Control Measures for Kaizen Costing - Formulation and Practical Use of the Half-Life Model

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Abstract

Kaizen costing focuses on continuous reductions of costs, which should be realized for existing products in a company. For planning and control purposes, comprehensive and efficient tools for measuring performance are required. For this purpose we suggest the so-called ”half-life model”. It is based on the practical experience, that any defect level decreases at a constant rate over a certain time period. This paper gives the mathematical formulation for this model and illustrates its practical use with different examples.

1 The paradigm of kaizen costing

Kaizen costing focuses on continuous reductions of costs, which should be realized for existing products in a company[1]. To shape a company's cost structure according to competitive requirements, a sound analysis of a company's cost drivers is needed. From a customer's perspective, only so-called value-adding cost drivers are relevant, e.g. no. of durability tests, mean-time-between-failure, etc. As those cost drivers provide the customer-value, customers will pay for the resources consumed. However, resource consumption should be reduced in order to improve a company's productivity. On the other hand, non-value-adding cost drivers, e.g. no. of deferred deliveries, wrong deliveries, transportation time etc., lead to resource consumption, which customers do not want to pay for. Therefore, non-value-adding cost drivers have to be adjusted according to "best practice"-standards. To avoid losses, they must either be reduced to a competitor's minimum level or they have to be eliminated completely. To reach this goal, a company's cost drivers have to be analysed systematically.

Cost driver analysis

Each key cost component of the above mentioned gap between the level of actual costs and the identified "best practice" cost level has to be analysed in the following steps[2].

- *Determine the activities that drive the key cost components of the cost gap.*

For example, the actual costs could contain penalties, which have been paid to customers. To avoid losses in the future, they should be eliminated completely. Therefore it is necessary to identify the activities that caused penalties by breaking their root causes down into a finer and finer level of detail, such as,

1 Cooper, 1995, p. 239.

2 See a similar method described by Atkinson et al., 1991, pp. 72--77.

penalties caused by partial shipments, late shipments, and/or shipments of wrong products.

- *Determine the root causes of the activities that drive the key cost components.*

A more detailed analysis of the shipment-related drivers showed three root causes:

1?raw materials not within specification;
2?confusing sales order documentation; and
3?poor workmanship in the manufacturing process.

- *Determine the financial impact of the root causes of the cost gap.*

Once the root causes of the activities driving the key cost components of the cost gap are known, relative percentages of the total financial impact of the cost gap are assigned to the activities and to the root causes. In this way, the financial impact of a specific key cost component can be traced back to the specific activity and root cause. Finally, the identified root causes can be grouped together in turn to determine their financial impact. For example, the largest financial impact could rise from the root cause ”poor raw materials”.
The priority of improvement programs should be adjusted according to the financial impact of the root causes. For monitoring the cost reductions realized by the improvement of a company’s cost drivers, an appropriate management tool is needed.

Tools for monitoring the cost reductions

For planning and control of cost reductions, comprehensive and efficient tools for measurement are required. From a manager’s perspective, tools for monitoring the improvement of a company’s cost drivers are needed. For this purpose we suggest the so-called ”half-life model”. It is based on the practical experience, that any defect level decreases at a specific rate over a certain time period: ”A half-life curve measures the time it takes to achieve a 50 percent improvement in a specified performance measure”,[3] for example, cutting the number of defective lots received from a vendor by half (see exhibit 1).

