CCC 2022
Proceedings of the Creative Construction e-Conference (2022) 027
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
https://doi.org/10.3311/CCC2022-027

The Role of Friction in Complex Organization Networks

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Abstract

We assume an organization comprising a vast number of participants with varying interests and skills. In order to contribute to a common project, the members are interconnected to each other impacting adjacent players by their own attitude via nonlinear functions. Hence, an organization is modelled using systems theory as nodes representing the single variables and local interaction functions impacting next neighbours. Any such system starts with arbitrary values, i.e., a random starting state vector, and eventually develops towards equilibrium in a system-specific manner. While a purely determined system follows the given differential equation systems and, therefore, exhibits at least some principally causal character, realistic models need to take in stochastic variations on all variables representing local ideas, constraints, likes and dislikes, therewith bringing in the most important aspect of creativity. This add-on enforces non-linear interaction aspects raising the unpredictability of the development paths to possibly chaotic behaviour. The aim of this research is to investigate the developing character of systems close to these limits of determinability where unimpeded development tends to instable and finally chaotic behaviour. Based on the fundamental concepts of controlling loops, the loss of determinism is elaborated and a principal limit of controlling strength based on the local complexity is described. On this background, the role of friction within an organizational system formed by the fundamental delay to all interactions is investigated. The introduction of some additional artificial friction is furthermore proposed to help stabilizing the system in the long run. May this even slow down the local stabilizing processes, friction is expected to dampen random side effects to some degree and, hence, providing some safety margins against fundamental instability plays a crucial role.

Keywords: Organization Theory, Controlling, Systems Theory, Lean Management, Construction Management.

1. Introduction

The central task of any organization is to bring together a vast number of participants aiming at the optimal solution of a complex situation, comprising a number of issues connected by their mutual relationships while furthermore observing numerous boundary conditions [1, 2, 3].

With respect to construction projects, these "issues" are given by a huge number of technical, legal, economical, aesthetical, etc., parameters which are forming the actual physical construction as well as the processes of creating. They clearly depend on each other in numerous ways and range within certain boundaries given by external strict rules or just by more or less strongly pursued preferences. Numerous players are furthermore involved contributing to the definition or execution of these issues, also bringing in a number of parameters which as well are depending on many others. Clearly, most of the parameters are initially standing in contradiction to others and, hence, the situation is not acceptable and needs to be developed efficiently into a more agreeable version. In the end, a set of parameters is expected to be elaborated which meets all conditions simultaneously and is accepted by all participants as satisfactory [4].

In case of project organization, this would not be a long-term task but is put together in advance while expecting the organization to develop towards the optimal solution on the first attempt consuming the least possible volume of resources.

1.1. Exploring Equilibrium States

A favourable state would primarily be given by the fulfilment of all given boundary conditions and with all dependencies completely observed [5]. Since this is certainly impossible to achieve, a state of optimal fulfilment is aimed at where all requirements are at least fulfilled to a degree where in total every loss is balanced by respective gain, i.e., the set of parameters is representing a state of equilibrium.

Stability is furthermore achieved if any deviation from this state leads to an unbalanced situation which develops by itself towards the equilibrium. This behaviour refers to the inherent mechanisms of the organization to change parameters which is driven by the multiple targeted dependencies. Practically, this is to some degree a consequence of dependencies where a target value is simply determined by the source values, e.g., cost would be plainly given by the product of the required number and the price per unit. Beyond that, however, a significant number of dependencies are actively driven by the participating players' preferences, e.g., the investors pressure to finish in shortest possible time. The overall concept of economy is based on such driving effects and consolidating at states of stable equilibrium, e.g., equilibrium of markets [6, 7].

However, respective investigations [8, 9, 10, 11] reveal that stable systems need to be constructed carefully. Randomly generated structures will under no circumstances consolidate with some significant probability. This implies in particular two aspects:

First, parameters which need to be reliably held within a certain corridor need to be equipped with active controlling loops feeding back required modifications to the environment on respective deviations and so far, keeping the parameters close to the designed values [12, 13]. This applies, e.g., for the rate of consuming resources or the rate of producing a certain result. Such controlling mechanisms are in general not existing automatically but need to be carefully implemented in order to provide predictable stability.

