Has Quality Management Any Effect On Quality?- Analysis of Quality Management By A Non-linear Model

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Abstract

Many models have been developed to enhance the quality of information systems (IS) and therefore the Information Quality (e.g. Capability Maturity Model, ISO 9000, Malcom Baldrige Award). These frameworks maintain that quality will improve by applying various methodologies. However, a critical or empirical appraisal of these methods is lacking which results in controversies in practice.

We propose a novel approach to characterize the effect of quality management on IS. A non-linear model has been developed based on the theory of dynamic systems. In our model we assume five hypotheses e.g that the effects of quality management to be either positive or negative depending of the intensity on measures taken. Furthermore it is supposed that a time lag exists between a measure taken and its expected effect. The non-linear model allows to analyze and characterize the correlation between quality management and its effects. The characterization shows the stability of correlation dependent on the estimated parameters. The mathematical concept based on dynamic systems is applied in an empirical study. Data from a German branch of an international insurance company were provided. Evaluation of the data by the non-linear model shows that the data have a square multiple correlation of $R^2 = 0.7891$. In this case IS quality management has a provable effect on IS. We can identify a time lag of 2 months between a measure taken and its proposed effect. Our study shows no evidence of instable or even chaotic behavior of quality management on IS.

Keywords: IS management, IS evaluation, quality, system quality

Introduction

Research on quality management relies mainly on different frameworks for control and improve IS (e.g. [Paulk et al., 1993,Paulk et al., 1995,Herslebet al., 1997,ISO, 1992,ISO, 1994a, ISO, 1994b]). There is no doubt in industry that quality management is absolutely necessary. This view is shared by academic research as well [Grady, 1997, Hersleb et al., 1994]. Proving the efficiency of quality management is difficult and contradictory. On one hand internal reports usually show success stories of quality management (e.g. [Donie and Dette, 1992, Caldiera, 1993, Winston, 1993, Hersleb et al., 1997, Hass et al, 1998]). This positive view could be due to the self referencing nature at these reports. In contrary external surveys come to a different conclusions (e.g. [Loken and Skramstad, 1995, Stelzer et al., 1996]. They often conclude that the goals have not be reached by quality management. A model is lacking for analyzing objectively the effects of quality management.

In this context we develop a non-linear model based on dynamic theory which gives us information about the characteristics of the effects of quality management on IS.[1] Usually the linear regression model is used because "it is considered to be extremely powerful" [p. 88, Sethi and King, 1999]. But Sethi and King [Sethi and King, 1999] have shown, that non-linear models can perform better than linear models to map the phenomena quality management.

[1] Basic literature for dynamic theory: [Arrow, 1988, Li and Yorke, 1975, Lorenz, 1963, Poincaré, 1938]

This paper is structured as follows. In the next section, we introduce our non-linear model and show which implications can be drawn from several trajectories. In section 3 we apply the non-linear model in an empirical study; in the conclusion (Section 4) we resume the findings of our research.

The non-linear model

In this section we present the theoretic base of the non-linear model. Five hypotheses of the non-linear model are introduced and the different possibilities visualized.

Hypotheses of the model

The reason for applying non-linear models for IS quality management arises from empirical observation and has led to the following five hypotheses. We assume that a quality management is installed proposed by e.g. ISO 9000 or CMM. This pragmatic approach allows us in the empirical part an easy access to relevant data of companies using these frameworks.

Hypothesis 1: Non-linearity

The impact of IS quality management cannot satisfactorily be described as linear. E.g. a linear increase of the IT (information technology) budget will not lead necessarily to a linear increase in the quality of output. Therefore a non-linear modeling is more realistic than a pure linear model. In this context of non-linearity follows hypothesis 2 and 3.

Hypothesis 2: Saturation

Saturation has already been described in the political economy and is also conceivable in IS quality management. Saturation effects are often depicted by an S-shaped curve. E.g. in practice an unlimited build-up of IS quality management is unlikely to reach the goal intended if the capacity of people involved are not taken into consideration. The ability of the employees is bound to the acquisition of new knowledge through training. Further training of the employees will not lead to a further increase of the productivity if the saturation limit is reached.

Hypothesis 3: Threshold values

Under a certain limit the system remains relatively immune against action taken from outside. Change and an apparent impact occur only if a critical threshold value is exceeded. By than a critical mass in the measures is reached and causes improvement. E.g. insufficient equipment of IS, which does not reach the threshold value, does not lead to an increase in productivity.

Hypothesis 4: Dynamic aspects

Measures taken due to IS quality management will be effective with delay. Therefore it is important to model the effects with a time lag. E.g. build-up a project database will not result in immediate benefits. They will be apparent after some time.

Hypothesis 5: Separation into growth and decay effect

Every measure taken can lead either to improve or to worsen the quality. This is considered as a growth and decay effect. A measure that has a positive and a negative effect simultaneously we assume to be neutral as a result.

Setup of the non-linear model

Figure 1 shows the separation into two effects, the input and output. The *complete effect* is separated into a *growth* and *decay* effect. Both effects result from the input shown by the two arrows pointing to the box. On the input side the situation of IS is described by the effectiveness ratio which will be later deluded to. The second input are the costs of IS quality management. The non-linear model emits as output the current effectiveness ratio. Note that the current effectiveness ratio is used as feedback for calculating the following situation.

The effectiveness ratio is a quotient, which describes the maximum effectiveness and the actual effectiveness. If the effectiveness ratio has the value 1, then the goal has been fully achieved as proposed by the management. The maximum must not be exceeded.

