ON THE LONG TERM BEHAVIOUR OF THE PERFORMANCE-POTENTIAL-METAMODEL PERPOT

Jürgen Perl, Peter Dauscher, Michael Hawlitzky

Institute for Computer Science, University of Mainz

Abstract

PerPot has been developed for modelling, simulating and optimising the interaction between load and performance in training processes in sport but can be used for modelling general physiological adaptation processes as well. The basic idea of PerPot is that a time-dependent load input feeds buffer potentials, from which a performance potential is fed by specifically delayed antagonistic flows (e.g. see Mester & Perl, 2000; Perl & Mester, 2001).

However, dealing with the special phenomenon of atrophy we learned by mathematical analyses that neither short term atrophy nor even load itself change the system's balance. So, training load in the PerPot model not really "feeds" potentials but just pump their contents around. High load rates speed up the pump. On the short run this can be helpful to increase performance. In the long run, however, it disturbs the system's balance and so can cause irreparable negative effects.

Introduction

Analyses of the functional behaviour of PerPot show the following effects, which are primarily interesting under the aspect of model dynamics but also can be discussed under the aspect of similarity to physiological phenomena (see Perl, 2001; Perl, 2002):

(a) Independent on time and load input, the internal load balance of PerPot has a constant value only depending on the initial values of the potentials. The reason is that load input does not effect substantial increments but only effects a re-distribution of the available amount of potential substance. In so far, load just plays the role of a pump. However, too intensive or fast pumping can cause that single potentials get overflows or become empty, which means a temporarily irreversible loss of stability.

(b) The quality of PerPot-simulation can be increased by adding atrophy components. Due to (a), two different types of atrophy have to be distinguished: Temporary atrophy, which does not affect the constant balance property, has mathematically to be modelled by a delayed re-flow from the performance potential PP to the response potential RP. So on the one hand the current performance is reduced by temporary atrophy. On the other hand, the increased response potential causes an initially delayed but then speeded up recovering of the performance value. Quite different, the life long atrophy, modelled as an output flow, reduces the amount of performance substantially. This effect changes the internal balance of the model and cannot be compensated by additional load.

(c) The delay parameters determine the behaviour of the model. In particular, changing these parameters changes the asymptotically reachable maximum value of the performance potential. However, changing model parameters consequently means changing the model – i.e. adapting the model to a changing system. This aspect opens a new view to the modelling of training by coupling two PerPots: An external PerPot, which models the temporary or short term interaction between load and performance, is itself influenced by an internal PerPot, which in particular affects the delay parameter of the outer one and so can improve its long term training results substantially. For example, load input to the inner model can cause a reduction of the response delay of the outer model, which then not only increases the maximum value of performance but also speeds up the increasing process of performance – without any violation of balance. In the long run, however, speeding up the pumping process this way can cause performance reduction and serious instability of the whole system (as has been pointed out in (a)).
The presented aspects regarding atrophy and long term behaviour of PerPot show a certain analogy to that of adaptive systems like athletes. So, as already has been done with the temporary load-performance-interaction using PerPot, simulation can help to better understand and optimise long term training under the aspects of atrophy and improving parameters. Finally, aspects of life-long-training have to be discussed in order to avoid instability, break downs, or even sudden death phenomena.

Basic PerPot

Structure and dynamics

The basic concept of the performance potential-metamodel, which has been used in PerPot, is that of antagonism: Each load impulse "feeds" a strain potential as well as a response potential. These buffer potentials in turn influence the performance potential, where the response potential increases the performance potential (delayed by DR) and the strain potential reduces the performance potential (delayed by DS), of course depending on the maximum capacities and on the current states of the respectively involved potentials (see figure 1).

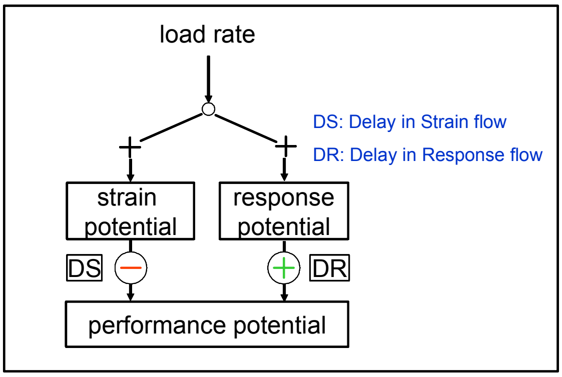

Figure 1. Antagonistic structure of the basic performance potential-metamodel.