Second, players need to bring in the personal readiness to adjusting their local parameters of preference [4, 14, 15, 16, 17]. Otherwise, no stability can be achieved. This can be encouraged by the use of respective contracts, in particular treating the issues of coordination and motivation allowing to helpfully provide maximizing their local utility functions. In reality, this aspect implies that each player is in fact interested in the project's outcome and invests a lot to adapt himself to the very needs. Such behaviour is identical to local controlling loops observing for differences to sensible values and adjusting accordingly. Obviously, controlling mechanisms need to be substantially stronger than the destabilizing effects of the system.

1.2. Introducing Time Delays Expressing Practicability

In order to negotiate these deviations, communication is required. Lean Management tends to favour fast and widely targeted communication while hierarchical approaches prefer strong separability and hence avoidance of long looped communication in order to have fast consolidating but starkly local communication clusters [18, 19, 20, 21]. The preference of the one or the other is not to be discussed here, however, we need to agree on the existence of a not vanishing time pattern of communication. Even under ideal circumstances, a player needs some time to survey and understand the requirements of the environment, to consider the local possibilities and to compile and initiate a respective offer. Hence, all kinds of reacting mechanisms required to develop consolidation will happen with a minimal but significant time delay [22, 23]. This very realistic property is expected to have the effect of slowing down communication, therewith slowing down the process of consolidating towards an equilibrium just in the same way as the term "friction" would describe in a very perfunctionary way.

1.3. Creativity

As already pointed out in section 1.1. [4], the willingness to adjust of any participant is required for consolidation. Considering in particular personalized players, not merely mathematical functions or inevitably occurring consequences are dictating the reaction on the needs of the environment, but in particular unthought-of solutions and proposals are expected, namely creative ideas. Creativity happens to the participants to their best knowledge and will. Semantically, this is a rather obvious conclusion. However, the actual effect of creativity with an organization has not been described up to now in detail and is to be investigated in this paper, providing a respective proposal.

2. Considerations of Potential Driven Motion

2.1. Model of an Organization as a System

In order to study the fundamental behaviour of organisations, typically models according to system's theory are used [24, 25, 26, 27, 28]. All participants, physical issues as well as persons, are represented by elements, i.e., nodes, while their interaction is given by unidirectional functions on the respective ties. On the most fundamental level, all nodes bear exactly one variable q_i which is the target of all inbound tie-functions determining required changes of the q_i. The state vector $\vec{Q}$ is spanned by the multiplicity of all variables q_i. Developing the tie-functions into Taylor series is used to linearize the system, which is applicable in the close proximity of equilibrium vectors as long as the functions are sufficiently differentiable. Then, the impact of the in-ties on a single variable is linearly cumulated as well:

$$\frac{\partial q_i}{\partial t} = \sum c_{i,j} q_j \tag{1}$$

Since absolute values of a state vector are of no interest when investigating the dynamical behaviour close to states of equilibrium, a respective transformation of the coordinate system can be applied where the origin represents the state of equilibrium $\vec{Q} = \vec{0}$. This approach considers in particular the changing characteristics, i.e., adjustability of local parameters towards the requirements of the adjoining system for each participant regardless of their absolute value. This approach leads to linear differential equation systems where the solutions are given as exponential functions. These allow for damping as well as for escalating behaviour depending on the sign of the tie strength $c_{i,j}$ in case of complex number also for oscillation which may as well be damped or escalate [23, 29].

2.2. Concept of a Potential

A system comprising vast numbers of interactions between the respective variables initially represents a state of discrepancy where most conditions are not fulfilled, i.e., far from equilibrium [30]. However, interactions are not merely stating the local inconsistency but include a mechanism to modify target elements towards an improved situation where less discrepancy is observed. This is the inherent working of a system to develop towards equilibrium, where either all relationships are completely fulfilled or at least are fulfilled to some degree where all impacts are compensating for each other at every node [31].

Hence, the degree of overall discrepancy as a function of all n variables q_i semantically plays the role of a n- dimensional potential $\Omega(q_i)$ which is to be minimized. A global minimum reflects the particular state vector where the cumulative discrepancy is minimal and cannot be improved further. No external means need to be established developing the state towards this vector but the impact functions themselves take care of the respective modification of their targets leading to equilibrium.

Classical algorithms searching for a minimum state on a multidimensional potential likewise operate simultaneously on all variables q_i (i.e., coordinates of the space of states) and take small modifying steps into the direction of the gradient $-\nabla\Omega(q_i)$. Therewith, a path "downward" the potential is taken, finally ending at the respective minimum where the gradient is zero $-\nabla\Omega(q_i) = 0$and no more sensible steps can be derived. Using a physical understanding, the negative gradient is used as a virtual "force" driving the particular variables towards the minimum where no more directional "forces" are in effect.