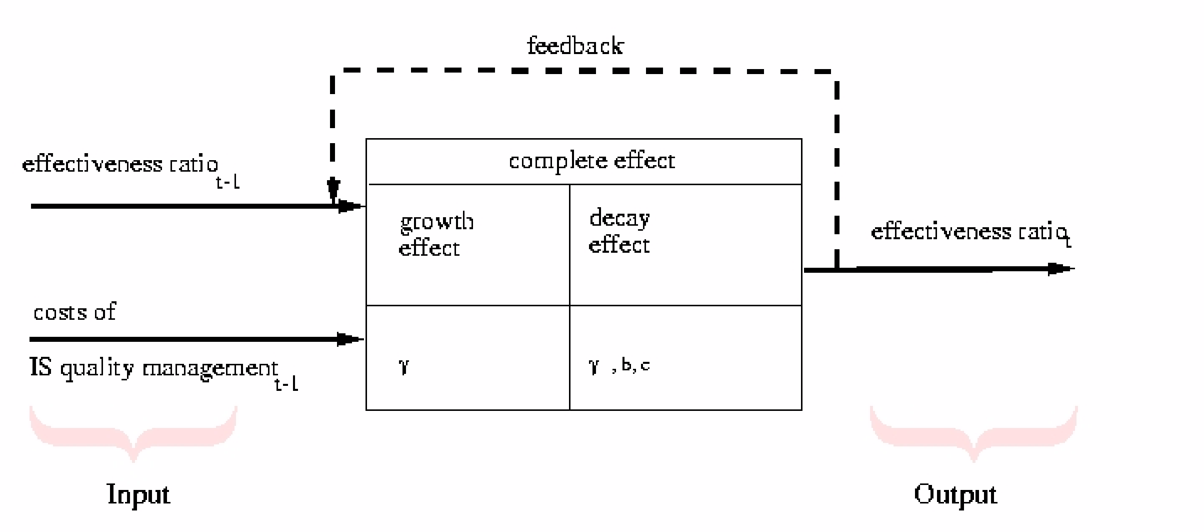


Figure 1: The non-linear model

Definition 1 (effectiveness ratio): *The ratio is defined:*
$E_t := quality_{(t-1,t]} / maximum\ quality$

Equation 1

In this study the number of abnormal ends is used to measure the effectiveness (further details are shown in appendix A). This rate is called *failure rate*.

Definition 2 (non-linear model)

$$E_t = g(E_{t-1}, Q_t)$$

Equation 2

$$g(E_{t-1}, Q_t) := \gamma E_{t-1} - \gamma E_{t-1}^{\,b+c\,Q_t}$$

Equation 3

with	g	mapping $g:[0;1] \rightarrow [0;1]$,
	E_0	efficiency ratio at the beginning
	E_t	efficiency ratio for time, $0 \leq E_t \leq 1$
	t	time t, $t \in N$,
	γ	factor for effect of increase and decrease, $\gamma \geq 1$,
	Q_t	costs for IS quality management in t, $Q_t \in R$,
	b	parameter $b \in R$,
	c	parameter $c \in R$,
	$b+cQ_t$	non-linear factor NLF_t.

The mapping g (cf. Equation 3)) belongs to the logistical mappings. This represents a first order differential equation with discrete time. The decay effect is provided with a non-linearity factor. The growth effect and the decay effect have the same pre-connected factor γ .This styling allows a modification of the decay effect in comparison with the growth effect.[2]

We will analyze Equation 3 in detail by discussing the elements of the formula.

The effectiveness ratio E_t rises if the growth rate of the effectiveness ratio E_t exceeds the rate of the quality management costs Q_t. Figure 1 shows an example of the Equation 3 with the parameters $\gamma = 1.5$, and $Q_t = 0.05$ and $b = 2$ and $c = -1$.

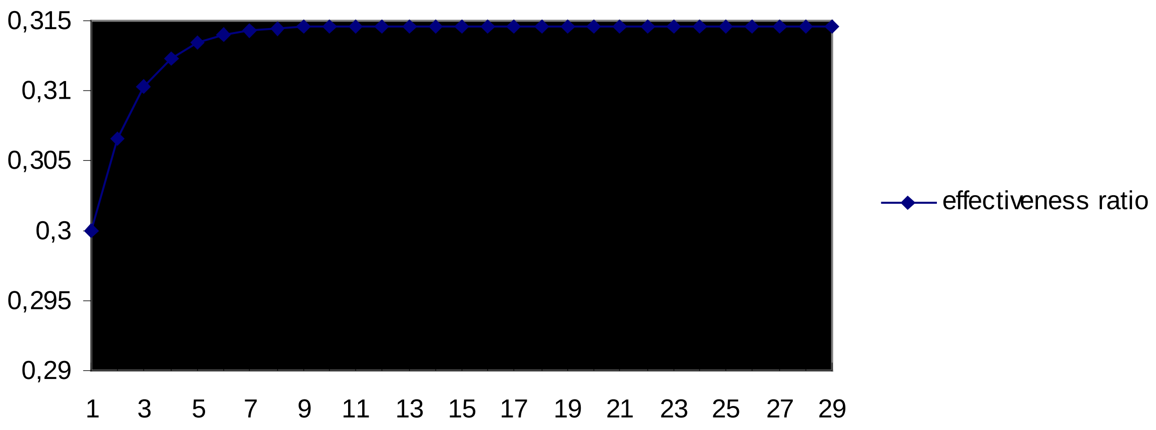


Figure 2: Effectiveness ratio with γ=1.5, b=2, c=-1, and constant Q_t = 0.05

This modeling allows for self-control, whereby an approximation to the upper and lower limit triggers the decay mechanism. This mechanism prevents exceeding of the predefined limits. The postulated saturation arises.

Equation 3 breaks down into two terms, namely into a first term, which describes the growth effect, and a second term, which represents the negative decay effect. If the parameter γ accepts a value more than 1, the first term describes an exponential growth of the effectiveness ratio.

