The Good, the Bad and the Mediocre: Creating Insightful Stories on Process Improvement

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Abstract: *Building upon previous work in the field of system dynamics, a generic model of multiple improvement initiatives is outlined. The model is used to create insightful stories on success and failure in process improvement initiatives. The simulation experiments reveal that plants should strive for implementation patterns that focus on programs exhibiting higher organizational complexity rather than technical complexity. Furthermore, the simulation analyses provide insights in the interplay between organizational learning, program commitment, and process improvement. The value of the conducted approach lies in the explicit investigation of the impact of varying improvement program patterns on plant performance.*

Introduction

According to Jay W. Forrester, system dynamics "is a way of studying the behavior of [dynamic] systems to show how policies, decisions, structure, and delays are interrelated to influence growth and stability" (Forrester 1961: vii). Working with graduate students in the field of system dynamics, the author feels that quite too often students spend a lot of effort on explaining the model structure but comparatively little on the discussion how the structure of a model influences its behavior. One might get the idea that students seem to avoid this task even if they are asked to equally spend effort on system thinking, modeling, and simulation. The reason to this might be that students are more confident in explaining model structure due to its formal form then in analyzing why a certain pattern of behavior occurs. This might also be the case as methods of formal mathematical behavior analysis, e.g. on loop dominance (Richardson 1995), are still the domain of a few experts in that field (e.g. Ford 1999; Mojtahedzadeh, Andersen, and Richardson 2004; Kampmann and Oliva 2006; Güneralp 2006). In addition, user-friendly software tools like "Digest" (Mojtahedzadeh, Andersen, and Richardson 2004) are still experimental and thus only applicable to a limited extent. Thus, a one-click application for behavior analysis is not available up to date. However, in the author's opinion one might read a lot of interesting stories from the behavior of a system even with the naked eye, even though it often takes an experienced system dynamicist to reveal the dominating loops from model behavior (cf. Kampmann and Oliva 2006). One challenge to education in system dynamics may lie in teaching students to read those insightful dynamic stories which models tell us.

To foster this idea of dynamic story telling, this article focuses on the behavior of a generic process improvement model, which has been generated in order to provide insights to success and failure of multiple improvement initiatives in manufacturing. This is part of an ongoing research project. The model will be introduced in the next section. Subsequent to this, three different simulation experiments are outlined in broader detail. The article ends with a discussion of the results and with an outlook on subsequent research.

Quantitative and qualitative modeling approaches

In spite of its early entry into system dynamics, the concept of generic structures is still developing. Based on Forrester's notion of "general purpose models" (Forrester 1961: 313), the concept of generic structures has evolved mainly into the branches of quantitative and qualitative models (Coyle 2000; Liehr 2004, 2001). The former type includes "generic (canonical) situation models" and "abstracted micro-structures", the latter "counterintuitive system archetypes" (Lane and Smart 1995). Forrester's "Market Growth as Influenced by Capital Investment" (1968) or Lyneis' "Corporate Planning and Policy Design" (1988) are examples of generic models. They are the formal representation of a problem and structure common to many situations. These models—contrary to micro structures—are not designed as building blocks for larger models. Micro structures differ from generic models in both the extent of their structure and their transferability into other contexts. Due to their high aggregation, they can be applied to other situations as building blocks. Micro structures can be classified into those which serve as building blocks to structures from certain areas and into those which are applicable in many different contexts (Paich 1985). As building blocks of systems, micro structures can facilitate understanding of complex interactions in social systems (Milling 1972). The second branch of generic structures—system archetypes—are mainly based on Meadows's (1982: 98) "persistent, system-dependent malfunctions" and on Senge's (1994) monograph "The Fifth Discipline". Senge especially emphasizes the generic characteristics of his nine archetypes which can provide an explanation to counterintuitive behavior in different contexts. The value of system archetypes lies especially in their limited extent and their transferability to recurring system behaviors.

The same categorization in qualitative and quantitative approaches can also be found in previous work in the field of system dynamics analyses on process improvements. As an example of the former, Carrol, Sterman, and Marcus (1997) use a case study at Du Pont for their investigation on proactive maintenance programs. They use a qualitative system thinking approach without explicit system dynamics modeling, although they use level-rate-diagrams for model illustration (cf. Sterman 2000). They outline a typical fixes-that-fail-archetypical behavior, i.e., that less proactive maintenance activities increase productivity in the short run but decrease in the long run, due to the increasing equipment downtime. Repenning and Sterman (2001), Keating et al. (1999), Repenning and Sterman (1997) as well as Oliva, Rockart, and Sterman (1993) abstract from specific improvement programs and analyze process improvement programs more generally with system thinking as methodology. All four articles base on case studies from multiple improvement programs examined at different sites. Beside other valuable findings, they outline that improvement initiatives can facilitate subsequent improvement efforts, if they are evaluated as successful by both managers and workers. However, in the case of low perceived success the same interrelation can also hinder continuous process improvements. Kim (1993) provides two case studies upon process improvement programs (total quality management [TQM; cf. Shiba, Graham, and Walden 1993] and product development management) in which Senge's system archetypes have been applied in order to facilitate organizational learning.