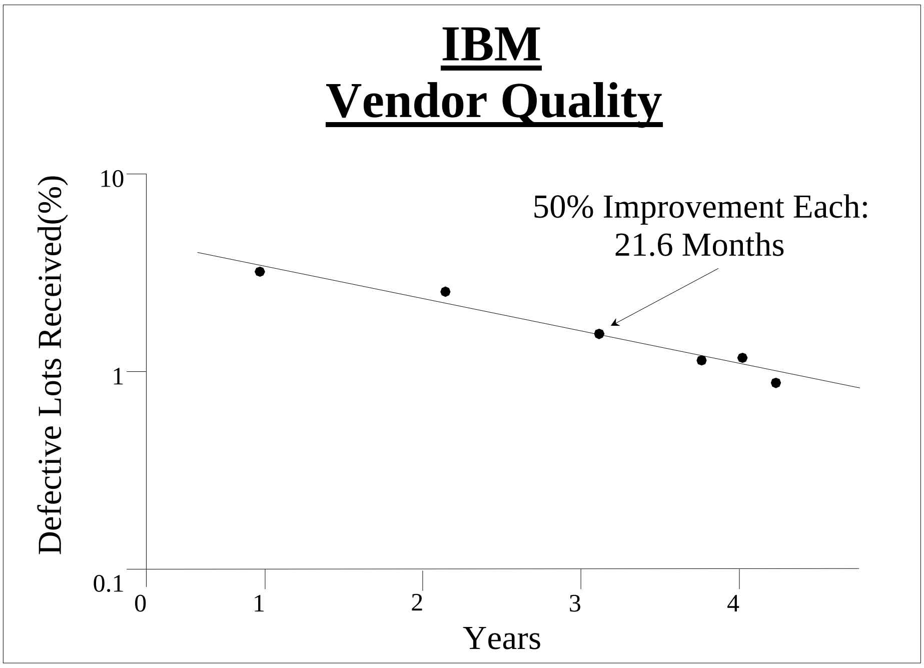

Exhibit 1: Reduction of defective lots with the half-life model
(Source: Arthur M. Schneidermann, “Setting Quality goals”: 55)

In general, starting points for cost reductions may be found within the product features, the activities performed in the value chain, or the resources consumed in those activities. As non-value-adding cost drivers, e.g. ”customer response time”, ”deferred deliveries”, ”late deliveries”, and ”first-pass-yield”, need to be reduced in order to improve a company’s profitability, they may be considered to be defect levels in a more general sense. By measuring the rate of reduction of non-value-adding cost drivers, therefore, the half-life model provides a useful tool for closing an existing cost gap in the kaizen costing process.

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[3] Garvin, 1993, p. 89; Schneiderman, 1996, p. 12.

2 Formulation of the half-life model

2.1 Basic half-life model

In this model, Y_t represents the defect level at any given time t. The word "defect" is used in its most general sense, which includes errors, rework, yield loss, unnecessary reports, cycle times (manufacturing, design, administrative, etc.), unscheduled downtime, inventory, employee turnover, absenteeism, lateness, unrealized human potential, accidents, late deliveries, order lead time, setup time, cost of poor quality and warranty costs. In fact, Y_t can be any measurable quantity that is in need of improvement but only if the aim is to reduce this performance measure. We will also use the word "problem" interchangeably with the word "defect". Y_t can represent any measure that deviates from its optimal value.

The difference of the initial defect level Y_{t_0} and the minimum defect level Y_{min} decreases by 50 percent within a constant time period, which is called (defect) half-life t_H. Consider for example, an initial defect level of 1,000 units and a defect half-life of six months. Then, after the first six months, the defect level would be down to 500 units, after the next six months down to 250 units, and so on.

To determine the half-life function of a business process, the following five steps have to be carried out within a company:

1?selection of the business process and half-life parameter to be analysed (e.g. cycle time of customer order processing);

2?determination of an appropriate half-life measure (e.g. days);

3?determination of the initial defect level (Y_{t_0});

4?evaluation of the defect level (Y_t);

5?calculation of the half-life time (t_H).

Plotting the defect level Y_t against time t on a semi-log scale reveals a negative linear relationship between the two variables (see exhibit 1). The shorter (longer) the half-life of the analysed process, the steeper (lower) the line runs.

After one half-life (t_H) has passed, the remaining defect level (Y_t) at time t can be described as follows:

(1) $$Y_t = \frac{1}{2} Y_{t_0}.$$

Dependent on the number i ($i \in R_0^+$) of performed half-life cycles the defect level (Y_t) can generally be calculated as:

(2) $$Y_t = \left(\frac{1}{2}\right)^i Y_{t_0}.$$

Inserting $i = \frac{t - t_0}{t_H}$; $(t = \text{time},\ t_0 = \text{initial time})$ into the equation yields the following expression:

(3) $$Y_t = \left(\frac{1}{2}\right)^{\left(\frac{t - t_0}{t_H}\right)} Y_{t_0}.$$

To calculate the half-life (t_H) we have to take the natural logarithm of equation 3. An example shall illustrate the practical use of the modified half-life model. In January ($t_0 = 1$) a company had to deal with $Y_{t_0} = 1{,}000$ customer complaints. In July (t = 7) the level of customer complaints has come down to $Y_7 = 125$.

How long is the half-life t_H?

(4) $$t_H = \frac{(t - t_0)\left(\ln \frac{1}{2}\right)}{\ln Y_t - \ln Y_t} = \frac{(7 - 1)\left(\ln \frac{1}{2}\right)}{\ln 125 - \ln 1{,}000} = 2.0 \text{ months.}$$

How many half-life cycles have been realized between January and July?