[2] This is the well-known mapping of Verhulst, published in 1838 [Verhulst, 1838]. This mapping plays a major role in the theory of dynamic systems.

The second term of the equation describes the non-linear decay effect. The decay effect has an inhibitory influence on the growth of the effectiveness ratio. A raise in the effectiveness ratio becomes more difficult the closer the effectiveness ratio is to 1. The non-linearity factor should be larger than 1 because smaller values compensate for the decay.

The parameter γ

The parameter γ has an effect on the growth and decay effects. With respect to the growth effect γ can be interpreted as a growth rate. Without consideration of the decay effect it produces an exponential growth of the effectiveness ratio. This also applies to the decay effect, in that the decay effect strengthens itself if γ increases.

The parameter γ can also be interpreted as a factor for the effectiveness of the quality management system. High values indicate a high effectiveness of the IS quality management.

The non-linearity factor

The non-linearity factor results in term $b+cQ_t$ (cf. Equation 3). The non-linearity factor determines the structure and intensity of the decay between IS quality management and the effect on the IS. The stronger the non-linearity the larger is b. The effect of the IS quality management on the non-linearity factor depends on the sign of b.

Increasing costs for the IS quality management reduce the non-linearity factor, if there is a negative sign for b. The relationship between costs for the IS quality management Q_t and the non-linearity factor are positively correlated. If the non-linearity factor is greater than 1, then only positive ratios are possible. The partial derivative 2 shows the coherence between the complete effect g and the non-linearity factor. An arbitrary constant t is assumed in all following derivatives.

$$\delta g/\delta NLF_t = -\gamma E_{t-1}^{b+c\,Q_t} \ln E_{t-1} > 0$$

Equation 4

A raise of the non-linearity factor yields a higher effectiveness ratio in t. This result is plausible, because the non-linearity factor determines the decay effect together with the effectiveness ratio of the pre-period. This decay effect, which slows down the rise of the effectiveness ratio, sinks at a given effectiveness ratio in combination with the increasing non-linearity factor.

The components of the non-linearity factor Q_t, c and b shall now in detail be examined and a distinction made between $c \geq 0$ and $c < 0$.

1st case: Let c be positive. c is positive, if for increasing costs of IS quality management the decay effect drops (cf. Equation 5).

$$\delta g/\delta Q_t = \gamma\, E_{t-1}^{b+cQ_t} \ln E_{t-1}\; c \geq 0$$

Equation 5

If c is positive the non-linearity factor correlates positive with c. A rise for the costs of the IS quality management leads to a higher effectiveness ratio. There can be the following reasons:

1. The measures from the IS quality management do not have any negative side effects. They contribute to the effectiveness in full extent.

2. The effectiveness ratio is provided by the management and to this extent the costs are planned for IS quality management. However, the actual expenditures for the IS quality management are below the planned expenditures, this can lead to a decrease of the effectiveness. The measures from the pre-periods lose its effect.

2nd case: Let c be negative. The partial differentiation of g and Q_t yields:

$\delta g/\delta Q_t = -\gamma\, E_{t-1}^{b+c\,Q_t} \ln E_{t-1}\, c < 0$

Equation 6

The negative sign of the partial differentiation 6) shows that increasing costs for the IS quality management lead to a lower effectiveness ratio. Because of the raised costs for the IS quality management the non-linearity factor decreases and the decay effect consequently also strengthens itself. However reduced costs weaken the decay effect.

The following reasons support this argumentation:

1. Additional expenditure for the IS quality management is reduced upon a strong rise in the effectiveness ratio. Investments will be made in other parts of the company.

2. The management provides the results for the effectiveness ratio usually at the beginning of a calculation period. The costs for IS quality management are planned for the predefined effectiveness ratio. If the actual costs for the IS quality management are below the predefined costs, this can nevertheless lead to the increase of the effectiveness ratio, if measures from the preceded periods still operate.

3. Increasing costs for the IS quality management can be caused by using new technology. The remedies for the IS quality management are used, but the effectiveness ratio decreases because of problems using the new technology.

The parameter b shall be viewed in more detail. A derivative of the complete effect g after b provides the following term:

$\delta g/\delta b = -\gamma\, E_{t-1}^{\,b+c\,Q_t} \ln E_{t-1} > 0$

Equation 7

A positive sign of the derivative (7) shows, that a rise of b leads to a higher effectiveness ratio. The decay effect weakens, if b increases. The decay effect approaches the saturation limit.

After an analysis of the parameters from the equation (3) a discussion follows about the two effects: growth and decay.

The growth effect

The complete effect summarizes the growth and decay effect. First the growth effect shall be viewed more exactly in equation (8).

Definition 3 (growth effect) *The growth effect WE_t is:*
$WE_t := w(E_{t-1}) = \gamma E_{t-1}$

Equation 8

The derivatives of γ and E_{t-1} are:

$\delta w/\delta\gamma = E_{t-1}>0$

Equation 9

$\delta w/\delta E_{t-1}=\gamma> 0$

Equation 10

A rise in γ causes a rise in the growth effect (cf. Derivative (9)). A rise of the effectiveness ratio E_t leads also to a rise of the growth effect (cf. Derivative (10)). This growth effect describes the future effectiveness ratio under the condition, that no decay effect exists in the quality management.

The increase in the effectiveness ratio can be related to the improved use of the IS quality management. The growth effect describes therefore the intended effect of the quality management.

The decay effect

In addition to the growth effect there is the decay effect, which prevents the unlimited rise of the effectiveness ratio. The decay effect is now examined in detail.

