) but insights, which have emerged during the process of our inquiry:

The Coupled Roles of Mindset and Autonomy

Operational closure is a generative mechanism that can produce organizational autonomy. From the Greek roots *autos* (self) and *nomos* (law), we can infer that an autonomous system is a law unto itself. It determines its own rules of operation and governance. One strength of operational closure is in the adherence to established values, procedures and interpretations, in short, a paradigm, which reinforces and consolidates identity. In addition, it is precisely this identity, which constitutes the ultimate embodiment of a system's autonomy. The ultimate strength of an organization's autonomy, then, is in leveraging the meaning jointly defined and given to the system by its members. Addressing the question of meaning in the organization is more important than most of the other tasks of management. In other words, it is the shared mindset that governs the fate of an organization.

A Different Light on Organizational Transformation

In principle, joint mindsets tend to be stable. They can be a formidable strength in shaping the behaviour of a social system in the self-activating, recursive, self-stabilizing process of paradigm change. However, they are also a main factor of organizational inertia and resistance to change. The power of an operationally closed system can

become a weakness when a new situation calls for adaptation. Under such circumstances, autocatalytic forces are needed that trigger change. The source of such forces lies in the domain of neither matter nor energy but in the domain of information, communication, knowledge, understanding and wisdom; the key to transformation is self-reference. It is the main force that can change the endogenous dynamics of an organization and lead to paradigm transition.

A Complexity View on the Dynamics of Change

Organizational change is often designated as a complex process. We have studied a concrete organizational transformation, capturing its complexity by concentrating on two distinct but complementary angles: operational closure and self-reference. Beyond that, we have fleshed out the transformation phenomenon in a simulation model, which builds on the case study, but can be considered rather general and reaching beyond our specific case study. The results of our experiments with the model have, in particular, highlighted that the pattern of paradigm change can be anticipated. We have also shown that paradigm changes are not only triggered by disruptions in the environment, but can also, and at least as much, be facilitated by interventions that enforce self-reference. The ideal timing—operationalized by starting point and duration of the perturbation—of such interventions can be estimated as a function of the dynamics of the system under study. Also, the intensity of interventions can be ascertained. The evolution of a new paradigm does not necessarily lead to its domination. The process is highly non-linear. Bifurcations can arise along the way, and are likely, if the interventions are not properly 'dosed' in terms of timing and intensity. Beware, however, because the threshold to transition is a tipping point, and paradigm change can also go 'the wrong way', that is, contrary to expectations.

In addition to the analysis given here, our results could also be discussed in terms of a number of theoretical concepts, for example, resistance to change, punctuated equilibrium, breakdown, knowledge assimilation and strategic leadership,

but that is not possible because of limited space. Our initial question was if *operational closure* and *self-reference* are insightful descriptors of processes of organizational change. We cannot claim that the analysis based on these concepts leads to entirely different conclusions than studies based on other frameworks, as they can also be found in qualitative research (e.g., Pettigrew and Whipp, 1991, Floyd and Woolridge, 2000, Gioia *et al.*, 2010).

In any case, we can claim that our study is different from 'the easy research that relies on surveys and public databases [which] is very likely to discover empty clichés and superficial rationalizations' (Starbuck, 2010: 1398) and is paramount in mainstream research (Parnas, 2007). 'Researchers can learn things that are more realistic by using methods that penetrate façades' (Starbuck 2010: 1398). Our contribution is special in its systemic-cybernetic approach and therefore offers, in our view, a valuable complement to the mainstream works.

The findings in this article justify the claim that the descriptions based on the systemic concepts presented here have 'penetrated façades' in that they provide a broad, holistic perspective on complex processes: We observe an organizational process as a whole, with the analysis hinging on two lead concepts only, and do not delve into additional analytical details, such as the analysis of self-referential sub-processes or the description of decisions or structural changes in different areas of an organization. In this way, several new insights have been gained, namely, by leveraging the complementarity of qualitative and quantitative analyses as synthesized in the paper. The core concepts of our study, operational closure and self-reference, have lent themselves to an operationalization, therewith tightly coupling the case study and the simulation model. These concepts facilitate parsimonious formulations, and that might explain their power for analyzing complex systems on both the qualitative and the quantitative tracks.

We trust that the evidence from our analysis leads to a better understanding of the structures underlying the change within organizations with the help of the systemic concepts *organizational closure* and *self-reference*. We must preclude a fragmented

picture that would focus on partial aspects only. By adopting a holistic stance, we try to capture the paradigm-transition process as an encompassing pattern of change pervading the whole organization. The systemic concepts applied here are particularly appropriate for studying organizations as wholes.