If the delays are identical the rates compensate each other, resulting in a constant performance potential. Otherwise, the relation between the delays specifies types of balancing out, one of which is the so called super-compensation. These effects are well-known from adaptation processes.

Strain overflow

An interesting observable effect not represented in the basic structure is that of collapsing: If the load integral over a period of time becomes too high, the performance breaks down spontaneously. This effect can be modelled using the concept of overflow: Potential capacities are limited. So, if in particular the strain potential is fed over its upper limit, an overflow is produced, which reduces the performance potential immediately, i.e. with a rather small delay DSO.

Atrophy

Finally, atrophy in a first step had been modelled as flow of performance leaving the system – as is shown in figure 2, comparing the types of so far modelled system behaviour.

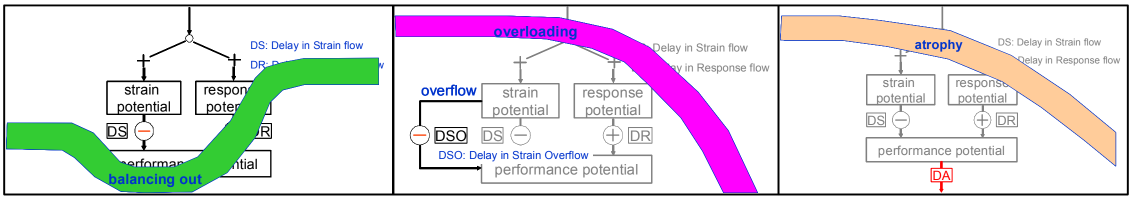

Figure 2. PerPot dynamics: Balancing out (left), overloading (middle), and long term atrophy (right).

However: This type of atrophy is not reversible and so can not be used for modelling short term atrophy effects that can be balanced by training. Deeper analysis leads to the following mathematically based result:

The modelled system of load and performance is closed – i.e. load rate just "turns the wheel" without changing the stable amount of performance producing "substance". Due to this fact, in case of reversible short term atrophy the atrophied potential has to be fed back (delayed by DA), which mathematically only can be done feeding it back to the response potential (see figure 3). (Colleagues from sport medicine ensured us that this result meets physiological expectations.)

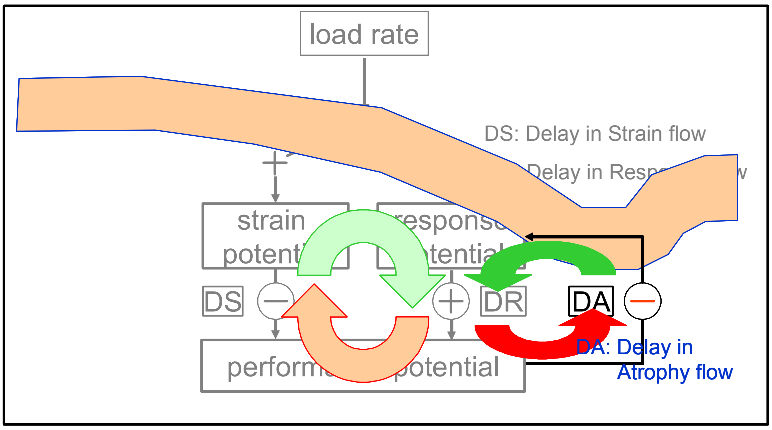

Figure 3. Atrophy as a closed loop extension of PerPot.

In figure 4 the typical effect of atrophy is shown: After reducing the load to "0", performance after a specific delay is decreasing – and than again balancing out on a low level. As can be shown according to experiences from practice, newly activating the load rate would normalize the situation rather fast.