Definition 4 (decay effect)
The decay effect is defined as follows:
$r(E_{t-1}, Q_t)=\left| -\gamma E_{t-1}{}^{NLFt}\right| = \left| -\gamma E_{t-1}{}^{b+c\,Q_t}\right|$

Equation 11

The decay effect for the effectiveness ratio is stronger the higher the effectiveness ratio in t-1 is and the higher γ and the lower the non-linearity factor are. The non-linearity factor is lower the stronger the non-linearity factor is. Furthermore, the non-linearity factor decreases with increasing costs for the IS quality management and with decrease of b. The derivative shows the coherence between the decay effect and the effectiveness ratio of the pre-period.

$\delta r/\delta E_{t-1}=-\gamma\,(b+c\,Q_t)E_{t-1}{}^{b+c\,Q_t\,-1}<0$

Equation 12

The negative sign of the derivative (12) shows that the decay effect is lower if the effectiveness ratio increases. This effect corresponds to the idea that further raises in the effectiveness ratio become more difficult, the stronger the effectiveness ratio approaches 1. This fact corresponds with the demanded saturation.

Stability of the effectiveness ratio

The effectiveness ratio approaches a limit as long as the decay effect doesn't exceed a certain intensity. Let γ be 1.5 for our example and the rest of the parameters as in Figure 2. Thus the non-linearity factor doesn't exceed the critical limit. Figure 3 shows for several initial states a family of paths for the effectiveness ratio. The values for γ are 0.1 , 0.2 , 0.4 , 0.5 and 0.6.

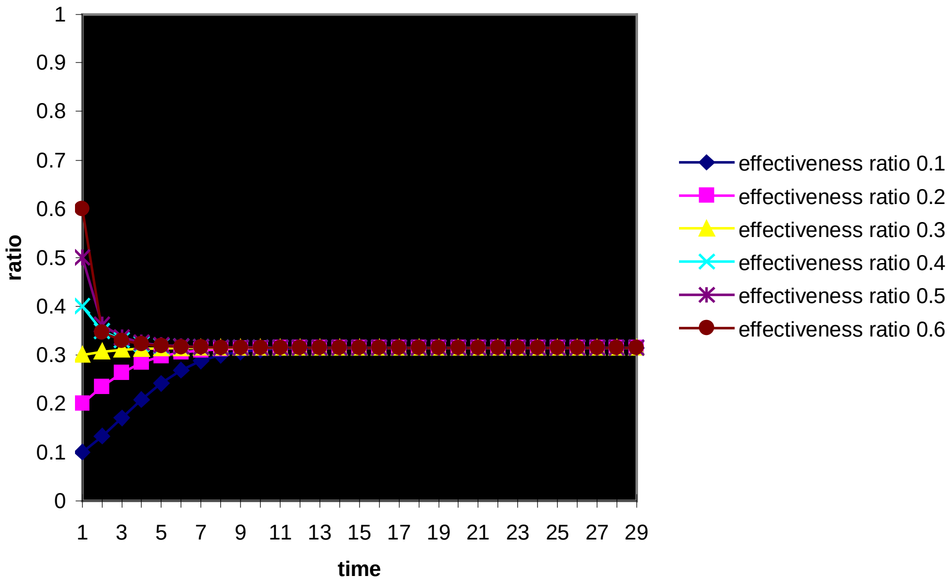


Figure 3: Trajectories for several start states with γ= 1.5

In all cases the effectiveness ratio reaches a fixed point and is in a "stable state". Various effectiveness ratios in the initial state don't have any influence on the terminal state. Even under the assumption that the costs sway strongly for the IS quality management, there are fixed points. The effectiveness ratio consequently isn't sensitive to alterations in the IS quality management, if the above boundary conditions are valid. For γ= 1.5 the system is in a "stable state". External shocks hardly influence the system.

However if γ= 3.1 is accepted, there is a cycle visible. The effectiveness ratio swings between two values (cf. Figure 4). A bifurcation is responsible for the swinging.

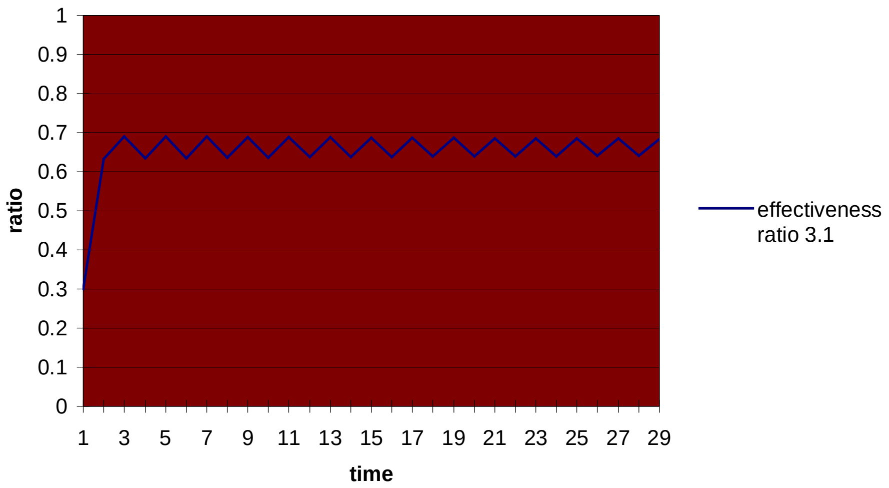


Figure 4: Trajectory for γ= 3.1

A further rise in the parameter γ leads to a path where the effectiveness ratio becomes fundamentally more complex (cf. Figure 5). The existence of several bifurcations [Li and Yorke, 1975] leads to deterministic chaos and the behavior can be described by so-called ‘‘strange attractors”.