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APPENDIX: EQUATIONS OF THE SYSTEM DYNAMICS MODEL

(001)	Actual Work Performed = INTEG (change actual work performed,0) Units: task
(002)	adequacy of current routine relative to organizational environment = WITH LOOKUP (requirements of organizational environment,([(0,0)-(10,10)],(0,1),(1,0))) Units: dmnl
(003)	allocation change time = 10 Units: Day

(Continues)

- (004) avg life time = 60
Units: Day
- (005) benefits of new routine = costs of dissolved work * Dissolved Work
Units: USD
- (006) change actual work performed = generation rate of work not solved by current routine + work completion rate
Units: task/Day
- (007) change delay time = 4
Units: Day
- (008) change time to adjust forgetting = 5
Units: Day
- (009) competence gap in current routine = target competence for current routine - Competences in current Routine
Units: competence unit
- (010) competence gap in new routine = target competence for new routine - Competences in new Routine
Units: competence unit
- (011) Competence new routine double = Competences in new Routine * 2
Units: competence unit
- (012) Competences in current Routine = INTEG (learning of current routine - forgetting ep, 1)
Units: competence unit
- (013) Competences in new Routine = INTEG (learning of new routine + "pilot (un)-learning rate", 0)
Units: competence unit
- (014) completion of work by new routine = max(min(effect of reflexivity competence on work rates * resources for new routine * productivity new routine, Work not solved by current Routine / TIME STEP), 0)
Units: task/Day
- (015) completion of work with new paradigm = max(min(resources for current routine * productivity new routine, Work Remaining / TIME STEP), 0) * effect of rel fraction on paradigm change
Units: task/Day
- (016) confidence adjustment time = 10
Units: Day
- (017) confidence based on competence mtpl = 1
Units: confidence unit / competence unit
- (018) Confidence in current Routine = INTEG (net change of confidence in current routine, indicated confidence in current routine)
Units: confidence unit
- (019) costs of dissolved work = 120
Units: USD/task
- (020) "costs per competence unit (current routine)" = 150
Units: USD/competence unit
- (021) "costs per competence unit (new routine)" = 150
Units: USD/competence unit
- (023) dissolution rate = max(Work not solved by current Routine * fractional dissolution rate, 0) * (1 - effect of reflexivity competence on work rates)
Units: task/Day
- (024) Dissolved Work = INTEG (dissolution rate - obsolescence rate, 60)
Units: task
- (025) duration pulse = 60
Units: Day
- (026) effect of competence in new routine in confidence in current routine = effect of competence in new routine in confidence in current routine T(Competences in new Routine / maximal competences of routine)
Units: dmnl
- (027) effect of competence in new routine in confidence in current routine T([(0,0)-(1,1)], (0,1), (0.397554, 0.925439), (0.70948, 0.811404), (0.868502, 0.710526), (1, 0.6))
Units: dmnl
- (028) effect of competences on productivity current routine = effect of competences on productivity T(Competences in current Routine / maximal competences of routine)
Units: dmnl

(Continues)