(5) $$i = \frac{t - t_0}{t_H} = \frac{(7-1)}{2} = \frac{\ln 125 - \ln 1{,}000}{\ln \frac{1}{2}} = 3 \text{ half-life cycles}.$$

How many customer complaints have to be expected in November (t=11)?

(6) $$Y_{11} = \frac{1}{2}^{\left(\frac{t-t_0}{t_H}\right)} \cdot Y_{t_0} = \frac{1}{2}^{\left(\frac{11-1}{2}\right)} \cdot 1{,}000 \approx 31 \text{ customer complaints.}$$

The underlying assumption of the half-life model shows high similarity to the decay phenomenon known from physics[4]. There a decay constant λ expresses the probability that a radium nucleus will decay within the next moment. Thus, the number of radium atoms at actual time t can be expressed as follows:

$$n_t = e^{-\lambda t} n_{to}$$

n_t: no. of atoms at time t,

n_{to}: no. of atoms at initial time t_o,

l**:** decay constant.

If the number of atoms decreases by 50 percent at a certain time period (i.e. half-life t_H), the decay constant is determined by $\lambda = (\ln 2 / t_H)$. Entering this in the above formula we get:

$$n_t = e^{(-\ln 2)\frac{t}{tH}} \cdot n_{t0} = \left(\frac{1}{2}\right)^{\frac{t}{tH}} \cdot n_{t0} \ .$$

Setting $t_0 = 0$ and $Y_{min} = 0$, this equation is identical with the half-life model which we used for measuring continuous improvement.

A closer look at the mathematical derivation of the half-life function shows that the half-life time of a business process is determined by a single measure of the defect level at time t (Y_t). The half-life model describes the efforts of a company to reduce non-value adding cost drivers. To close an existing cost gap between

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4 e.g. Gerthsen/Vogel, 1993, p. 649.

target costs and drifting costs as soon as possible, an appropriate selection of measures for the company's most critical defect levels is necessary:

- no. of defect products;
- no. of customer complaints;
- no. of late deliveries;
- no. of incomplete deliveries;
- no. of product reworks;
- order cycle times;
- department cycle times (R&D, Manufacturing, Sales, Service);
- function cycle times (Set-up, Maintenance, Transport).

The half-life model enables managers to plan "ex ante" the progress of continuous improvement programs[5]. It is important to reach a high **relative improvement rate** (i.e. realized degree of improvement within a certain time period, e.g. day, month, year): the shorter the half-life of a business process, the higher is the improvement rate of the organization. Thus, the half-life time becomes an indicator of a company's capability to perform "organizational learning".

2.2 Modifying the basic half-life model

The assumption for the basic half-life model is that any defect level decreases at a specific rate[6]. The proposed model focuses on the determination of necessary reductions in various measures of corporate operations (e.g. order cycle times, deferred deliveries), which are defined as the difference between some initial value of the parameter (Y_{t_0}) and its desirable minimum value (Y_{min})[7]. This approach may raise the question of why, in the context of

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5 Stata, 1989, p. 69.

6 Schneiderman, 1988, p. 53.

7 Schneiderman, 1988, p. 53.

continuous improvement of processes, the targeted minimum level (Y_{min}) should be held constant, even though new optimal minimum values might occur over time. To make predictions about future values of the examined parameters (Y_t), forecasts would have to be based on the initial value (Y_{t_0}) instead of the ex ante determined improvement value ($Y_{t_0} - Y_{min}$). This would avoid forecast errors resulting from a mistakenly estimated desired value (Y_{min}). In doing this, the original mathematical foundation of the concept given by Schneiderman needs to be altered. This is done in the following way.

Y_{min} represents the minimum achievable level of Y_t. When talking about defects or errors, Y_{min} is potentially zero. However, when considering for example cycle times or yields, a value of zero might violate the laws of physics. The term ($Y_t - Y_{min}$) can be thought of as a mathematical generalization of waste or *muda* as it is called by the Japanese. This expression is not targeted at manufacturing defects only; it is applicable to anything in need of improvement.