As an example of quantitative approaches, Sterman, Kofman, and Repenning (1997) analyze a TQM program at Analog Devices and provide a fully documented system dynamics model (documentation is available in Repenning and Sterman 1994). In their case study with Analog Devices they reveal that due to Analog's TQM program the productivity grew faster than customer demand and did thus generate excess labor capacity and massive layoffs. The authors provide an extensive model which is highly specific to the Analog case. In spite of the great value of their work to management literature, the transferability of the model is therefore limited. Other formal modeling approaches on process improvement programs have been conducted by Repenning (2002, on TQM) and Maier (2004; 2000, both on total productive maintenance [TPM; cf. Nakajima 1988]). Even though both authors provide mathematical equations to some model interrelations, they do not include a complete model listing. In contrast, Thun (2006) analyzes the interplay of different components of TPM and provides all model equations in his article. For this purpose he expands Sterman's (2000) proactive maintenance model by further components that are specific to the TPM approach (e.g. autonomous maintenance and maintenance prevention). His insightful analyses are very specific to the TPM approach and therefore it is only possible to generalize his results to a limited extent to the implementation of other process improvement programs, which is aimed by the study outlined in this article.

A generic, quantitative model of multiple process improvement programms

Building upon both qualitative and quantitative approaches, a generic model of multiple improvement initiatives is outlined. Existing micro structures are applied as building blocks where possible (e.g. from Hines 2005, Sterman 2000, Repenning and Sterman 1994, and Lyneis 1988). The model is intended to provide insights in several program implementation patterns. This is necessary as different patterns show varying success in plant performance (Filippini, Vinelli, and Voss 2001). Figure 1 gives a brief overview of the model structure:

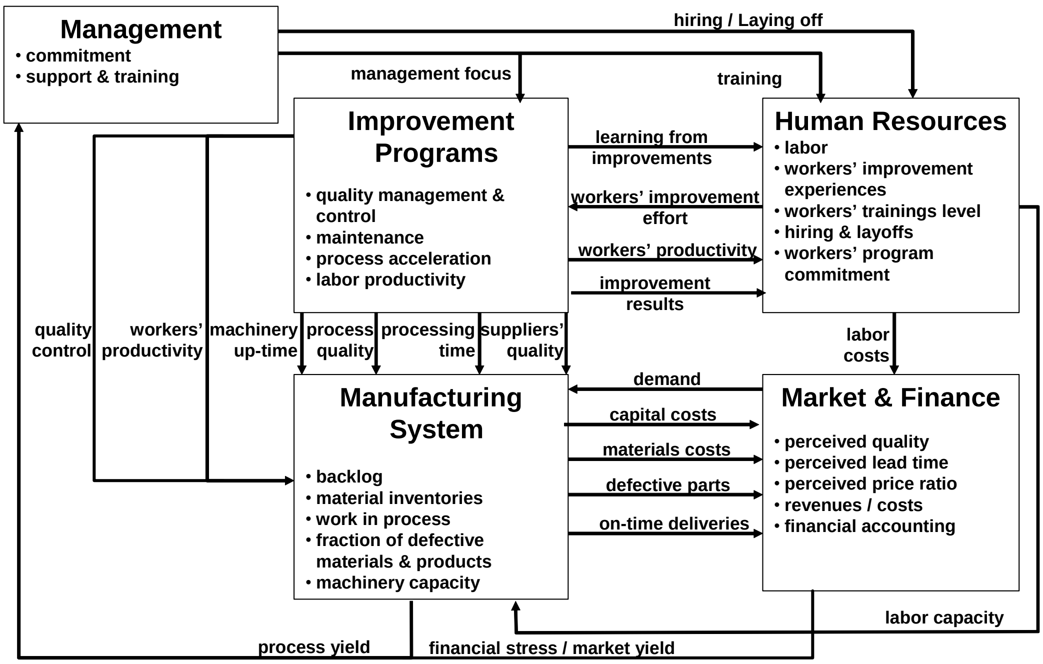

Figure 1: Overview of model structure

The model consists of five sectors. The model equations can be found in the supplementary file. In the human resource section of the model, hiring and laying-off of workers is conducted according to the perceived labor productivity and desired gross production rate. The latter is derived from customer demand, which means that low (high) workers' productivity and comparatively high (low) demand leads to hiring (laying-off) of workers (Hopp and Spearman 2001). The training level of the workers depends on on-the-job training provided by management (Armstrong 2003). Contrary to that, workers' improvement experiences cannot be controlled directly by management in the model. Management can only provide free time to the workers to gain experiences with process improvements, as it is the case in the concept of Kaizen (Imai 1986). But how the workers use this freedom and benefit from it mainly depends on their program commitment (Armstrong 2003). The program commitment deteriorates if the workers perceive a low job security (Meyer and Herscovitch 2001) and it increases if the improvement initiatives show to be successful (Meyer and Allen 1991). Furthermore, the workers' program commitment depends on the perceived management support which is necessary for the improvement initiatives (Senge 1999). An empirical investigation conducted by Neubert and Cady (2001) shows that the factors job security, program success, and management support have significant impact on workers' program commitment, and that in turn workers' program commitment is leading towards higher workers' effort for improvement programs. This is also underpinned by the findings of Sterman and Repenning (2001) *et al.*, examining improvement initiatives at different plants. Management (see management sector) will only provide support to the workers if they also evaluate the improvement initiatives as successful. In the model, management's program commitment therefore depends on both, perceived improvement results and improvement expenses and financial stress, respectively (Repenning and Sterman 2001, *et al.*).