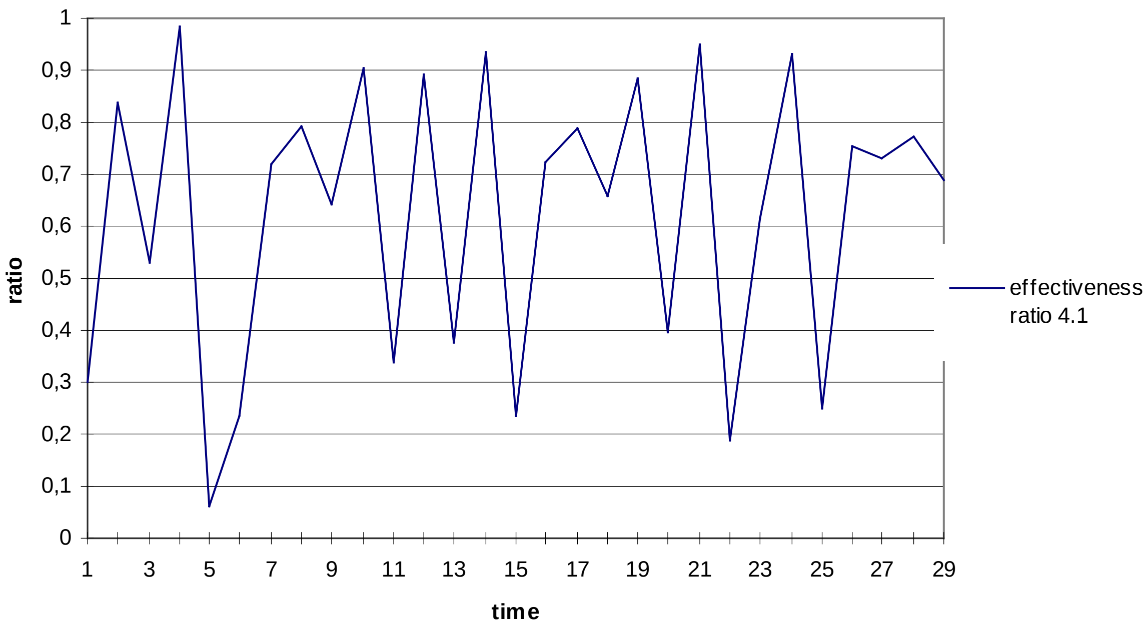


Figure 5: Trajectories for γ= 4.1

Analysis of the parameter γ shows that for $\gamma < 3$ a stable effectiveness ratio exists. The resulting paths are stable in face of fluctuations of the costs for the IS quality management and the various initial situations. The model is consequently stable under the above hypothesis in face of perturbations. However, if γ exceeds the critical limit of 3.7 this leads to an unordered behavior. Cycles occur and deterministic chaos results in the long term.

This fact can be illustrated by figure 6. γ is shown on the horizontal axis. The range covers the section of 1.1 to 4.1. The effectiveness ratio can be seen on the vertical axis. The unordered behavior of the effectiveness ratio starts at the limit of 3.1. At the value of 3.7 chaos exists for the observer. The smallest external effects have various paths.