According to Schneiderman[8], the modified half-life model is mathematically formulated as follows:

After one half-life (t_H) has passed, the remaining improvement gap ($Y_t - Y_{min}$) can be described as follows:

(7) $$Y_t - Y_{min} = \frac{1}{2}\left(Y_{t_0} - Y_{min}\right).$$

Dependent on the number i of performed half-life cycles ($i \in R_0^+$), the improvement gap ($Y_t - Y_{min}$) can generally be expressed as:

(8) $$Y_t - Y_{min} = \left(\frac{1}{2}\right)^i \cdot \left(Y_{t_0} - Y_{min}\right).$$

8 Schneiderman, 1988, p. 53.

The number of half-life cycles i which occurred within a certain business process, is dependent on the sequence of half-lives t_H, which could have been realized in the period between initial time t_0 and time t. Inserting this relation into equation (8) yields the following expression:

(9) $$Y_t - Y_{min} = \left(\frac{1}{2}\right)^{\left(\frac{t-t_0}{t_H}\right)} \cdot \left(Y_{t_0} - Y_{min}\right).$$

with

Y_t	=	defect level at time t,
Y_{t_0}	=	defect level at initial time t_0
Y_{min}	=	minimum defect level,
t	=	time t,
t_0	=	initial time,
t_H	=	half-life time.

To calculate the half-life t_H of a specific business process we have to take the natural logarithm of equation (9).

Again, an example can illustrate the practical use of the modified basic half-life model.

At the end of January ($t_0 = 1$) in the new fiscal year, the sales manager at XYZ Corp. had to deal with $Y_{t_0} = 1{,}000$ customer complaints. As a minimum achievable defect level the company wants to have $Y_{min} = 10$ customer complaints. In July (t = 7) the level of customer complaints has come down to $Y_7 = 134$.

How long is the half-life t_H?

(10) $$t_H = \frac{\left(t - t_0\right) \cdot \ln\frac{1}{2}}{\ln\left(Y_t - Y_{min}\right) - \ln\left(Y_{t_0} - Y_{min}\right)} = \frac{(7-1) \cdot \ln\frac{1}{2}}{\ln(134-10) - \ln(1{,}000-10)} \approx 2.0 \text{ months}.$$

How many half-life cycles have been realized between January and July?

(11) $$i = \frac{t - t_0}{t_H} = \frac{(7-1)}{2} = \frac{\ln(134-10) - \ln(1{,}000-10)}{\ln\frac{1}{2}} \approx 3 \text{ half - life cycles}.$$

How many customer complaints could the sales manager expect to deal with in November (t = 11)?

(12) $$Y_{11} = \left(\frac{1}{2}\right)^{\left(\frac{t-t_0}{t_H}\right)} \cdot \left(Y_{t_0} - Y_{min}\right) + Y_{min} = \frac{1}{2}^{\left(\frac{11-1}{2}\right)} \cdot (1{,}000-10) + 10 = 41 \text{ customer complaints}\cdot$$

In which month t will the company have reached the number of $Y_t = 21$ customer complaints?

(13) $$t = \frac{t_H\left[\ln\left(Y_t - Y_{min}\right) - \ln\left(Y_{t_0} - Y_{min}\right)\right]}{\ln\frac{1}{2}} + t_0 .$$

For $Y_{t_0} = 1{,}000$, $Y_{min} = 10$, $t_0 = 1$ (January) and $t_H = 2$ months the results are:

(14) $$t = \frac{2\left[\ln(21-10) - \ln(1{,}000-10)\right]}{\ln\frac{1}{2}} + 1 \approx 14 \text{ months (i. e end of February next year)}\cdot$$

When will the company probably reach the achieved minimum defect level $Y_{min} = 10$?

If we would like to answer this question, we have to think of the (theoretical) possibility that $Y_t = Y_{min}$ (note: In the above described basic half-life model, the same question would arise for $Y_t = 0$). Thus, the equations for determining the half-life will contain the following expressions:

(15) $\ln\left(Y_t - Y_{min}\right) = \ln 0 \to \infty$ (basic half-life model: $\ln\left(Y_t\right) = \ln 0 \to \infty$).

This means, t will take an infinite value. In other words, the achieved minimum defect level Y_{min} could be realized only in infinite time.

This problem could be handled by the definition of a tolerance zone $\varepsilon = \left|Y_t - Y_{min}\right|$ where

- ε = 1 for discrete Y_t (e.g. no. of customer complaints, late deliveries etc.); and
- 0 < ε < 1 for continuous Y_t (yield, cycle times etc.).

The smaller the value of ε, the higher the corresponding values of t would become.
With the data of the above described example, for different values of ε the corresponding values of t_H would be:

- $\varepsilon = 0.1$ →t = 27.55 months;
- $\varepsilon = 0.01$ →t = 34.19 months; and
- $\varepsilon = 0.001$ →t = 47.48 months.