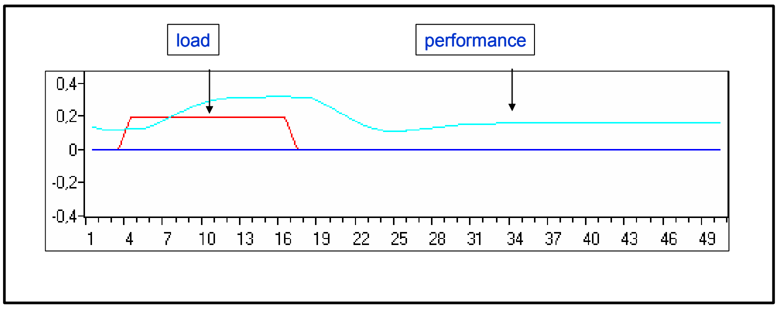

Figure 4. Atrophy of performance after reducing the load rate to "0"; delay DA=16.

The aspect of pumping performance in a closed loop by means of load is not only helpful in order to understand the phenomenon of short term atrophy. Moreover, it can help to understand the long term effects of high load training, as is dealt with in the following section.

Long term training, modelled by two-level-PerPot

Changing delay parameters

As has been pointed out in connection with atrophy, short term behaviour of a physiological adaptation system has to be kept distinct from its long term behaviour: The short term system can be thought to be closed and rather stable with regard to its parameters. Its dynamics can be described like that of a load-triggered pump, which is activating and moving available potentials. So far, the short term behaviour is modelled by PerPot – which however does not answer the question how performance potential can be increased or decreased substantially over time.

The following aspects could help to answer the question:

If the strain delay DS becomes greater compared to the response delay DR then the maximum performance potential in the long run becomes greater (see figure 5).

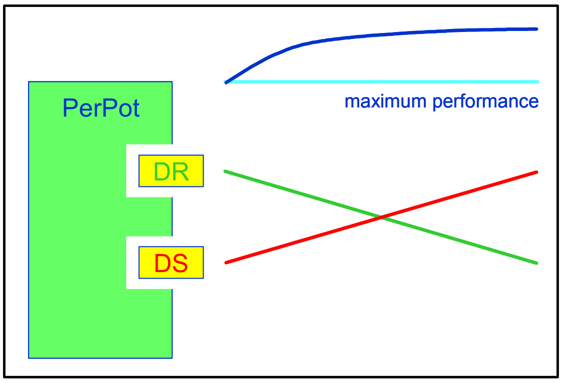

Figure 5. Increasing the maximum of performance depending on the relation between DR and DS.

The physiological interpretation of that change could be that corresponding physiological reproduction components (controlled by relatively decreasing response delay DR) become faster or increase their flow volume. So, constant delay parameters characterize the athlete's temporary condition and the effect of short term training, where changing delay parameters can be understood to be the long term effect of training, directed to improve the performance by improving the physiological training condition.

Figure 6 shows how closely the performance can be connected to the delay parameters and how weak then the interaction between load and performance can be.

(The data from figure 6 are virtually generated. For original data and specific explanations see Perl & Mester, 2001.)

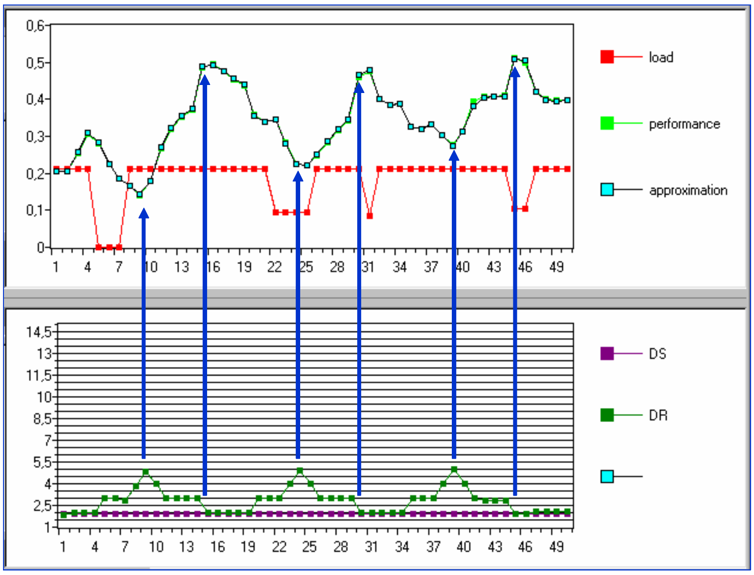

Figure 6. Influence of delay parameters to the performance maxima.