Remark: This understanding resembles physical potentials, however, is not the same. In this context we discuss the applicability of the physical terms like "potentials", "forces, "energy" etc. and their properties on the development of an organizational system. Therefore, all needed properties need to be explicitly derived from the given differential equations rather than unreflectedly taken from well-known physics.

2.3. Linearized Interaction

Restricting interactions to linear functions leads to the well-known differential equation system of control which provides exponential solutions - oscillating or monotonously escalating or damped.

In the present discussion we reduce the multidimensional linear differential system exemplarily to a single control loop instead of considering the feed-back impact of numerous multi-step loops implying no restriction to generality. The overall character of motion is then given by the magnitude and the sign of the combined controlling strength β which might be a complex number.

$$\frac{\partial q_i}{\partial t} = -\beta q_i \quad \Rightarrow \quad q_i \sim e^{-\beta t} \tag{2}$$

On this background, the generalized force inducing the respective modification is defined by

$$F_i = \frac{\partial q_i}{\partial t} = -\beta q_i \quad \text{leading to the potential} \quad \Omega(q_i) = -\int F_i \, dq_i = -\int -\beta q_i \, dq_i = \frac{\beta}{2} {q_i}^2 \tag{3}$$

This is a positive square potential where generalized forces $F_i(q_i) = -\partial\Omega(q_i)/\partial q_i$ are consequently leading towards the equilibrium state $q_i = 0$.

In particular is to be noted that the generalized force in question is explicitly set by the differential equation as a function of the value q_i only, completely disregarding any possible previous value. Therefore, no issues of "history" are maintained.

From this we take the general understanding of a potential in the controlling context: Assuming a closed system, completely determined by the potential, all acting forces are taken exclusively from the gradient. Hence, at any location q forces are given, triggering a modification of q which lead to a new state where the potential yields a lower level. This reduction of potential (representing the improvement of the state regarding optimization) can never be reversed since forces always lead "downwards" (negative sign), unless there were means to "store" this potential difference somewhere and retrieve later being a different source of forces possibly driving states upwards a potential. However, in the case considered here the linear differential equation provides only the one given generalized force and no means of storage. Hence, this will not happen on the controlled system discussed here. Correspondingly, such virtual forces are understood as being "static" while "dynamic" forces resulting from history are not existing.

Remark: Obviously, the potential reflects the physical potential energy, while "storing" would be correspondent to kinetic energy.

2.4. Introducing Inertia and Friction

As pointed out in [23], any controlling delay due to finite detection patterns, time consuming considerations and finally the required time to get consequences into action is absolutely realistic and has the effect of virtual inertia as well as virtual friction. Therefore, sensible equations of motion are complete only if taking these terms into account as well:

Subjected to some substantial time delay Δt the integral controller differential equation

$$\frac{\partial Q}{\partial t} = -k_C Q \quad \text{develops into} \quad \frac{\partial Q(t)}{\partial t} = -k_C Q(t - \Delta t) \tag{4}$$

A second order Taylor development of Q close to the point of time t leads to

$$Q(t-\Delta t) \simeq Q(t) - \Delta t\frac{dQ}{dt} + \frac{\Delta t^2}{2}\frac{d^2Q}{dt^2} + \ldots \text{and} \frac{d^2Q}{dt^2} = \frac{-2k_C}{k_C\Delta t^2}Q + \frac{2(k_C\Delta t-1)}{k_C\Delta t^2}\frac{dQ}{dt} \tag{5}$$

In close analogy to the physical description of a harmonic oscillator the coefficients of the terms can be identified

$$\frac{\partial^2 Q}{\partial t^2} = -\frac{\beta}{\mu}Q - \frac{\rho}{\mu}\frac{\partial Q}{\partial t} \text{ and result in } \mu = \frac{\Delta t^2}{\tau_C} \quad \beta = \frac{2}{\tau_C} \quad \rho = 2\left(1 - \frac{\Delta t}{\tau_C}\right) \tag{6}$$

Remark: The formal solutions of this differential equation reflect the observed behaviour of controlling mechanisms very well, allowing for escalating or damped monotonous or oscillating functions [32].