In our example, for a tolerance zone $\varepsilon = \left|Y_t - Y_{min}\right| = \left|11-1\right| = 1$, time t for reaching the achieved minimum defect level $Y_{min} = 10$ can be calculated as follows:

(16) $$t = \frac{2\left[\ln(11-10)-\ln(1{,}000-10)\right]}{\ln\frac{1}{2}} + 1 \approx 21 \text{ months (i. e September next year)}.$$

Exhibit 2 summarizes the different values of actual defect levels Y_t for any specific performance measure. It becomes obvious, that projections for necessary improvements of a specific performance measure can differ, depending on which half-life model is chosen.

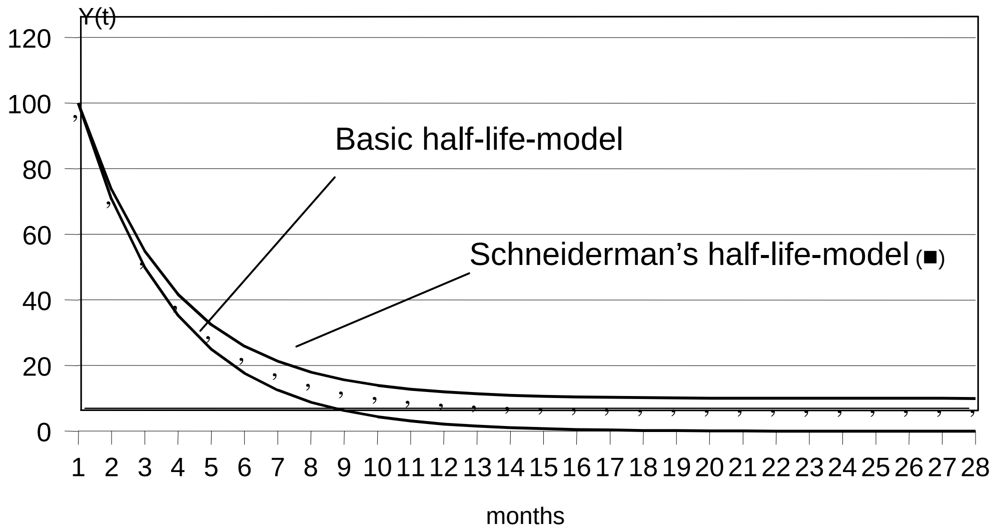

Exhibit 2: Comparison of the different concepts of the half-life model

3 Validity of the half-life model

The validity of the half-life model depends upon the reliability and stability of a once computed half-life over time. Exhibit 3 summarises the results of fitting 64 independent improvement projects to the model.

Improvement project	half-life time t_H (months)	no. of improvement cycles i	coefficient of determination R^2
Vendor defect level transistors	9.6	3.7	0.997
Late deliveries to customers (+0.-2 weeks)	30.4	0.8	0.994
Defect levels customers´ incoming QC	10.1	7.1	0.989
Failure rate dip soldering process	3.7	8.6	0.980
WIP	6.3	1.1	0.979
Defective lots received from vendors	21.6	1.7	0.976
Customer returns because of product	12.4	2.9	0.974
Defects caused by pits piston rings	5.5	3.5	0.968
Absenteeism caused by accidents	14.8	4.0	0.956
First year warranty costs	27.8	2.6	0.950
Defects per unit	7.6	4.6	0.948
Missing product features	12.5	2.9	0.947
COPQ goggles manufacturer	4.7	1.9	0.942
Customer returns caused by administrative	6.3	3.8	0.941
Equipment downtime	13.1	2.1	0.940
Manufacturing cycle time	16.9	2.5	0.937
Scrap and repair costs	5.0	1.6	0.918
Failure costs (internal + claims)	37.9	1.9	0.909
Accident rate	21.5	2.8	0.907
Vendor defect level IC linears	7.4	4.9	0.906
Failure rate line assembly	7.5	3.2	0.886
Defects in vacuum molding	5.6	4.6	0.882
Error rate perpetual inventory	12.1	3.0	0.862
Field failure rate	20.3	1.3	0.857
Defects on arrival	16.9	2.0	0.848
Defective stockings	2.7	2.2	0.843
Yield loss PCB photo imaging	2.9	2.3	0.843
Vendor defect level transformers	7.2	5.0	0.842
Post-release redesign	19.0	2.5	0.842
Late orders to customers	3.0	2.7	0.838
Vendor defect level microprocessors	18.5	1.9	0.838
Operations sheet errors	0.6	4.2	0.834
Vendor defect level capacitors	5.7	6.3	0.812
Scrap costs	13.8	1.7	0.805
Rework rate	8.0	1.4	0.801
Days late in delivery	0.8	7.6	0.774
Warranty failure rates	36.2	2.5	0.769
Scrap costs die coat inspection	2.4	2.0	0.754
Typing errors in bank telegram department	2.9	2.0	0.754
PCB photo imaging resist flake	1.9	3.3	0.748
Scrap and repair costs	5.0	0.8	0.746
Manufacturing cycle time	7.6	2.7	0.741
Insertion defect rate	3.3	3.4	0.738
Yield loss die coat inspection	2.4	2.3	0.733
Product development cycle time	55.3	1.1	0.733
Aluminum smears from IC test pads	2.4	5.1	0.717
Accounting miscodes	6.4	2.5	0.709
Setup time	9.5	0.6	0.690
Nonconformances	16.9	0.7	0.666
Defects at turn on	14.9	1.3	0.624
Rejects caused by bends and dents	1.3	1.7	0.590
Downtime of facilities	4.5	1.3	0.562
In-process defect rate	5.3	1.1	0.550
Process sheet errors	1.4	2.1	0.535
Errors in purchase orders	2.3	1.5	0.531
Off-spec rejects	8.8	5.1	0.531
Manufacturing scrap	7.0	3.9	0.530
Late spare parts to customers	5.3	1.1	0.471
Computer program execution errors	29.9	0.4	0.364
Average	**10.2**	**2.6**	**0.738**