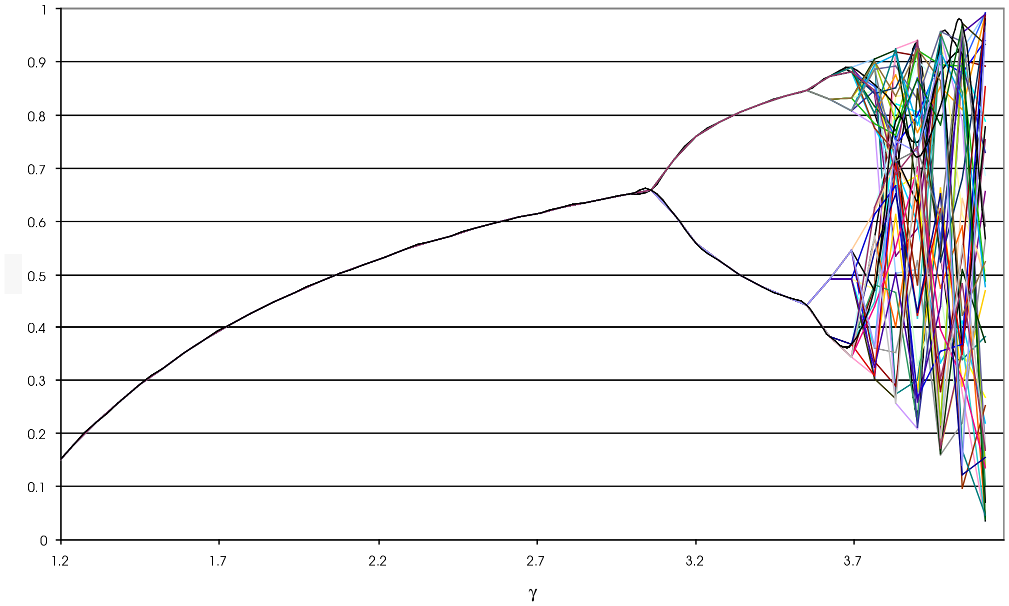


Figure 6: Trajectories for b = 2, c = -1, and constant Q_t = 0.05

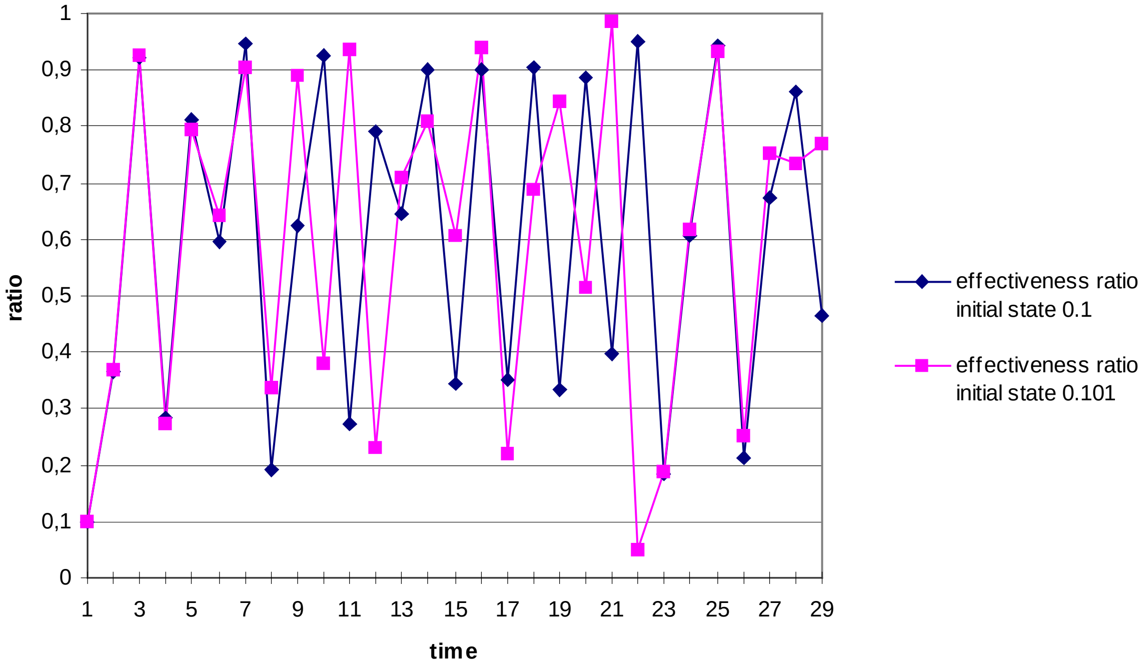


Figure 7: Marginal different start states for 0.1 and 0.101 with γ= 4.1

A marginal alteration of the initial situations can lead to various trajectories (cf. Figure 7) in non-linear models. The effectiveness ratio of 10% and 10.01% serves as start points for the examination of the sensitivity of the paths at marginally different initial states.

In the preceding discussion stability considerations were made dependent on γ.This can also be done with the non-linearity factor, but we leave this to further considerations.

The discussion showed that the existence of fixed points depends on γ and on the non-linearity factor. If γ or the non-linearity factor exceed a critical limit, bifurcations and chaotic behavior occur.

The following statements can be made with regard to the coherence between γ and the non-linearity factor:

- In the case of stable trajectories the fixed point for the effectiveness ratio is higher, the higher γ and the non-linearity factor are.
- An exceeding of the limit of γ and the non-linearity factor can cause bifurcations and can trigger deterministic chaotic behavior.

Empirical study

This section describes the empirical study of IS quality management. The non-linear model is applied to the IS department of an insurance company. It is the target of the application to check the hypothesis of the non-linear model.

IS quality management in an insurance company

A German branch of an international insurance company (AXA Colonia) was investigated. This company has a sophisticated quality management system with sufficient extent data.

The permanent change of technology and several take-overs led to problems for the IS quality in this insurance company. Interviews with the internal customers of the IS department showed a lack of customer satisfaction. Reasons for this discontent were errors in the production and long queuing times for the realization of new IS. The management saw this problem and founded a project. The project concerned all important processes in the IS department. Core processes were order management, release management, project management, and development environment.

The project pursued three targets:
1. enhancement of development and production
2. improvement in profitability
3. Re-engineering of the IS
4. architecture and reduction of the complexity of the IS architecture

The project organization split into a *technical* and *organizational* part. The technical part dealt with the optimization of the development and test process and the reduction of the architecture complexity. The organizational part developed a strategy for culture and optimized the department structure [Colonia, 1999].

Application of the non-linear model

The IS department consists of twenty employees who look after standardized procedures.
The services of the data warehouse are:
1. Obtaining data from various sources
2. Transforming data into a uniform data model
3. Selection of data from the uniform date model and various sources

The IS department offers standardized procedures which make specific date selection and data preparation easier. When the data are prepared, the customer can carry out the following evaluations:

- Creating standardized reports
- Creating personalized reports
- data mining

Figure 8 shows the intensity of the measures and the development of the efficiency ratio. In appendix A the data used are shown. We used the failure ratio to obtain the efficiency ratio. Reducing the failure means to improve the quality of IS especially to enhance the functionality, reliability, and user friendliness. The source of failures can be mainly wrong data, incorrect functions, and technical obstacles.