The market and finance sector exhibits three figures for plant performance: the 'perceived lead-time' for *time*, 'perceived price ratio' for *costs*, and 'perceived quality' for *quality*. The plant loses and gains market shares pursuant to its performance in comparison to its competitors (Hill 2000). Costs per units are determined by the plant's material, labor and capital costs (Milling 1974). The price is calculated with a profit margin over unit costs, which is endogenous and changes according to a desired market share (Hanson 1992). The three performance figures for cost, quality, and time change according to the price for products, the fraction of delivered defective parts, and the order lead-time. The latter two are determined in the manufacturing system.

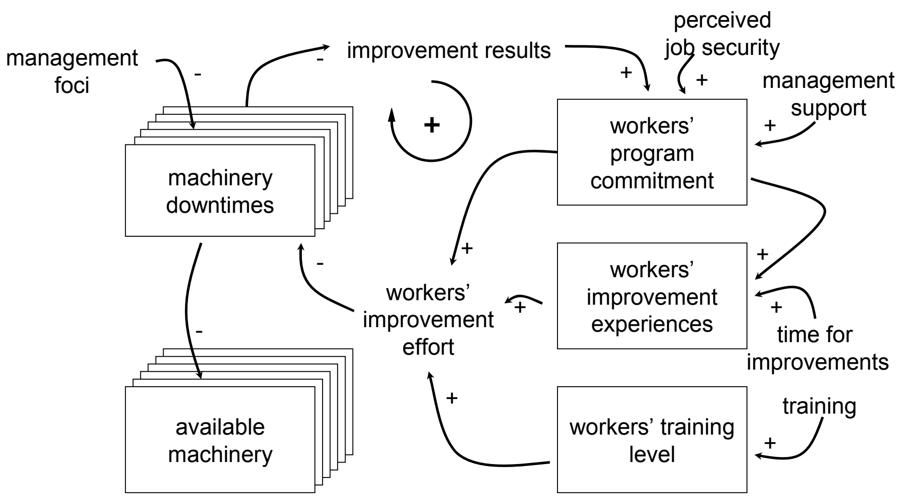

Figure 2: Interactions between management foci, workers' commitment and defects levels

In the manufacturing system, materials are processed through the production stations and inventories (also for the following, cf. Hopp and Spearman 2001). Defective materials might be delivered from suppliers or can occur due to inadequate production processes. Some of the defective parts are detected through Quality Control (cf. Ishikawa 1985) but some are delivered to the customer, which deteriorates the quality reputation of the plant. In addition, the production capacity depends on both machinery uptime and labor capacity. Besides available production capacity, the production lead-time of the manufacturing system is also depending on the machinery processing time.

Every constraint in the production system—suppliers' quality, process quality, quality control, machinery uptime, labor productivity, and processing time—is represented by a level of defects in the model (see improvement sector). In this article, the term 'defect level' is used in its most general sense according to Schneiderman (1988: 53), like "errors, rework, yield loss, […] unscheduled downtime, […] poor quality", and so on. In the model, each defect level is the target of an improvement initiative, as illustrated in Figure 2, showing the main connections between the sectors 'management', 'human resources', 'improvement programs', and 'manufacturing system'. Schneiderman (1988) found in an empirical investigation that experienced improvement teams maintain a constant improvement rate, i.e., the level of defects exhibits a similar behavior as radioactive decay, which means that the amount of time necessary for a level of defects to drop by 50% is constant. In addition, Schneiderman revealed that the constant half-life time (t_{HL}) increases according to organizational and technical complexity of the improvement effort. Schneiderman found that initiatives which are placed in the left bottom part of the matrix in Figure 3 exhibit half-life times of approximately one month and in the right upper part of twenty-two months. An improvement initiative in suppliers' quality—for example—involves people from different functions and organizations and thus possesses high organizational complexity. Contrary to that, the dimension of technical complexity grasps the novelty of the applied technology and therefore reductions in processing time feature a higher technical complexity than improvements in suppliers' quality. The adopted Schneiderman-Matrix with an indication of each improvement initiative incorporated in the model is illustrated in Figure 3.

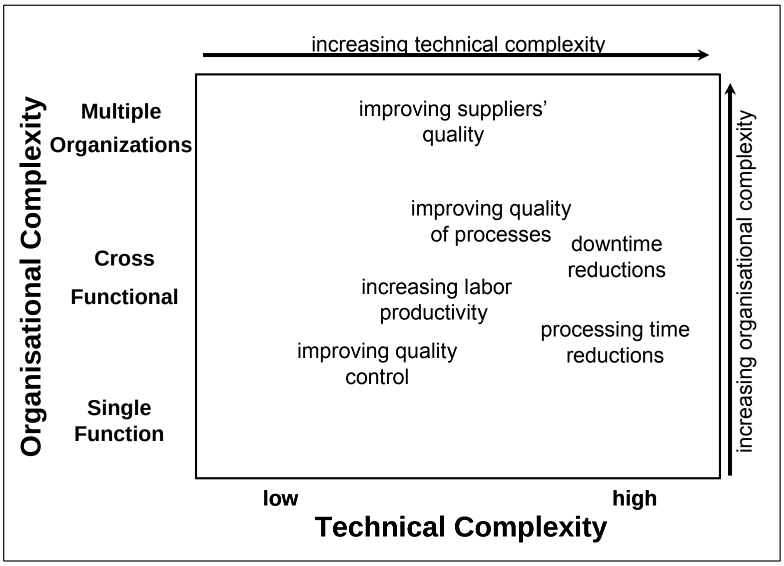

Figure 3: The Half-Life/Complexity Matrix adapted from Schneiderman 1999, 1988)