In addition to the recognisable term of retarding force β a mechanism of "inertia" reflects the ability of a variable to maintain the recent rate of modification ("motion") for some time and implies a "storing" memory effect. The therefrom resulting generalized forces go with the second derivation of q and are controlled by the parameterμ. A second derivative implies that the previously given rate of modification is maintained, however, just infinitesimally modified by this term. Hence, the "history" of the situation plays a significant role as the development is principally continued, only small changes are made to the speed. Here, "dynamic" generalized forces come into play.

Furthermore, a "friction" term turns up, proportional to any present modification of q, i.e., proportional to the first derivative of q, in particular with negative sign, i.e., continuously reducing speed of motion. This is also a dynamic force, since it derives from the past speed of modification. However, if this term dominates over the inertia term, the differential equation can be reduced to the undelayed situation. Otherwise, the friction term contributes a certain share to the inertia term (i.e., setting a friction-modified change to the current rate of development), in the end leading to the observed damping effects on the oscillating solutions.

This background clarifies that in controlling structures "friction" is closely coupled to "inertia" and cannot be understood separately. Any time delay leads to inertia forcing oscillations as well as to friction reducing such behaviour.

Remark: The magnitude of these effects is, however, controlled independently by the time delay Δt and the controlling time constant τ_C. As expected, reducing the time delay to zero leads to vanishing inertia and constant friction, reducing the differential equation to the original first-order form:

$$\Delta t \to 0: \quad \mu\frac{\partial^2 Q}{\partial t^2} = -\beta Q - \rho\frac{\partial Q}{\partial t} \quad \Rightarrow \quad 0 = -\frac{2}{\tau_C}Q - 2\frac{\partial Q}{\partial t} \quad \Rightarrow \quad \frac{\partial Q}{\partial t} = -\frac{1}{\tau_C}Q \tag{7}$$

On the other hand, raisingτ_C produces increased friction up to a constant value while reducing inertia as well as (naturally) the controlling strengthβ:

$$\tau_C^{-1}(=k_C) \to 0: \quad \mu \to \mu \cdot k_C \quad \beta \to \beta \cdot k_C \quad \rho = \rho_0 - \rho_v \to 2 - \rho_v \cdot k_C \tag{8}$$

Potential approach: The so far extended differential equation requires a different setting when attempting a potential approach. Obviously, three terms represent the respectively acting forces "acceleration", retarding forces and "frictional" forces. Typically, non-conservative forces like (dissipative) friction cannot be described by potentials and need to be treated separately. Nevertheless, at least the inertia part is available:

$$\mu\frac{\partial^2 q_i}{\partial t^2} = -\beta q_i - \rho\frac{\partial q_i}{\partial t} \overset{\rho\to 0}{\Rightarrow} \frac{\partial^2 q_i}{\partial t^2} = -\frac{\beta}{\mu}q_i \qquad q_i \sim e^{i\omega t} \quad \omega = \sqrt{\beta/\mu} \tag{9}$$

Such second order potentials are known as a situation effectuating undamped oscillations as are observed.

The potential is then also a positive square (however, generalized forces are defined different from the previous section).

$$F_i \sim \frac{\partial^2 q_i}{\partial t^2} = -\frac{\beta}{\mu} q_i \quad \Omega_i = -\int F_i dq = -\int -\frac{\beta}{\mu} q_i dq = \frac{\beta}{2\mu} {q_i}^2 \tag{10}$$

Understanding dynamical forces/storing on potentials: On this background, the dynamical aspect renders comprehensible. Since the differential equation just sets the change of the modification rate (and not the modification rate itself), any force derived from the potential, i.e., from reducing the potential level, goes into a new dynamic state, i.e., the rate of change. This implies, that changes of this rate need a gradient of the potential to be created. Then, clearly, reducing the rate of change also requires a gradient of the potential which is only possible if this mechanism works *vice versa* as well. As a consequence, a rate of change "stores" the reduction of the potential, which originally created the rate, while a negative reduction of the potential level, i.e., a rise of potential, follows from emptying the “rate” storage, i.e., reducing the rate of change. Hence, a respective storage mechanism is available in this setting.

Understanding of friction on the potential: The effect of friction as a term proportional to the rate of change contributes to the virtual forces. Hence, this term is not depending on the location$q$but on the motion and can therefore not be modelled using a potential. However, the friction term creates nonetheless a generalized force which is to be understood as a well-defined decrease of potential, though not in dependence of q (but of $\partial q/\partial t$ which is history). Hence, friction can be denoted as a reduction of the potential which occurs at any location$q$. This share of diminishing the potential value can clearly not be stored somewhere and is understood as being “lost”.