Exhibit 3: Validity of the half-life model (Source: A. M. Schneiderman, “Setting Quality Goals”: 52)

A large value for the number of improvement cycles indicates a mature project, while a small value is indicative of a start-up effort. The final column contains the coefficient of determination (R^2) of the regression and is a measure of how well empirical data fit with the theoretical half-life model. A value of R^2 close to one indicates that the model explains the data at a high statistical confidence level. A value close to zero implies that little of the observed data is explained by the model. The specific interpretation of values between but not equal to either zero or one is so far an unresolved issue:

“The question is often asked as to how high R^2 should be before the results are valid. The answer to this question, unfortunately, is it depends. For some applications, an R^2 of 0.95 is not good enough, while for others, 0.5 would be considered adequate. In medicine, for example, regression equations are often not accepted unless $R^2 \geq 0.99$, while in behavioral or marketing studies where human behavior is involved, R^2 values of about 0.15 or 0.2 are considered satisfactory.”[9].

The data in exhibit 3 show an average value of R^2 = 0.77. The statistical significance of the results should be judged against the qualitative criteria given above. The average number of improvement cycles was i = 2.6. That corresponds to a reduction (by a factor) of $2^{2.6}$ or an average reduction of $\left(1-0.5^{2.6}\right)\cdot 100\% = 83.5\%$ for the defects being addressed by the improvement projects. The high average values for both R^2 and the observed improvement factors suggest that the data strongly substantiate the proposed model.

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9 Schneiderman, 1988, p. 54.

4 Classification of half-life projects

The aggregated data shown in exhibit 3 mask some fundamental differences between the projects. It is tempting to try to group the data into discrete classes of projects. One classification is suggested along the dimensions of span of control or organizational complexity[10]. For example, a number of projects appear to be within a single organizational function as measured by the team's ability to autonomously solve, approve, and implement. These could be called **uni-functional problems**.

A second group of problems is cross functional in nature, involving, for example, marketing, design, purchasing, manufacturing, quality assurance, and sales. From a traditional perspective there might be functional winners and losers in the solution of the problem. Under QIP, these internal trade-offs are weighed against the entire organization's commitment to improved value for its customers. Often the process is facilitated by the one person in the organization who has managerial control over different functions. But the process of coming to a consensus necessary for a solution can be expected to increase the time of a problem solving process - particularly in organizations that are large, bureaucratic, or both. These types of problems could be classified as **multi-functional problems**.

The third category logically follows. These problems involve different business entities: the problem-solving team and its external customers or suppliers. In this case there is no single person with the authority to reconcile differences. Action must result from negotiations. This process further adds to the time needed for improvement. These are so-called **cross-entity problems**.