Due to increasing half-life times, a plant has to allocate more efforts to complex than to simple programs in order to achieve improvements. For example, improvements in labor productivity can be achieved with little effort, comparatively. However, increases in labor productivity do not necessarily stimulate demand. Therefore, high improvement rates in labor productivity can lead to excess capacity if demand is not increasing at the same rate. Thus, plants should also engage in improvement efforts that upgrade the plant's performance in 'order qualifying' and 'order winning' criteria, respectively, like quality and time (Hill 2000). Lower costs due to higher productivity might not be sufficient to generate higher demand, if price is just an 'order qualifying' criterion. Schneiderman (1999) also emphasizes that the half-life times outlined in his matrix can only be achieved by an experienced improvement team and that not every plant will be able to achieve such improvement rates right from the start. He suggests that plants with low experience in process improvements should start with less complex initiatives which can contribute to organizational learning (cf. Stata 1989). Gains in process improvement experience facilitate the plant's capabilities to handle higher organizational and technical complexity, and from that the plant can strive for more ambitious improvement efforts. This process of organizational learning with the interplay between workers' improvement experiences, gains in machinery up-time, and process yield is illustrated in Figure 2.

Transforming Schneiderman's original equation to an integral form (1988, 1999), a level of defects (Y_i), its improvement (imp_i) and deterioration rate (det_i) can be calculated according to[i]

$$Y_i = Y_{0_i} + \int (det_i - imp_i)\, dt \; ; \qquad imp_i = \frac{\ln(2)}{t_{HL\,i}} (Y_i - Y_{\min_i}) * \alpha_i * \beta \; ; \qquad det_i = \frac{\ln(2)}{t_{E\,i}} * (Y_{\max_i} - Y_i) \; .$$

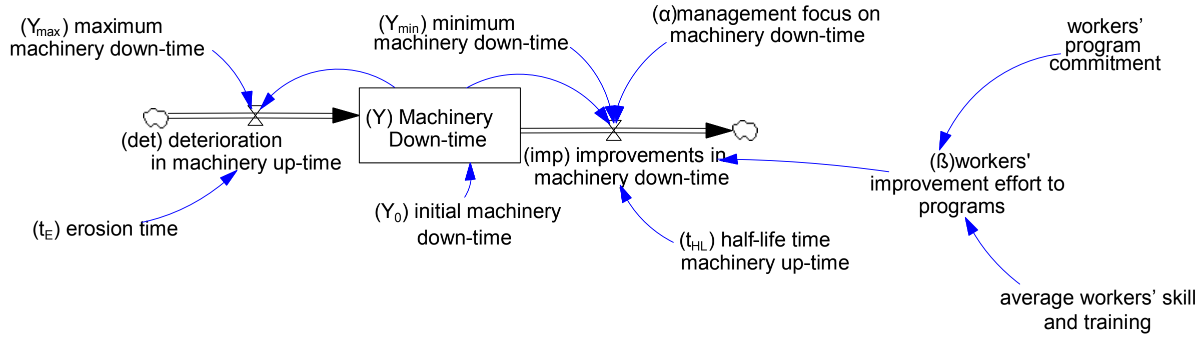

Figure 4: Representation of machinery down-time in the improvement program sector

One shortcoming in Schneiderman's concept is his explicit assumption that the waste reduction rate (i.e., the improvement rate) is given and constant over time (cf. Dutton and Thomas 1984). This implicitly implies the underlying learning rate to be exogenous and thus, independent of managerial efforts, workers' commitment and gains in experience. Contrary to that, Lapré *et al.* (2000) show in a longitudinal empirical investigation that improvement rates are changing over time in accordance to managerial efforts and a continuous process of learning. In order to incorporate these findings, Schneiderman's original improvement rate equation is supplemented with the factors α_i for management focus for defect level i and β for program commitment, workers' skills and training level. Therefore, if management is solely focusing on improvements in defects level i (α_i=1) and workers are highly experienced and motivated (β=1) the plant will yield the same improvement rate as outlined in the half-life/complexity-matrix. On the other hand, if management and workers do not make a sufficiently high effort towards maintaining process improvement, the defect level deteriorates to its maximum value.

Figure 4 illustrates the stock and flow structure of the defect level ‘machinery down-time’, which stands for an equipment maintenance initiative. Improvements are represented with an outflow and deteriorations with an inflow, respectively. The other improvement initiatives are modeled correspondingly, with specific initial values, half-life times, erosion times, and management foci towards improvement. In its initial state, the model is set into equilibrium[ii], which means that the management foci on the varying improvement initiatives are adequate in order to maintain the defects levels and the market share goal in accordance to the workers’ program commitment, training and experience. Without any adjustments to the different foci, the market share goal, or the customers’ expectations on quality, time, and costs, the plant maintains its *status quo*. This case is referred to as ‘The Mediocre’ in this article. In the following, two different insightful dynamic stories are being discussed.