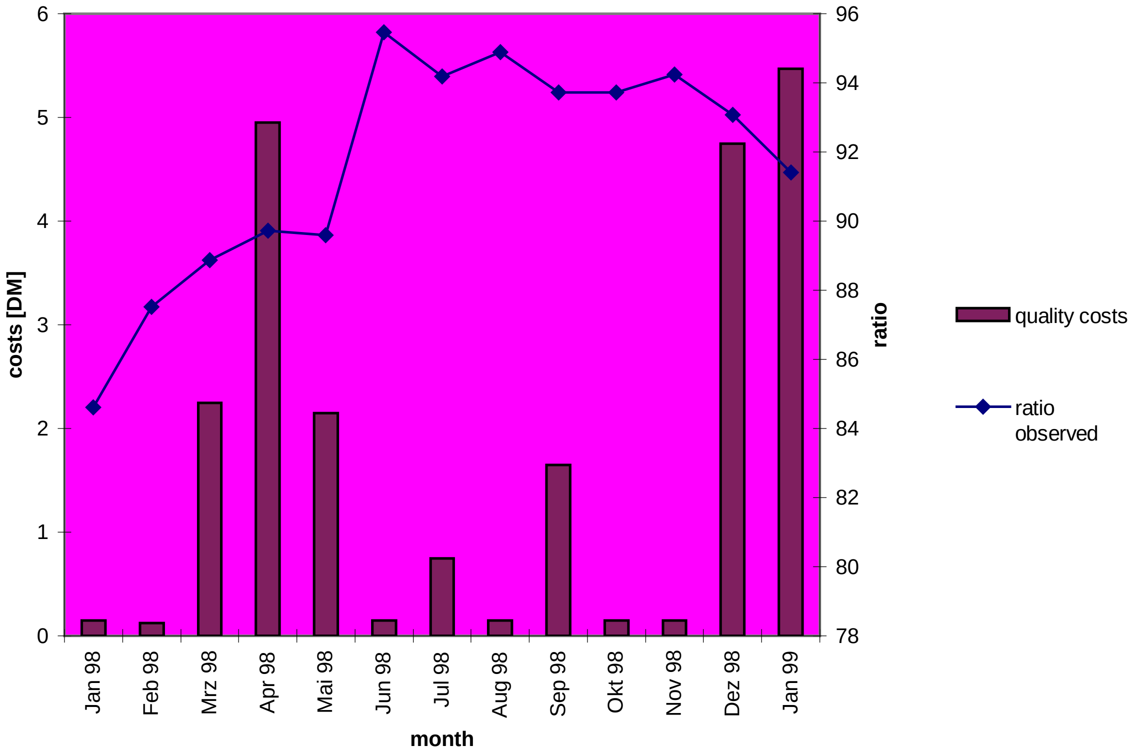


Figure 8: IS quality management and failure rate (cf. Table 4)

The evaluation of the data for the IS department produces, with a bimonthly deceleration, a square multiple correlation of R^2 = 78.91% (cf. Table 1).

$E_t = 1.0242\, E_{t-1} - 1.0242\, E_{t-1}^{58.3078 + 5.8874\, Q_{t-2}}$		
correlation	R^2 =0.7891	
	value	range
γ	1.0242	1.0090 / 1.038
b	58.3078	44.8873 / 71.7283
c	5.8874	-4.5932 / 16.3681

Table 1: Results for the IS department

The range of confidence for γ, b and c show a mixed picture. For γ and b the ranges are clear, while for c both negative and positive values exist. It can however be stated that the IS quality management has a non-linear effect, since b is definitely positive.

Figure 9 shows the observed and calculated effectiveness ratios for the IS department.

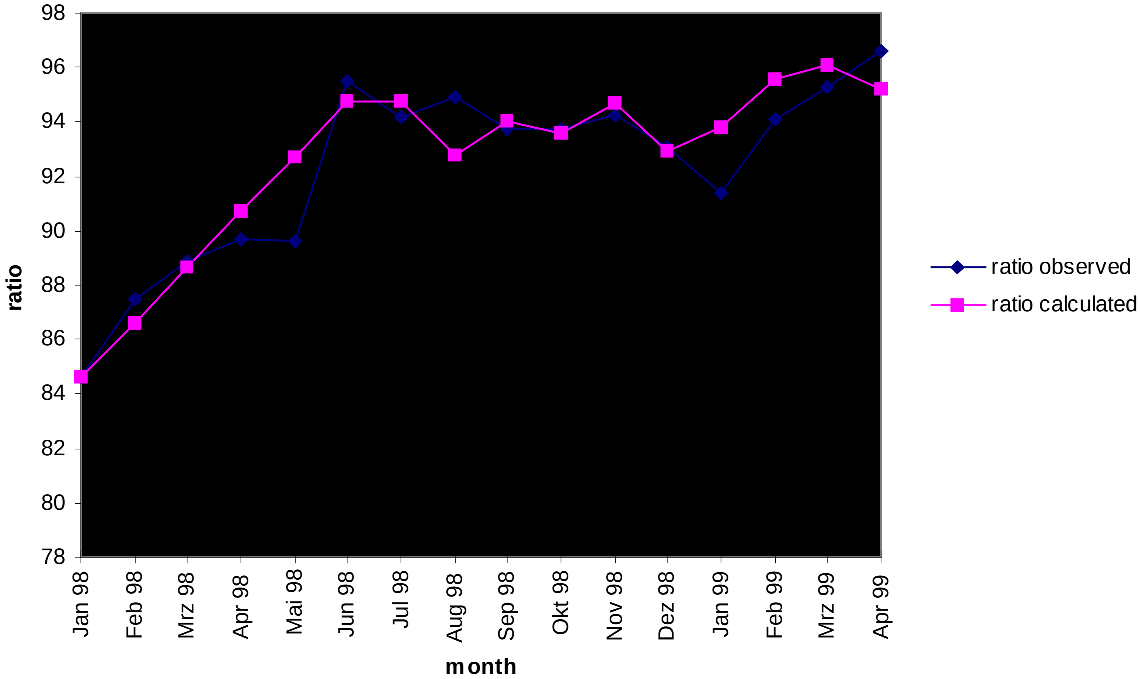


Figure 9: Observed and calculated effectiveness ratios of the IS department

Both curves coincide tightly. In an impressive way they confirm the hypothesis from the model. This assessment is also reflected in the correlation of 78.91%.

For the tests for autocorrelation and on homogeneity of the variance SPSS was used. The values of the evaluation are shown in Table 2 and 3.