It is interesting to go through the entries of exhibit 3 and make a best guess at the appropriate classification for each of the projects. Because the entries are in the order of increasing half-lives, we would expect that the class one (unifunctional) projects would tend to group at the top, class two (cross functional) in the middle, and class three (cross entity) near the bottom. Based

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[10] Schneiderman, 1988, p. 56.

on this classification, the following half-life model values might be proposed as initial values for project goals, until better quantitative data are available within a company[11]:

- uni-functional projects: expected half-life range 0 to 6 months;
- multi-functional projects: expected half-life range 6 to 12 months;
- cross-entity projects: expected half-life range 12 to 24 months.

5 Financial evaluation of continuous improvements

The half-life model describes improvements of mainly non-financial performance measures according to the amount of time needed for a reduction of 50 percent. These improvements may be interpreted as drivers of future financial performance of a business or a company.

For a rough estimation of achievable improvements in financial performance, the following steps needs to be followed:

- select performance driver, e.g. total cycle time;
- measure impact of a 50 percent reduction of the selected performance driver on different cost categories; and
- calculate total expected savings from a 50 percent reduction of the selected performance driver.

The future savings from a 50 percent reduction of total cycle time might be easily derived from a profit & loss account as illustrated in exhibit 4[12].

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[11] Schneiderman, 1988, p. 57.

[12] Thomas, 1991, pp. 13--15.

Cost Category	Improvement per cost category from a 50 % reduction of total cycle time	Typical Cost (percent of Sales)	Typical Savings (percent of Sales)
Depreciation	20 %	12 %	2.4 %
Blue-Collar Cost	15 %	10 %	1.5 %
White-Collar Cost	25 %	35 %	8.8 %
Logistics Cost	50 %	5 %	2.5 %
Material Cost	7 %	23 %	1.6 %
Total		85 %	16.8%

Exhibit 4: Savings from a 50 percent reduction of total cycle time (Source: Ph. R. Thomas, ”Getting Competitive”: 15)

In addition to the proposed methodology, the model of the experience curve might be used to determine the financial impact of continuous improvements. The experience curve[13] tries to link improvements of mainly financial parameters (i.e. value added costs per unit) to the cumulated output volume. In order to reach a specific cost level, the “cost drivers” have to be shaped. The following paragraphs describe a methodology to link together both concepts for the control of operations.

The two models are based on different basic assumptions: the experience curve describes cost reductions which are dependent on the accumulated production volume and therefore is independent of the time which is needed. In contrast, the half-life model shows quality improvements dependent on the time needed and independent of the accumulated production volume. While the use of the experience curve is limited to real value-added costs per unit, the half-life concept could be used to describe the development of any non-financial performance measure. Both concepts represent long-run trends which are mathematically derived from regression analysis. The two main reasons for cost reductions shown by the experience curve could be traced to static economies

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[13] Henderson, 1974.

of scale on the one hand and dynamic learning efforts on the other hand. The latter stem from a higher level of rationalization which leads to simplified structures and less resource consumption. The elimination of non-value-adding activity drivers which is supported by the half-life concept, leads to cost reductions which can be derived from the experience curve. Hence, the half-life model could be used to explain the reasons for dynamic cost reduction which inturn, could be analysed by the concept of the experience curve.

Exhibit 5 shows as an example of the linkage between the half-life concept and the experience curve based on empirical data from Airbus Industries[14]. In January 1976 the first Airbus aircraft was manufactured. Between the years 1976 and 1980 and between 1980 and 1989 the manufacturing time of a single aircraft as a non-financial cost driver has been reduced from 340,000 over 65,000 down to 40,000 hours. On the basic assumption that one manufacturing hour costs 30 DM, we could easily derive the financial savings of real manufacturing costs. (Note: for our calculations we assume, that the data published by Airbus Industries have been measured in January of the years 1976, 1980 and 1989 respectively).

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[14] Simon, 1992, p. 284.

	Half-Life Model		Experience Curve		
	years	**manufact. time**	**manufact. costs**	**accum. output (units)**	
• half-life time t_H = 1.676 years (=20.1 months) • no. of hl-cycles i = 2.387	***Jan. 1976***	340,000 h	10,200,000.-- DM		• experience rate: L = 0.781 • no. of doublings of the accum. output: i = 6.70
	Sept. 1977	170,000 h			
	May 1979	85,000 h			
	Jan. 1980	65,000 h	1,950,000.-- DM	1	
• half-life time t_H = 12.849 years • no. of hl-cycles i = 0.70					• experience rate: L = 0.853 • no. of doublings of the accum. output: i = 3.048
	Jan. 1989	40,000 h	1,200,000.-- DM	8	