- (029) effect of competences on productivity new routine = effect of competences on productivity new routine T (Competences in new Routine/maximal competences of routine)
Units: dmnl
- (030) effect of competences on productivity new routine T([(0,0)-(1,2)],(0,0.75),(1,1.25))
Units: dmnl
- (031) effect of competences on productivity T([(0,0)-(1,2)],(0,0.75),(1,1.25))
Units: dmnl
- (032) effect of perceived attractiveness of new routine on pilot learning rate = effect of perceived attractiveness of new routine on pilot learning rate T (perceived relative attractiveness of new routine/reference perceived relative attractiveness of new routine)
Units: dmnl
- (033) effect of perceived attractiveness of new routine on pilot learning rate T
([(-2,-2)-(2,2)],(-2,-2),(0,0),(2,2))
Units: dmnl
- (034) effect of reflexivity competence on perception bias = 1-reflexivity competence*reflexivity competence
mtpl
Units: dmnl
- (035) effect of reflexivity competence on work rates = delay1(reflexivity competence*reflexivity competence
mtpl,change dely atime)
Units: dmnl
- (036) effect of rel fraction on paradigm change = effect of rel fraction on paradigm change T(relative fraction of competences in new routine)
Units: dmnl
- (037) effect of rel fraction on paradigm change T([(0,0)-(1,1)],(0,0),(1,1))
Units: dmnl
- (038) effect of schedule pressure on resources for current routine = effect of schedule pressure on resources for current routine T(schedule pressure)
Units: dmnl
- (039) effect of schedule pressure on resources for current routine T([(0,0)-(2,2)],(0,0.5),(1,1),(2,1.5))
Units: dmnl
- (040) external reflexivity competence = 100*pulse(start time pulse, duration pulse)
Units: competence unit
- (042) forgetting ep = Competences in current Routine/forgetting time
Units: competence unit/Day
- (043) forgetting time = smooth(if then else(Competences in new Routine > threshold for forgetting, forgetting time when old,1e + 006),change time to adjust forgetting)
Units: Day
- (044) forgetting time when old = 30
Units: Day
- (045) fraction of tasks correct and complete = 0.6
Units: dmnl
- (046) fractional dissolution rate = 0.3
Units: 1/Day
- (047) generation rate of work not solved by current routine = max(min(resources for current routine*productivity current routine*(1-fraction of tasks correct and complete), Work Remaining/TIME STEP),0)
Units: task/Day
- (048) indicated confidence in current routine = if then else(Switch awareness of external requirements = 0, Competences in current Routine*confidence based on competence mtpl*effect of competence in new routine in confidence in current routine, Competences in current Routine*confidence based on competence mtpl*adequacy of current routine relative to organizational environment*effect of competence in new routine in confidence in current routine)
Units: confidence unit
- (049) init work not solveable = 3
Units: task
- (050) init work remaining = 60
Units: task

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- (052) investment costs for current routine = $\max(0, \text{competence gap in current routine} \times \text{costs per competence unit (current routine)})$
Units: USD
- (053) investment costs for new routine = $\text{competence gap in new routine} \times \text{costs per competence unit (new routine)}$
Units: USD
- (054) learning of current routine = $\text{work completion rate} \times \text{marginal learning effect current routine} \times 0.5$
Units: competence unit/Day
- (055) learning of new routine = $\text{completion of work by new routine} \times \text{marginal learning effect new routine} \times \text{normal marginal learning}$
Units: competence unit/Day
- (056) marginal learning effect current routine = WITH LOOKUP (Competences in current Routine, $([(0,0), (100,0.3)], (0,0.25), (29.3578, 0.222368), (57.7982, 0.164474), (77.9817, 0.102632), (90.5199, 0.0552632), (100,0))$)
Units: competence unit/task
- (057) marginal learning effect new routine = WITH LOOKUP (Competences in new Routine, $([(0,0)-(100,2)], (0.611621, 1.74561), (28.1346, 1.52632), (54.7401, 1.14912), (75.5352, 0.736842), (89.6024, 0.359649), (100,0))$)
Units: competence unit/task
- (058) maximal competences of routine = 100
Units: USD
- (059) multiplication of efforts to solve unsolveable work = 2
Units: dmnl
- (060) net change of confidence in current routine = $(\text{indicated confidence in current routine} - \text{Confidence in current Routine}) / \text{confidence adjustment time}$
Units: confidence unit/Day
- (061) normal allocation of resources to current routine = 0.6
Units: dmnl
- (062) normal marginal learning = 0.19
Units: dmnl
- (063) normal pilot learning rate = 0.25
Units: dmnl
- (064) normal productivity = 2
Units: task/resource/Day
- (065) normal productivity new routine = 2
Units: task/resource/Day
- (066) obsolescence rate = Dissolved Work/avg life time
Units: task/Day
- (067) perceived benefits of new routine = $\text{benefits of new routine} / (1 + \text{perception bias} \times \text{effect of reflexivity competence on perception bias})$
Units: USD
- (068) perceived relative attractiveness of new routine = $\text{perceived benefits of new routine} - \text{perceived relative investment costs for new routine}$
Units: USD
- (069) perceived relative investment costs for new routine = $\text{relative investments costs for new routine} \times (1 + \text{perception bias} \times \text{effect of reflexivity competence on perception bias})$
Units: USD
- (070) perception bias = $\text{perception bias T}(\text{Confidence in current Routine} / \text{reference confidence in current routine})$
Units: dmnl
- (071) perception bias T $([(0,-2)-(3,3)], (0,-0.5), (1,0), (2.5,0.5))$
Units: dmnl
- (072) "pilot (un)-learning rate" = $\max(\min(\text{pilot learning rate} \times \text{effect of perceived attractiveness of new routine on pilot learning rate, Competences in new Routine} / \text{TIME STEP}), -\text{Competences in new Routine} / \text{TIME STEP}) \times \text{normal pilot learning rate}$
Units: competence unit/Day
- (073) pilot learning rate = WITH LOOKUP (Competences in new Routine, $([(0,0)-(100,4)], (0,4), (8.25688, 3.07018), (25.9939, 1.92982), (49.5413, 0.964912), (75.2294, 0.122807), (100,0))$)
Units: competence unit/Day