3. The Effect of Creative Ideas and Friction on Minimizing Potential

3.1. Interdependency of Inertia and Friction

As soon as storing mechanisms enter the system, changes of the state vectors become reversible. Therewith, infinitely unstable situations are not only possible but represent the fundamental solution of the differential equation systems. Only unstorable fractions allow for dissipating reductions of the potential, i.e., damping effects leading finally to stable equilibrium states.

The functionality of the friction term on a potential approach is easily understood as each bit of gained potential improvement is stored with the inertia term, however, reduced to some degree by the friction impact. Thus, stored and, hence, from storage retrieved shares are always less than the original amount. This effect principally impedes reaching any formerly attained state vectors and therewith reduces any rate of change over the time and eventually brings all changes to a halt.

As pointed out in section 2.4., inertia effects are caused by reaction delays which also provide the damping friction. Hence, depending on the ratio of these effects with the introduction of oscillations also the solution is brought in. According to [22] stable equilibrium is achieved if the controlling time constant τ_C exceeds the time delay Δt significantly providing a measure of stability $S_N < 1$.

$$S \sim \frac{1}{\tau_C - \Delta t} \frac{Q}{\dot{Q}} \overset{Normalized\ Q}{\Rightarrow} S_N = \frac{1}{\tau_C - \Delta t} \text{ and } S_N := 1 \quad \Rightarrow \quad \tau_C^{stab} = 2\Delta t \tag{11}$$

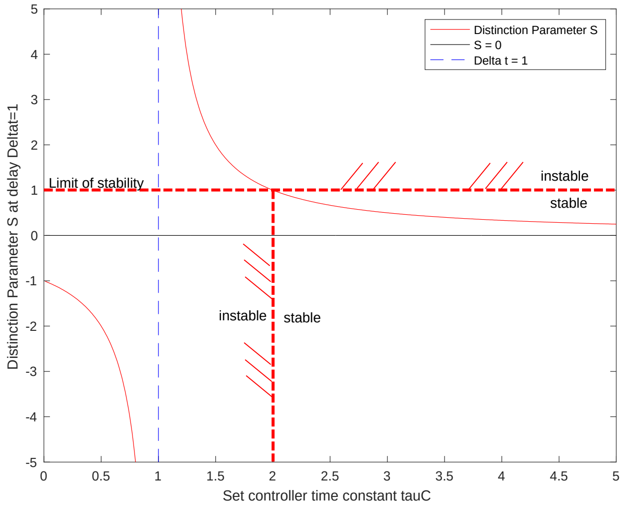

Figure 1. Development of distinguishing parameter S with $\tau_c$close to Δt

3.2. Creativity: Nonlinearity - Destabilizing Character - Chaos - Sub-optima

Accepting the bringing in of creative ideas implies a high degree of independence of a participant's reaction to the current situation. Thus, the restriction to linearity turns out to be a very limiting condition which no longer holds.

On this background, linear differential equation systems no longer reflect the true behaviour of the system. As a first consequence, so far induced situations lie far away from equilibrium where linear approximations provide only poor results. However, as long as dependencies are monotonous and differentiable, at least the given directions of approach are still valid, though stabilization time constants are no more reliably available. Furthermore, chaotic behaviour is likely to occur on nonlinear equation systems as soon as feed-back strengths are rising to substantial values. Such a scenario is clearly a realistic case, if a participant is reacting on an upcoming new idea with an innovative proposal himself. This may lead - as expected - to a completely new situation, where previously unknown characteristics are to be considered and explored. Therewith, the upcoming of multiple sub-optima as a consequence of nonlinear interaction is noted and needs to be tackled further in finding a globally optimal scenario.

3.3. Creative Modifications in Linear Systems

Creative modifications to a state vector have no directly corresponding counterparts in the linear differential equations. In particular, they cannot be described by generalized forces since the rate of change is in no way modified but solely the state vector is changed in no time. Furthermore, the reason, magnitude or direction of change cannot be derived from the present situation, e.g., the recent state vector determining the potential or any derivative. Hence, creative changes need to be understood as stochastically given, i.e., a random noise vector Q_{Rnd} added to the state vector at random times.

Investigating the impact on the stabilizing behaviour reveals easily that principally no stable equilibrium can be reached since continuously new ideas are coming up and need to be integrated (or damped away). Just adding a random constant vector to the state with each consolidation step simply adds the given uncertainty to the individual values as well as to the average result (and the final equilibrium state vector).