Autocorrelation				
$u_t = \rho\, u_{t-1} + \varepsilon_t$				
ρ	Sign.	ε	Sign.	Durban-Watson
-0.118	0.687	0.0	0.942	1.987

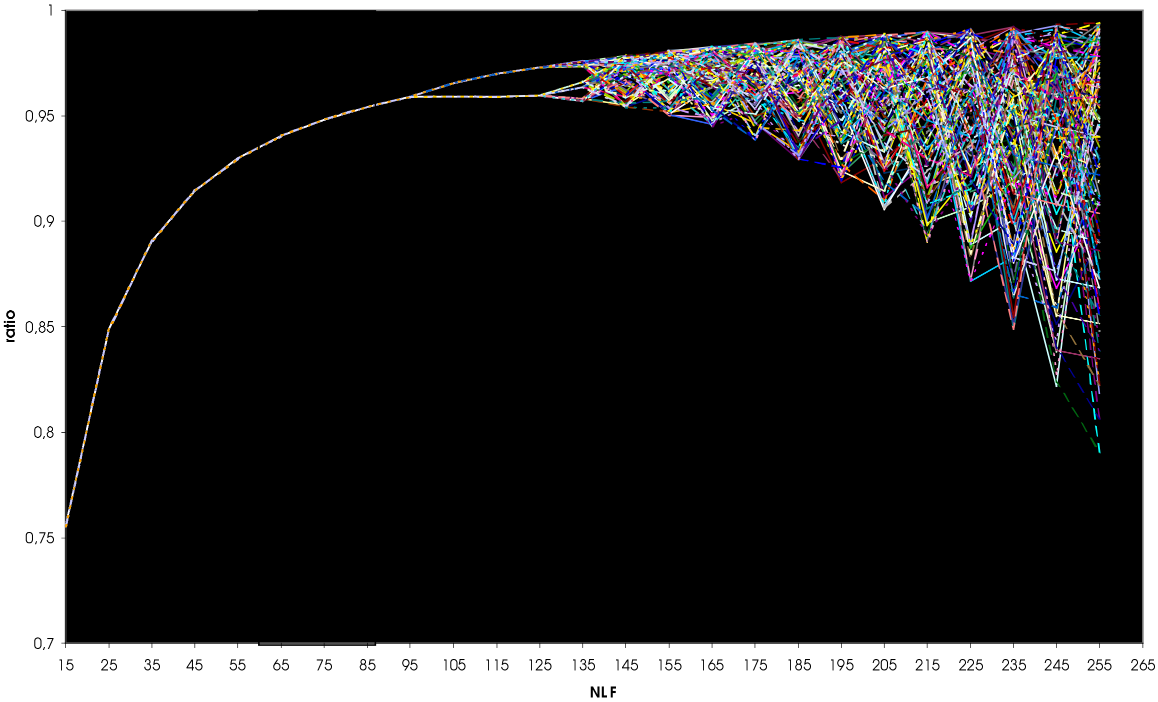
Table 2: Results of the validation

homogeneity of variance
Levene test
0.289

Table 3: Results of the validation (homogeneity)

These tests confirm that there is no reason to accept an autocorrelation of the residuum. The test on variance homogeneity also shows that no significant deviation of the supposition of the equal distributed variances exists.

The values of γ and b show that a stable state exists. There is a fixed point at around 94%. This indicates that the situation is stable in the IS department and the IS quality management has a high standard. The coherence between IS quality management and reduction of the errors is proven by the non-linear model. The stability consideration shows the parameter values to be in the stable range.



Ab

bildung 1: Bifurcation for $\gamma = 1.02$

The high correlation and the high stability in the system of the IS department show that the IS department has mastered quality management.

Conclusions

This study offers a novel approach for better understanding the nature of IS quality management. A non-linear model is used to correlate IS quality management and its effects.

The non-linear model theorizes that dynamic effects, non-linearity, saturation, and threshold values exist. The effects of IS quality management are separated into a growth and decay effect. These hypotheses developed in the first part, were tested and confirmed by the empirical study.

The dynamic effect is expressed by the time lag between measures taken and their effects. The data analysis shows that a delay of two months is realistic. The model could also substantiate the hypothesis that there is a non-linear correlation between measures and their effects. The existence of threshold values and saturation limits follows from the non-linearity.

The special advantage of the model lies in the characterization of the correlation between IS quality management and its effects. The correlation established by the non-linear model can be stable or unstable. The model allows to derive parameters in which external influences do not have large consequences for a stable system. For unstable systems this is different: an influence can lead to frictions. As the model proves with the empirical data, the correlation is stable. The model is also able to show the limits where the the system runs into chaotic behavior.

A Data of insurance company

Table 4 shows the months and the costs for IS quality management.

Month	year	costs [10.000 DM]
January	98	0.15
February	98	1.25
March	98	2.25
April	98	4.95
May	98	2.15
June	98	0.15
July	98	0.75
August	98	0.15
September	98	1.65
October	98	0.15
November	98	0.15
December	98	4.75
January	99	5.47

Table 4: Costs of IS quality management

Table 5 shows in the first column the months. In the second column the observed efficiency ratio ($E_{ob.}$) is shown. The nonlinearity factor (NLF_t) follows in the third column which is the result of b+c Q_{t-2}. The forth column is filled with the efficiency ratio $E_{calc.}$ which is calculated by the non-linear model.

month	**E_{ob}. [%]**	**NLF_t**	**E_{calc} [%]**
Jan. 98	84.61	59.19	84.61
Feb. 98	87.52	59.19	86.60
Mch 98	88.87	59.19	88.63
Apr. 98	89.72	65.67	90.69
May 98	89.59	71.55	92.73
Jun. 98	95.47	87.45	94.79
Jul. 98	94.18	70.97	94.74
Aug.98	94.89	59.19	92.80
Spt. 98	93.73	68.02	94.05
Oct. 98	93.73	59.19	93.56
Nov. 98	94.24	59.19	94.66
Dec. 98	93.08	58.31	92.91
Jan. 99	91.40	58.31	93.79
Feb. 99	94.11	58.31	95.60
Mch.99	95.28	58.31	96.12
Apr. 99	96.57	58.31	95.22

Table 5: Data of AXA Colonia AG

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