The problem however is that with increasing DS in the long run the system's balance becomes disturbed by overflow effects.
Because of this reason, PerPot can not be used to model short as well as long term effects on the same level. Instead, these two types of effect have to be distinct and modelled on different levels:

Two-level-PerPot

In order to model the interaction between long and short term behaviour, a two-level-PerPot has been developed, where the internal or long term model changes the parameters of the external or short term model: As can be seen from figure 7, the same load rate controls as well the internal model, affecting the delay parameters of the external model, and the external model itself, affecting its temporary performance.

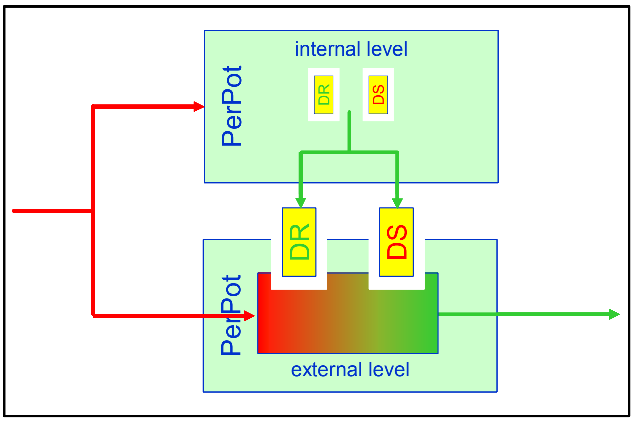

Figure 7. Load rate, controlling the internal and the external model of two-level-PerPot.

Some examples of the basic dynamics of that approach in the case of constant load are given in figure 8 and discussed below.

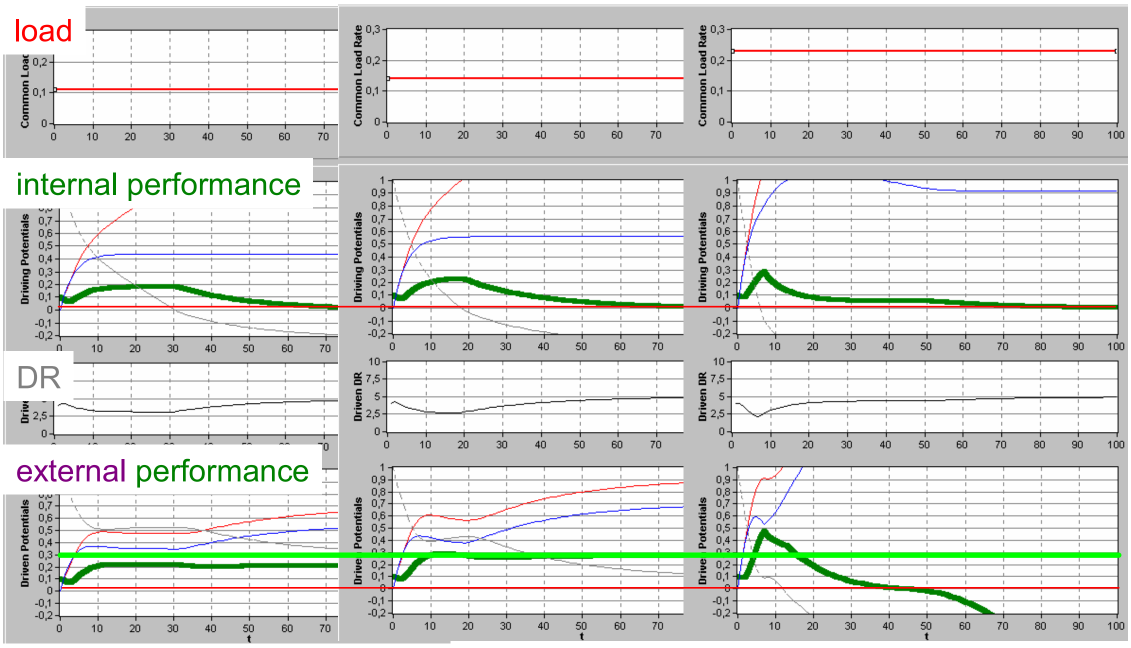

Figure 8. Basic dynamics of two-level-PerPot in case of different types of constant load.