3.4. Proposed Approach - Simulated Annealing

If linearity is not given, an intermediary situation may be investigated and reveals some of the properties close enough to equilibrium to follow the differential equations, however, far enough away to allow for creative ideas. Hence, as known, e.g., from [26], the local environment is assumed to be subjectable to first-order-Taylor-development providing sensible stabilizing mechanisms, while arbitrary creative moves are allowed to shift the situation to completely different locations.

In this case the known equations may apply, however, at least the existence of a vast number of multidimensional sub-optima needs to be taken into account. As a consequence, the given differential equation system may be applicable but in need of further assistance to stabilize on global optima rather than local minima. At this point, creativity comes into play helpfully by providing the random noise required for appropriate travelling away from local sub-optima in order to reach globally optimal values (Simulated Annealing [33]).

This concept is named "Simulated Annealing" used for optimizing a state vector on a potential which is characterized by numerous sub-optima. During the execution of classical hill-climbing algorithms a random modification is added on the state-vector (resembling Brownian motion) which inhibits sticking to local minima and allows for pushes towards a global solution. Over the optimizing process the magnitude of the add-on is reduced to zero forcing a stable equilibrium once it is reached. This corresponds to the cooling down process, diminishing the Brownian motion, hence the term "annealing". In order to avoid repeated jumps, i.e., artificial oscillations, a single criterion is to be observed: A Brownian jump will only be taken if the newly achieved state-vector leads to a significantly improved potential. Hence, no jump back is possible, due to some "loss" of potential, which corresponds to the functionality of friction.

3.5. Friction Representing the Decisive Criterion

The organization system considered here suffers from the existence of numerous sub-optima where the global minimum is searched for. Approximating the interacting functions by the use of the first Taylor terms allows for developing towards an optimum resembling the classical hill-climbing algorithm. However, creative ideas are required to be brought in in order to avoid stuck situations which correspond to sub-optima. Allowing for such erratic moves changes the situation and continually opens unconsidered options. Though, permittance of such moves also provides the same probability to worsen a given situation of temporary (local) agreement. At this point, artificially introduced friction terms limit the extent of creative ideas to such that are leading to an improved situation and, therewith, inhibit those ideas which worsen the situation. This concept corresponds to the method of simulated annealing.

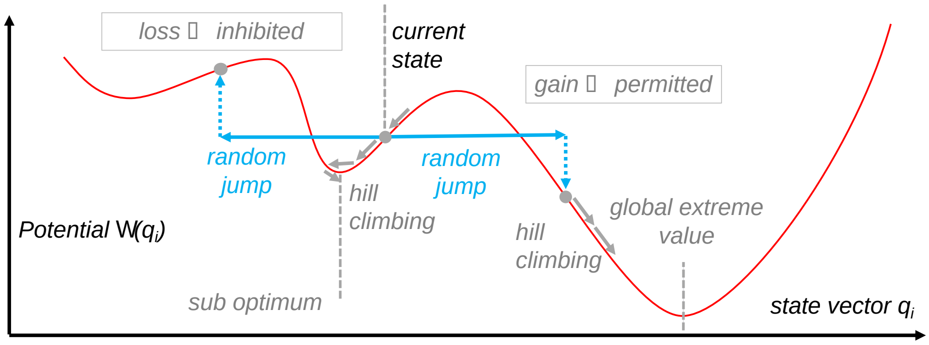

Figure 2. Random noise and friction on potentials with sub-optima.

However, friction on creative ideas is not the same as friction growing from controlling delays, though, serves the same purpose and has the same effect on potentials. In this case, friction does not originate automatically from the rate of change and is, therefore, not a dynamical force. Furthermore, creative moves are also not derived from the potential's gradient nor from dynamical memory but are randomly injected. Hence, the therewith gained potential cannot be stored at all, and, using the same reasoning, a rise of the potential is not capable to inhibit such a move.

Any permission to run a creative move based on the required improvement of the potential is not accountable, since no direct measure for the potential value is available. Hence, in contrast to "simulated annealing" a mechanism of "try and error" is necessary, initiating a creative idea and possibly pulling back if not meeting the potential requirements, i.e., improving the local situation. To accomplish this, an artificially introduced mechanism is required.