Insightful stories on process improvements

Inspired by the plot of Sergio Leone’s (1966) epic ‘spaghetti’ western “The Good, the Bad and the Ugly” of three men seeking a fortune in buried coins, the three different dynamic stories on process improvement are referred as ‘the Good’, ’the Bad’ and ’the Mediocre’, whereas the latter serves as a base run. In the plot outlined in this article, the Good and the Bad strive for market shares, which means that they increase their desired market shares by a constant rate over approx. 3 years. In order to stimulate customer demand, both protagonists undertake improvement initiatives, but choose different patterns of process improvement. The Good takes a path with comparatively high organizational and the Bad with high technical complexity, respectively, as can been seen in Figure 5:

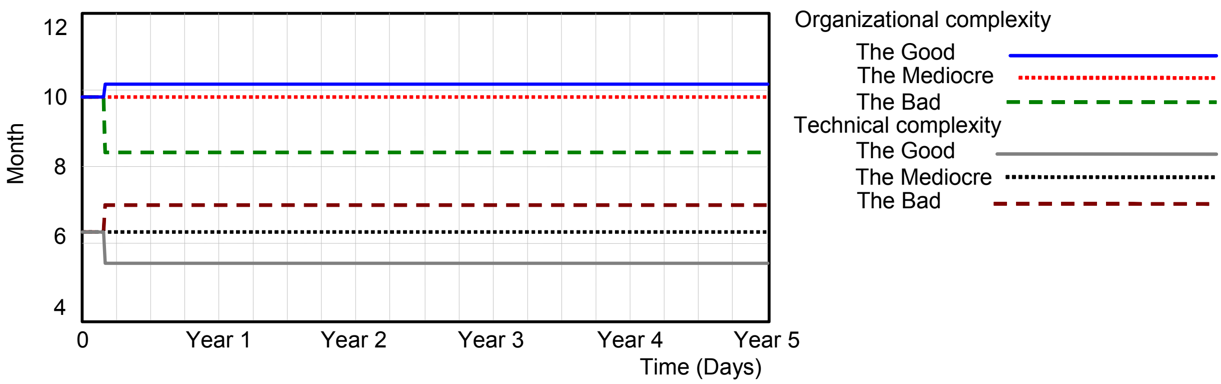

Figure 5: Organizational & technical complexity

Therefore, the Good is shifting his focus rather to the left upper part and the Bad to the right lower part in the half-life/complexity matrix in Figure 3. Nevertheless, even if the Good takes a ‘softer’ and the Bad a ‘harder’ improvements approach, they do not neglect other initiatives completely. This plot outline has been chosen since softer approaches showed to be more successful in means of process improvement than harder approaches (Filippini, Vinelli, and Voss 2001; Vargas and Cardenas 1999). These empirical findings serve for testing the behavioral validity of the model. It should be noted that according to Schneiderman organizational improvement programs imply comparatively higher complexity than technical initiatives. Thus, in Figure 5, the organizational exceeds the technical complexity in the equilibrium run (complexity is measured in months for half-life time).

In the dynamic stories outlined in the following, the Good and the Bad are changing their focus once and maintain it until the end of the simulation runs. It should be noted that both protagonists spend the same overall effort on process improvement initiatives, but with different foci. Except for their increasing desired market shares, all other parameters stay at their initial values.

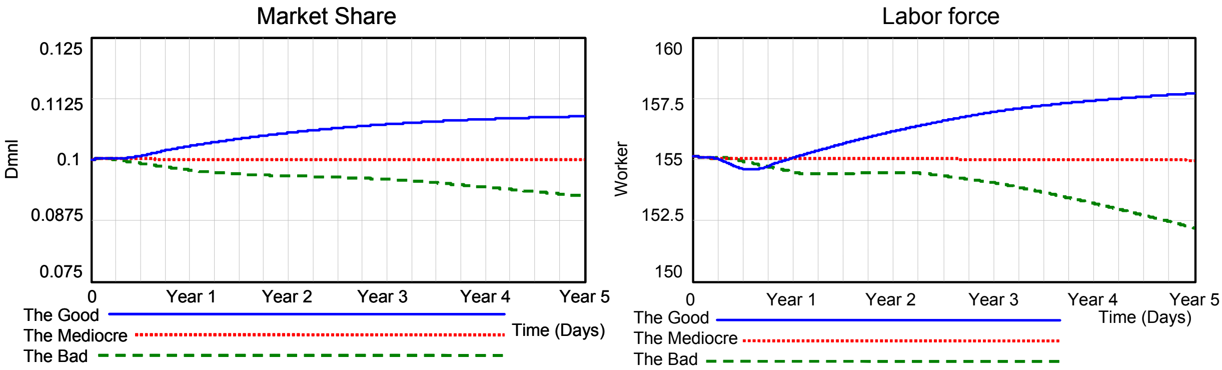

Figure 6: Market share and labor force

As can been seen in Figure 6, the Good is gaining market shares, while the Bad is constantly losing. This is due to the customers' different perception of their performances in quality, cost, and time. For example, the Good's performance in quality (see Figure 7) is increasing due to his higher focus on suppliers' quality, while the Bad undertakes more initiatives in process acceleration and machinery up-time. Gains in quality exhibit a beneficial side effect in the model (and reality), as they increase the net production rate while reducing scrap and inventories. Thus, the Good's unit costs are decreasing and the Bad's are increasing, respectively (see Figure 8). This increase in net production rate is also causing the Good's labor force to decline for approx. 3 months, until the effect from the rising market share develops its momentum and the labor force starts to increase.