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- (074) productivity current routine = if then else(Switch productivity = 0, normal productivity, normal productivity * effect of competences on productivity current routine)
Units: task/resource/Day
- (075) productivity new routine = if then else(Switch productivity new routine = 0, normal productivity new routine, normal productivity new routine * effect of competences on productivity new routine)
Units: task/resource/Day
- (076) "re-interpretation rate" = $\max(0, \text{Work not solved by current Routine} * (1 - \text{tolerable fraction of unsolved work-fractional dissolution rate})) * (1 - \text{effect of reflexivity competence on work rate})$
Units: task/Day
- (077) reference confidence in current routine = 40
Units: confidence unit
- (078) reference perceived relative attractiveness of new routine = 6000
Units: USD
- (079) reflexivity competence = $\min(\text{external reflexivity competence} + \text{reflexivity competences based on new routine}, 100)$
Units: competence unit
- (080) reflexivity competence mtp1 = 0.01
Units: 1/competence unit
- (081) reflexivity competences based on new routine = reflexivity competences based on new routine T (Competences in new Routine)
Units: competence unit
- (082) reflexivity competences based on new routine T $[(0,0)-(100,100)], (0,0), (100,100)$
Units: competence unit
- (083) relative fraction of competences in new routine = Competences in new Routine / Competences in current Routine
Units: dmnl
- (084) relative investments costs for new routine = investment costs for new routine - investment costs for current routine
Units: USD
- (085) requirements of organizational environment = WITH LOOKUP (Time, $[(0,0)-(180,10)], (0,0.2), (181.101, 1.40351)$))
Units: dmnl
- (086) resources for current routine = delay1(if then else(Switch schedule pressure = 0, total resources available * normal allocation of resources to current routine, total resources available * normal allocation of resources to current routine * effect of schedule pressure on resources for current routine), allocation change time)
Units: resource
- (087) resources for new routine = total resources available - resources for current routine - "resources required for dissolution and re-interpretation"
Units: resource
- (088) "resources required for dissolution and re-interpretation" = $(\text{dissolution rate} + \text{"re-interpretation rate"}) / \text{productivity current routine}$
Units: resource
- (090) schedule pressure = Work Remaining / init work remaining
Units: dmnl
- (092) start time pulse = 150
Units: Day
- (093) State of the System = $\max(\text{Competences in current Routine}, \text{Competence new routine double})$
Units: competence unit
- (094) Switch awareness of external requirements = 0
Units: dmnl
- (095) Switch productivity = 1
Units: dmnl
- (096) Switch productivity new routine = 1
Units: dmnl
- (097) Switch schedule pressure = 1
Units: dmnl

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- (098) target competence for current routine = 75
Units: competence unit
- (099) target competence for new routine = 75
Units: competence unit
- (100) task generation rate = RANDOM NORMAL(0, 10, 5, 1, 1)
Units: task/Day
- (101) threshold for forgetting = 80
Units: competence unit
- (102) TIME STEP = 0.125
Units: Day
- (103) tolerable fraction of unsolved work = 0.3
Units: 1/Day
- (104) total resources available = 6
Units: resource
- (105) Work Completed = INTEG (completion of work by new routine + completion of work with new paradigm + work completion rate, 0)
Units: task
- (106) work completion rate = max(min(resources for current routine * productivity current routine * fraction of tasks correct and complete, Work Remaining / TIME STEP), 0) * (1 - effect of rel fraction on paradigm change)
Units: task/Day
- (107) Work not solved by current Routine = INTEG (generation rate of work not solved by current routine - completion of work by new routine - dissolution rate - "re-interpretation rate", init work not solveable)
Units: task
- (108) Work Remaining = INTEG (multiplication of efforts to solve unsolveable work * "re-interpretation rate" + task generation rate - generation rate of work not solved by current routine - work completion rate - completion of work with new paradigm, init work remaining)
Units: task
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