3.6. Artificial Friction as Means to Handle Creativity

Creative moves are, though they are useful to escape from local sub-optimal traps, to be treated as disturbing artefacts which need to be damped down and ruled out through the existing controlling system. In this respect, they are forming additional noise which can be eliminated and brought to new equilibrium states only by dissipating terms, i.e., friction. Such terms are introduced by time delays, but their effect is to some degree also eaten up by the introduction of storing terms (“inertia”). Section 3.1. [22] described the limit of balance, where no friction effect is left for other purposes. Therefore, the controlling system needs to be designed in a way that the remaining friction suffices to dampen the brought in creative moves. Since constant noise added at a stable equilibrium state continuously fuzzifies the state vector, no improvement can be derived from further creative moves at this point. Thus, we state qualitatively the need to reduce the amplitude of noise over time once approaching the optimum ("annealing").

A suitable measure for these effects can be taken from the balance-limit mentioned above [22], where, however, the vectors Q are replaced by a representative component q_i:

$$S = \frac{\beta}{\rho}\frac{q_i}{q_i} = \frac{1}{\tau_C - \Delta t}\frac{q_i}{\dot{q}_i} \tag{12}$$

In this equation, q_i refers to the deviation of the respective variable to be ruled out. Any additional random noise on it is to be treated as an offset $q_i + \Delta q_i$. In order to compensate for the offset an increased distance between the controlling time constant $\tilde{\tau}_C$ and the controlling delay Δt maintaining the same degree of stability is required.

$$const = S = \frac{1}{(\tau_C - \Delta t)_{Mod}}\frac{q_i + \Delta q_i}{\dot{q}_i} \tag{13}$$

Clearly the magnitude of the random noise $\Delta q_i(q_i)$ as a function of the distance q_i determines the behaviour of the system approaching equilibrium and, hence, the demanded modification of $\tau_C \to \tilde{\tau}_C$ or $\Delta t \to \tilde{\Delta} t$ to compensate. Setting $\Delta q_i / q_i = \eta$, we need to investigate two border cases: Allowing for all kinds of creative moves, i.e., $\Delta q_i = const$ leads to hyperbolic development of $\eta(q_i)$ while forcing the noise to a limit proportional to q_i also limits η to $\eta(q_i) = const := \varepsilon - 1$

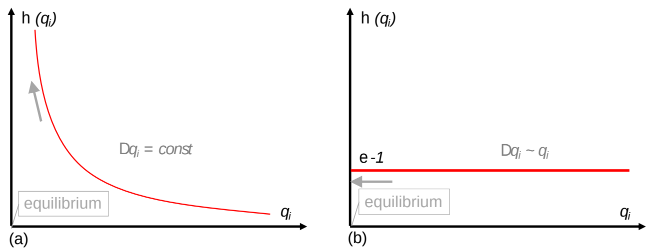

Figure 3. Requested compensation factor for constant (a) and proportional (b) noise.

$$const = S = \frac{1}{(\tau_C - \Delta t)_{Mod}}\frac{q_i + q_i\eta}{\dot{q}_i} = \frac{1}{(\tau_C - \Delta t)_{Mod}}\frac{q_i}{\dot{q}_i}(1+\eta) \tag{14}$$

Obviously, constant offsets cannot be handled and would lead to the demand of infinitely large controlling time-constants $\tilde{\tau}_C$ to compensate. Demanding the limitation of offsets proportional to q_i requires limiting the absolute noise amplitude to a noise factor $q_i + \Delta q_i = (1+\eta)q_i = \varepsilon q_i$. Then, the required compensation difference between the controlling delay and the controlling time constant is ruled by ε as well.

$$const = S = \frac{1}{(\tau_C - \Delta t)_{Mod}}\frac{q_i + \Delta q_i}{\dot{q}_i} = \frac{1}{(\tau_C - \Delta t)\varepsilon}\frac{\varepsilon q_i}{\dot{q}_i} \tag{15}$$

In particular, the original limit of stability is modified by either reduction of Δt or raising the reaction time constant τ_C with slightly different effects. Combinations are possible, however, not considered here:

$$\tau_C = 2\Delta t \quad \rightarrow \quad \tilde{\tau}_C = (1+\varepsilon)\Delta t = \frac{1+\varepsilon}{2}\tau_C \text{ resp. } \Delta t = \frac{\tau_C}{2} \quad \rightarrow \quad \tilde{\Delta} t = \frac{\tau_C}{1+\varepsilon} = \Delta t \frac{2}{1+\varepsilon} \quad \varepsilon > 1 \qquad (16)$$

$$\text{abbreviated } \tilde{\tau}_C = \tau_C/\gamma \qquad \tilde{\Delta} t = \gamma \Delta t \qquad \gamma = \frac{2}{1+\varepsilon} < 1 \qquad (17)$$