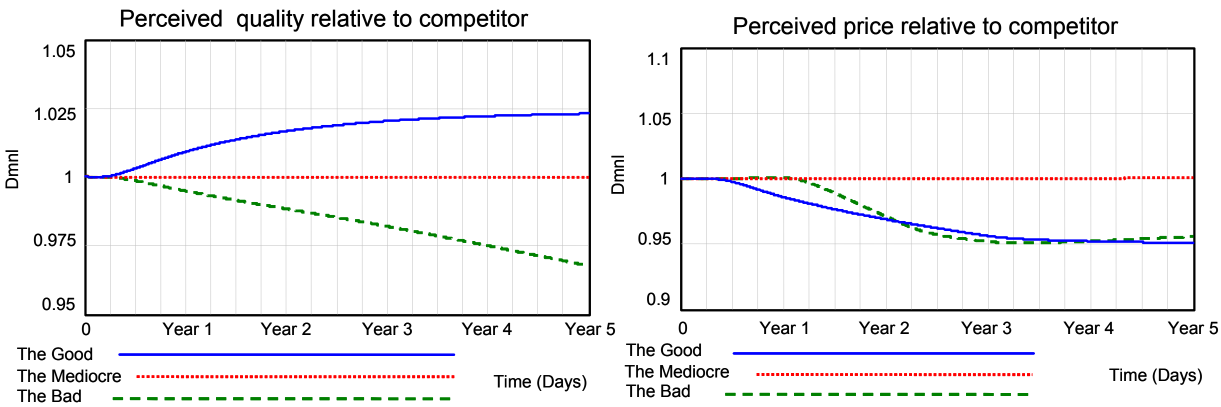

Figure 7: Perceived performance in quality and costs

The comparatively lower unit costs enable the Good to reduce his prices right after his shift in program focus and from that, he is constantly able to set lower prices than his competitors (see Figure 7). As the Bad is constantly losing market shares, while missing his market goal to a greater extent, he decreases his cost-plus margin until his prices nearly meet the costs per unit. Thus, the Bad's accumulated profits are leveling-off contrary to the Good (see Figure 8).

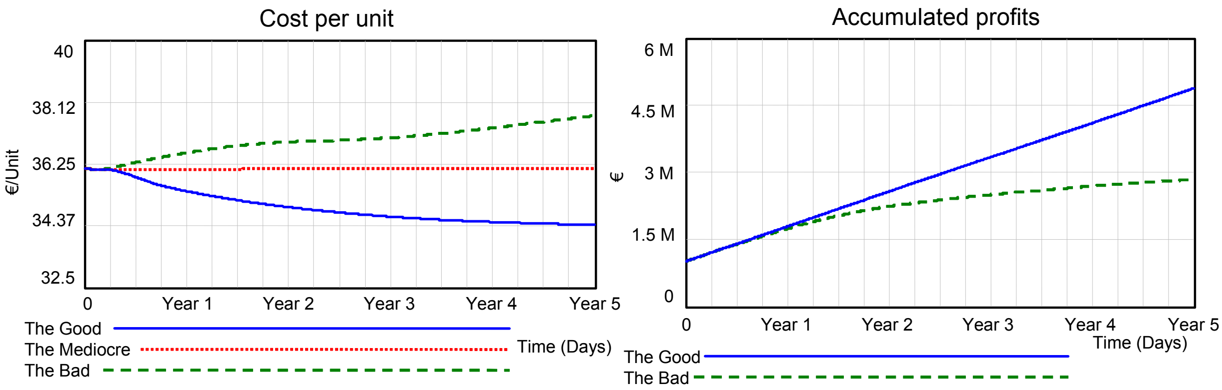

Figure 8: Cost per unit and accumulated profits

However, the Good does not dominate the Bad on all performance figures, as can be seen in Figure 9 on the aspect of time. The reasons for the Good's decreasing reputation in delivery dependability are twofold: first, he is less engaged in programs on process acceleration, and second, he builds up labor force delayed to increases in customer demand. The latter is due to the way he adjusts his desired gross production rate. In the model, this is done by exponential smoothing of the customer demand. This delaying effect could be partly eliminated by the use of a trend-forecasting function, as discussed for example in Lyneis (1988).