Comparing the first and the last row shows that with increasing level of load the maximum of obtainable performance increases as well. (Take the horizontal light green line as an orientation).
The third row shows that smaller values of the response delay DR (with the interpretation of improved internal condition) are the reason for this effect.
Changing DR behaviour is the result of affecting the internal model by the load, as can be seen from the second row: With increasing load the internal performance profile also increases its maximum but decreasing the length of that maximum phase.
The DR-profile of the external model is – more or less – the mirrored performance profile of the internal model. So, higher load causes a higher but shorter maximum phase of internal performance. In turn, it causes a lower but shorter minimum phase of the external DR profile, and this finally causes a much higher but much shorter maximum phase of the external performance.

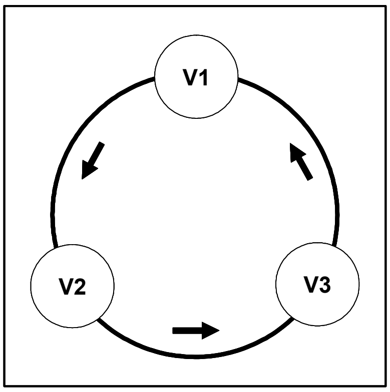

Figure 9. Pumping around in a closed loop.

As mentioned above, the characteristic behaviour "higher but shorter" of the maximum phase is a direct consequence of the pumping phenomenon of the closed PerPot-System, as is given in a different view in figures 9 and 10:

Pumping very fast from V2 to V3 can raise the level of V3 very much and very quickly. If however the flow from V1 to V2 is slow then V2 as quickly becomes nearly empty, and also the level of V3 quickly becomes low because of the flow from V3 back to V1.

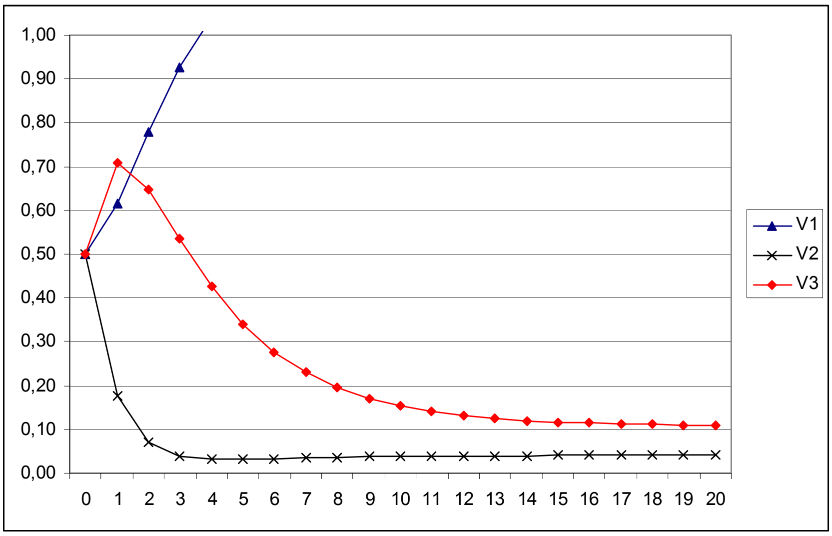

Figure 10. Dynamics of pumping around in a closed loop.

So far, the situation becomes bad but not disastrous. If however the overload of V1 causes an overflow as is modelled in PerPot then the system collapses if pumping is continued in the critical situation (see figure 11).

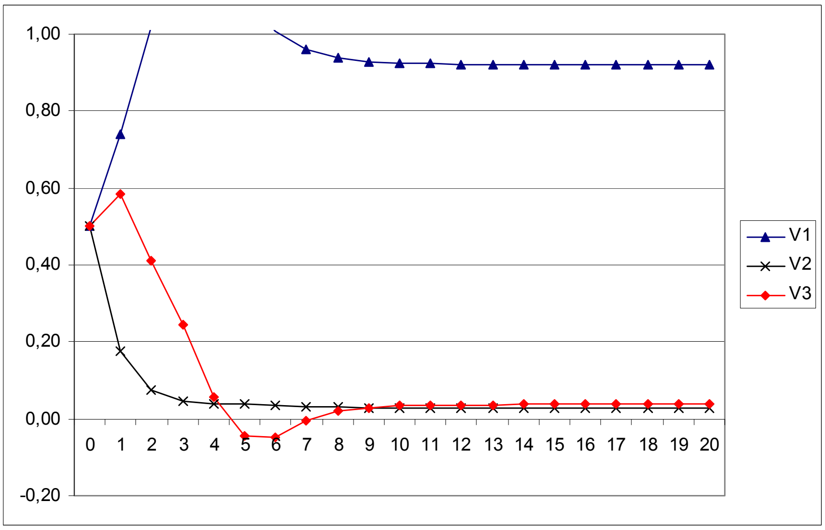

Figure 11. Collapse caused by overflow.