As pointed out in section 2.4., both approaches allow compensating for a given value of ε resp. γ. Table 1 shows the respective consequences on inertia, controlling strength and friction:

Table 1. Modification of parameters required for compensating for creative moves' amplitudes

	Modifying $\Delta t \rightarrow \tilde{\Delta} t = \gamma \Delta t$	Modifying $\tau_C \rightarrow \tilde{\tau}_C = \tau_C/\gamma$
Inertia $\mu = \Delta t^2/\tau_C$	$\mu \rightarrow \tilde{\mu} = \gamma^2 \mu$	$\mu \rightarrow \tilde{\mu} = \gamma \mu$
Contr. Strength $\beta = 2/\tau_C$	$\beta \rightarrow \tilde{\beta} = \beta$	$\beta \rightarrow \tilde{\beta} = \gamma \beta$
Friction $\rho = 2(1 - \Delta t/\tau_C)$	$\rho \rightarrow \tilde{\rho} = 2 - \gamma \rho_v$	$\rho \rightarrow \tilde{\rho} = 2 - \gamma \rho_v$

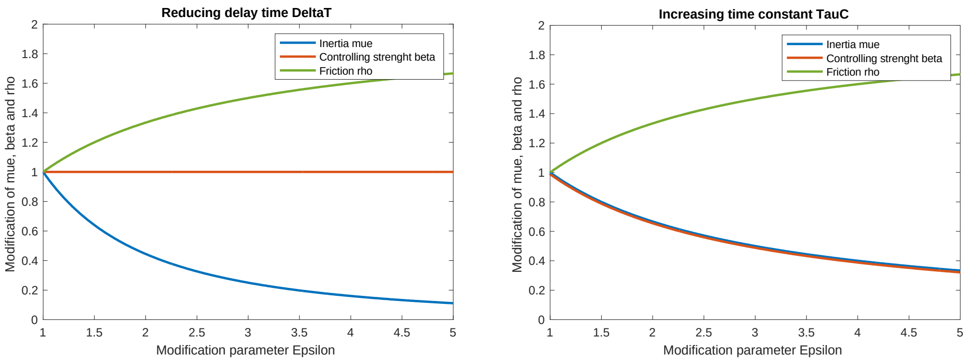

Figure 4. Development of inertia, controlling strength and friction at the limit of stability

Hence, both approaches are keeping the system in a sufficiently stable state. Modifying Δt seems to be more promising as it provides the same amount of friction, strongly (power of 2) reducing inertia while inflicting no change to β. However, Δt is usually enforced by the given situation as well as by the invested resources of control and, hence, is rarely available for modification, in particular not reducible. In contrast, modifying the time constants τ_C produces the same amount of friction, a little less reduction of inertia, but can easily be taken independently as this means to reduce the strength of coupling variables to each other.

4. Conclusion

Any organization of projects is in imperative need of strong mechanisms to approach a state of agreement regarding all the different aspects and participants. Preconditioned the willingness of all players to cooperate and contribute, resources as well as controlling processes need to be actively implemented and spent in order to achieve the project goal on the first attempt. Due to the strongly nonlinear complex nature of such systems, simple controlling mechanisms are principally under no circumstances sufficient for successful, i.e., cost- and time-efficient operation and finalizing. In particular, creative input is absolutely required to avoid sticking to suboptimal solutions while they are destabilizing the system on a principal basis. The need to operate delayed actions due to realistic considering and effectuating corrective actions follows the same pattern as it leads to oscillatory behaviour on the background of virtual inertia, but simultaneously introduces virtual friction allowing to dampen the resulting effects of instability. Overall, the therewith brought in concept of friction allows to handle the destabilizing effect of creative moves.

However, to make practical use of this, the magnitude of creative impact needs to be limited to values decreasing with approaching the final state, where no more proposals are permitted. This factor of proportionality is then used to compute the extension of the well-known limit of stability used for complex systems as a design criterion in order to keep the system capable of dealing with the respective creativity without losing its stability.

This proceeding leads to the requirement of weaker coupling, which is explicitly maintained by adapting all system variables to their sources, however, not fully but only to a limited percentage. Therewith, even while losing reaction time and, hence, agility, stability will be maintained and, thus, lead to earlier reaching states of equilibrium, which equals shorter project durations.

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