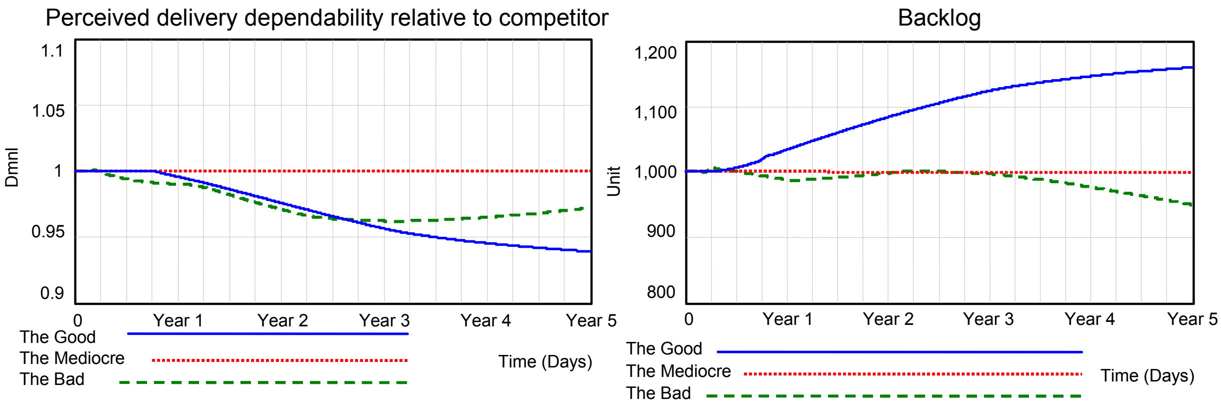

Figure 9: Perceived performance in time and orders backlog

Even though the Bad is focusing on programs on process acceleration, he can hardly fulfill customers' expectations on delivery dependability. The slight increase in the Bad's delivery dependability from the middle of year 2 on is partly caused by the decreasing customer demand. The fact that the Bad does not even perform well on the programs he is focusing on can be explained by the interplay between the sectors 'management', 'human resources', 'improvement programs', and 'manufacturing system', as discussed earlier in this article (cf. Figure 2). As the Bad's improvement initiatives are failing to show progress to both managers and workers, the program commitment decreases, as can be seen in Figure 10. The most influential factors for this decay are the decreasing support by management and the increasing financial effort for process improvement (see Figure 11). The latter affects the program commitment of the management and can be traced back to the accumulated profits leveling-off in comparison to the steady financial efforts for process improvements.

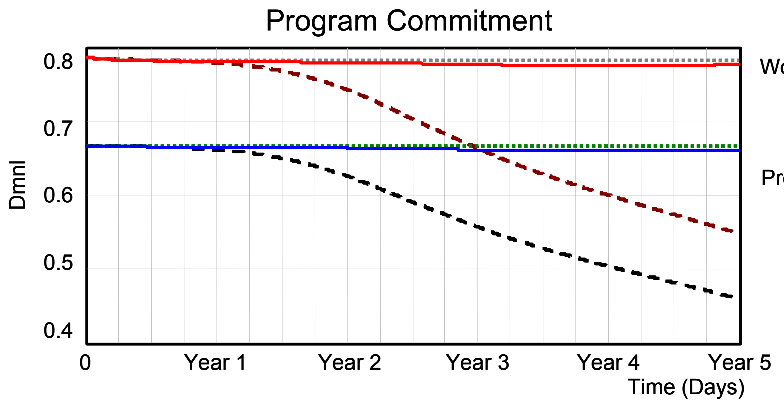

Figure 10: Program commitment of both, workers and management

In the case of the Good, the effect of the financial effort on program commitment is first exceeding the equilibrium run for approx. 2 years, then is falling below for another year, and is exceeding again until the end of the simulation run, which can not be clearly seen in Figure 11 due to the scaling. Hence, the workers' program commitment stays approx. at the same level as in the equilibrium run.

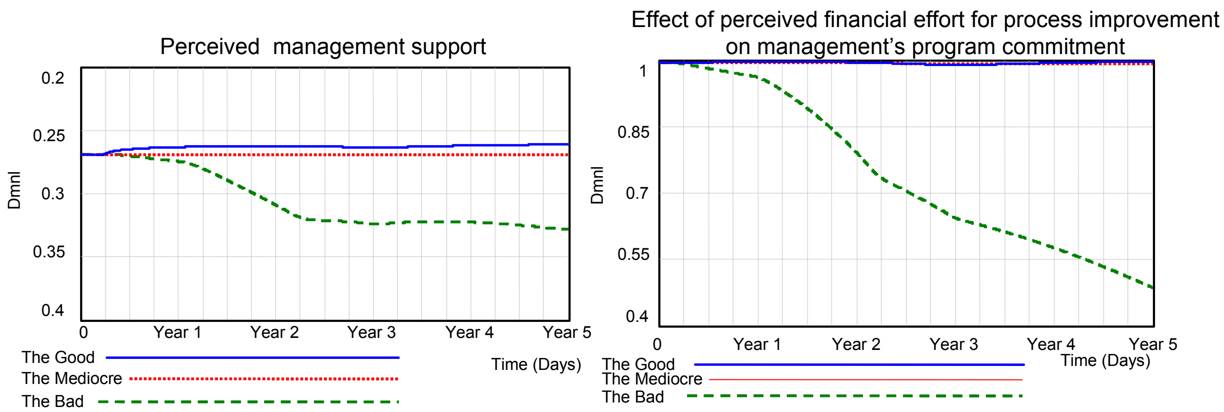

Figure 11: Effect of management support and financial improvement effort on program commitment

Due to the vanishing commitment in the case of the Bad, the organizational learning effect does not set in. Therefore, the workers do not benefit from the free time provided by the management, as can be seen for workers' experiences with improvements in Figure 12. In the model it is assumed that experiences in process improvements are more effective than formal training. This means that a lag in experience can only be partly compensated by formal training. Hence, the Bad's workers cannot provide the same effort to process improvement even though they exhibit a higher level in formal training. In the Good's case, the decreasing and subsequently rising behavior of the experience and training levels are due to the hiring of work force, as recruited workers have to be trained by their experienced colleagues.