This effect is quite similar to what we got in the third column of the external performance in figure 8: Small DR-values caused fast pumping and so produced not only a high but short maximum but also a collapse.
Interpreting the time scale as the life time the result means that an intensive training in the youth can increase the performance extremely but also can imply the hidden danger of an unexpected break down long time later.
The problem is how to optimize the long term training load in order to stabilize long term performance and avoid break downs. Figure 12 demonstrates how two-level-PerPot might give an answer:
The left column shows one very common scenario: During a period of time in the youth the load values are very high, causing a high (but not necessarily constant) performance.

Stopping training completely then leads to a reduction of the stable performance on a low level.
The middle column shows what happens (in the model) if training is not stopped but continued, maybe with even increased load: The internal system becomes "empty" (i.e. there is no organic reserve any more) and the external system collapses. In the special case demonstrated here, this happens without improving the performance at any time.
Finally, the right column demonstrates that already a small reduction of the load level can stabilize the performance on a very high level (horizontal light green line) without reducing the maximum performance (horizontal violet line).

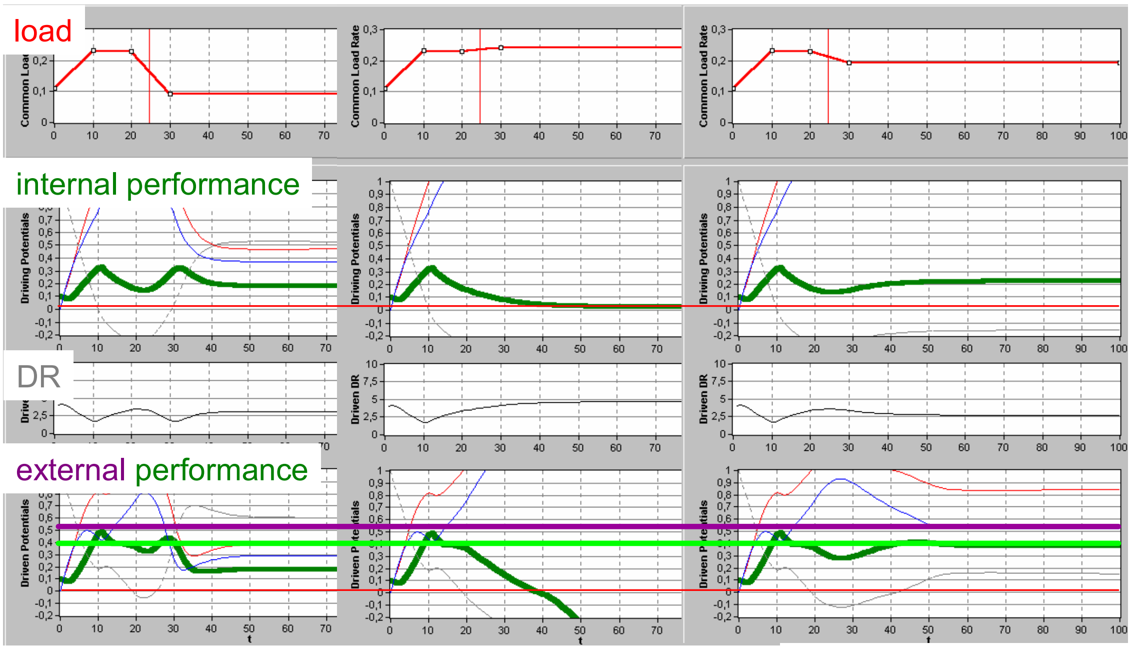

Figure 12. Optimizing long term training in order to stabilize long term performance