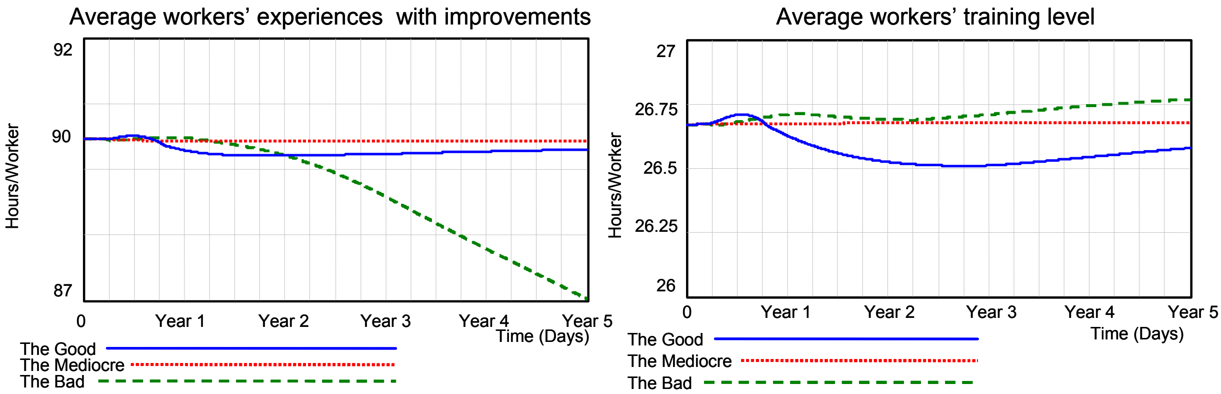

Figure 12: Workers' experience and training level

Similar to the plot in Leone's (1966) western, the Good wins and the Bad loses in the end. This is mainly due to the fact that the Bad fails to reduce unit costs while undertaking his improvement efforts. Hence both managers and workers lose their faith on the process improvement programs, and from that they omit organizational learning. These dynamic stories are underpinned by the empirical findings by Filippini *et al.* (2001) and Vargas *et al.* (1999). However, it should be emphasized that the way of reading and telling dynamic stories from the simulation runs is indeed useful for both the modeler and reader of an article to gain confidence in the validity of the model. A modeler should not be satisfied that the model shows an expected behavior, e.g. that model behavior fits to empirical data. By reading such dynamic stories from model behavior the modeler is forced to trace back its causes and by doing so he can discover anomalies in his model. An anomaly exists if the modeler fails to trace back the causes for a certain behavior pattern or if the pattern fails to fit in the dynamic plot the modeler is telling to the reader of an article.

Conclusion and outlook

It could be shown that one can read insightful stories from the behavior of dynamic models and that such dynamic story telling can increase the confidence in the model of both the modeler and the reader of an article. The plot outlined on success and failure in process improvement programs tells us that plants should focus on programs that exhibit higher organizational complexity rather than technical complexity. This is the case as the hard approach fails to contribute to organizational learning, and hence, organizational learning fails to gain momentum.

It should be noted that the different improvement patterns tested on the model so far are comparatively simple. In reality one would expect to find several shifts of a plant's foci and not just one. Howsoever, it is easier to trace back model behavior with comparatively simple improvement patterns and it has been shown that this dynamic story reading contributes to gain confidence in model validity. In a subsequent step, the model will be examined with more complex patterns of process improvement.

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i According to Schneiderman (1988, 1999), a level of defects can be calculated at a particular time t with

$Y - Y_{\min} = (Y_0 - Y_{\min})\exp(-\phi(t - t_0))$ and $\phi = \dfrac{\ln(2)}{t_{HL}}$,

which can be transformed to $\dfrac{dY}{dt} = -\phi(Y_0 - Y_{\min})\exp(-\phi(t - t_0))$, $\dfrac{Y - Y_{\min}}{Y_0 - Y_{\min}} = \exp(-\phi(t - t_0))$,

and thus the rate of improvement can be calculated as $\dfrac{dY}{dt} = -\dfrac{\ln(2)}{t_{HL}}(Y - Y_{\min})$,

where Y_{min} equals the minimum defect level achievable theoretically, Y_o equals the initial defect level, t equals time, t_o equals initial time, and t_{HL} equals the defect half life. Transformed into integral equations, one receives

$imp_i = \dfrac{\ln(2)}{t_{HL\,i}}(Y_i - Y_{\min_i}) * \alpha_i * \beta$ as improvement rate (supplemented with management focus α_i and workers' effort β), $det_i = \dfrac{\ln(2)}{t_{E\,i}} * (Y_{\max_i} - Y_i)$ as deterioration rate,

and $Y_i = Y_{0_i} + \int (det_i - imp_i)\, dt$ for the level of defects i.

ii The different management foci for process improvement initiatives, are therefore set to

$$\alpha_i = \frac{\dfrac{\ln(2)}{t_{E\,i}} * (Y_{\max_i} - Y_i)}{\dfrac{\ln(2)}{t_{HL\,i}} * (Y_i - Y_{\min_i}) * \beta}$$

with $\sum_i \alpha_i = 1$, $0 \le \alpha_i \le 1$, and $0 \le \beta \le 1$