Discussion and outlook

The two-level-PerPot seems to be able to simulate an often-discussed phenomenon – namely that high training load over a long time on the one hand can keep fit but on the other hand can cause spontaneous brake downs.
Of course, it is just a model and we do not have any practical experience with it. The idea was just to find out how "parameter training" – i.e. the adaptation of delay parameters – could be used for better understanding the long term training process.
From a structural and qualitative point of view the results are encouraging:
First, the decomposition into an internal ("organic") level that controls the external level of temporary performance seems to make sense: Training on the one hand influences temporary performance. But on the other hand, this effect in the long run depends strongly on the organic capacity, which is influenced by the same training.
Second, the fluctuations of delay parameters that can be observed in the analyses of original load-performance-data become more transparent and understandable if the temporary PerPot is imbedded in a long term controlling environment.
There are, however, a couple of questions that have not been answered yet:
The first question deals with the absolute values of time units: The PerPot "time" scale is independent of any particular interpretation of "time". So the interpretation of the

time units in the two-level-model as to be "years" is rather arbitrary. If such an absolute scale is needed it has to be found by calibration using original data.
The second question is somewhat more complicate: The idea of two-level-PerPot is based on the pumping-result, i.e. that the balance of a PerPot-system is not changed by load rates and so is constant over time. In the interpretation of "organic capacity" this means that this capacity is only reduced by irreversible long term atrophy. This could be in correspondence with ideas of "vital energy". But then the question is whether the scale of the long term performance values of a person is independent of or related to his age: Obviously, at least in the first phase of growing up the absolute performance values depend on the person's age.
In turn, it seems to be very unlikely that a person is able to increase his load amount with increasing age, as has been modelled in figure 12 in the second column. And also the situation in column 3 does not look very realistic.
One (however rather speculative) idea to answer those questions could be to assume something like an "(organic) capacity function" that is not constant but age-depending, controlled by a "capacity controlling function" (see figure 13):

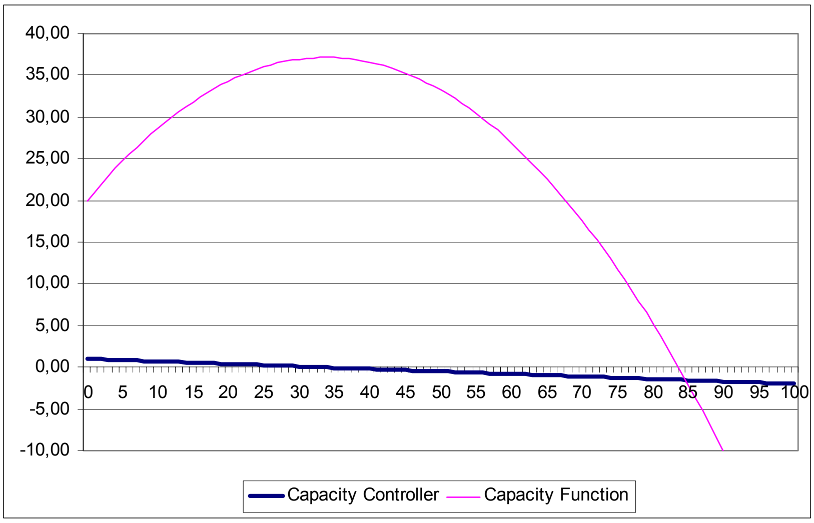

Figure 13. Non-constant capacity function depending on a linear capacity controller.

In this very first approach, the capacity controller is modelled by a linearly decreasing function (which is meant to specifically depend on the respective person):
In the first phase, i.e. as long as its values are positive, it plays the role of a generator and so characterizes the decreasing increments of the capacity function, starting with an initial birth value.
In the second phase, i.e. becoming increasingly negative, it plays the role of atrophy, continuously and irreversibly reducing the capacity.
(One interpretation of this "capacity" could be the cell multiplication ability.)
What we are going to do next is to imbed the two-level-PerPot in the frame of age-depending maximum capacity values given by the linear capacity controller.
Even if it does not seem to be realistic to validate such a generalized model it nevertheless might be helpful for a better understanding of system structures and dynamics phenomena. So, as already mentioned in the introduction, modelling and simulation at least might help to better understand and optimize long term training in order to avoid instability and break downs.

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