"improvement of cost driver" **"financial impa**

causes:
continuous reductions of manufacturing time (= dynamic organizational learning) →

effects:
real manufacturing costs decrease with every doubling of the accumulated output potentially by (1-L) %

Exhibit 5: Link between Experience Curve and Half-Life Model at Airbus Industries (assumption: 1 manufacturing hour costs DM 30.00)

In January 1976 the first airbus model was built with a total manufacturing time of 340,000 hours. Within four years the manufacturing time has been reduced to 65,000 hours. According to the basic half-life model we can calculate the half-life time t_H between the years 1976 and 1980 to:

(17) $$t_H = \frac{\left(t - t_0\right) \cdot \ln \frac{1}{2}}{\ln Y_t - \ln Y_{t_0}} = \frac{(5-1) \cdot \ln \frac{1}{2}}{\ln 65 - \ln 340} \approx 1.676 \text{ years (20.1 months)}.$$

Corresponding with this, the number of realised half-life cycles i can be determined as follows:

(18) $$i = \frac{t - t_0}{t_H} = \frac{5-1}{1.676} = \frac{\ln 65 - \ln 340}{\ln \frac{1}{2}} \approx 2.387 \text{ half-life cycles}.$$

The reduction in manufacturing time could be considered to be a ”driver” of potential cost reductions. Using the concept of the experience curve, the realised cost reductions could be calculated. Between the years 1976 and 1980, Airbus Industries has built 104 aircrafts. Following the principle of the experience curve, this leads to a number of doublings of the accumulated production volume as follows:

(19) $$104 = 1 \cdot 2^n \Leftrightarrow n = \frac{(\ln 104 - \ln 1)}{\ln 2} = 6.70$$

In the example shown in Exhibit 5, it is assumed that 1 manufacturing hour costs 30 DM. Furthermore, it is supposed that the manufacturing time in the years 1976, 1980, and 1989 was measured in January of each year. By multiplying the manufacturing time in the years 1976 and 1980 by the cost rate of 30 DM per hour, we get the total manufacturing costs per year. With this data we could easily calculate the learning rate L for the time period between the four years 1976 to 1980:

(20) $$K_{1980} = K_{1976} \cdot L^n \Leftrightarrow L = \sqrt[6.70]{\frac{1,950,000}{10,200,000}} = 0.781$$

The average learning rate of L = 78.1 % led to a reduction of the manufacturing time since the production has started. The real manufacturing costs of Airbus Industries show with every doubling of the accumulated production volume a reduction of (1 - 0.781) = 21.9 %.
Based on this practical example, we can see a general link between the half-life model and the experience curve: If a company has to reach a certain cost level within a limited time period, and if the relevant cost drivers have been identified, we could measure continuously with the half-life model, whether or not the targeted cost level could be realised within the actual organizational structures of a company. In the case of Airbus Industries, the management, for example, knew that a reduction of manufacturing costs from 10.2 million DM down to 1.95 million DM could be achieved only if the number of manufacturing hours could be brought down from 340,000 hours to 65,000 hours within the time period from January 1976 to January 1980. On the assumption that those cost savings could be reached by continuous process improvement, then we could derive, by the use of the half-life model, target values for the manufacturing time of 170,000 hours in September 1977 and 85,000 hours in May 1979.

In the same manner, we can show that a half-life time of t_H = 12.849 years should be realised between January 1980 and January 1989. A closer look at the empirical data shows that the learning speed of the realised improvements decreases. From this, a further reduction of the manufacturing time from 65,000 hours down to 40,000 hours can be derived. Multiplied by the cost rate of 30 DM per manufacturing hour, Airbus Industries could reduce its manufacturing costs from 1.95 million DM down to 1.2 million DM. Within the years 1980 to 1989, the real manufacturing costs of Airbus Industries have been reduced with every doubling of the accumulated production volume at an average rate of (1 - 0.853) = 14.7 %.

It becomes obvious, that savings in manufacturing costs can be effected by corresponding reductions in manufacturing time. In other words: Future improvements of financial results are directly linked with improvements of the corresponding non-financial performance driver.

By using the half-life concept we could shape the cost drivers according to the improvement which is necessary to reach a certain cost level. Thus, even in stagnating or declining industries we could control targeted cost reductions, neglecting the low levels or the absence of doublings of the accumulated production volume. A comparison of planned levels and realised levels of a specific cost driver shows precisely whether or not a certain intensity of quality improvement is sufficient to reach the targeted cost level or if further adjustments in the resources available are necessary.

6 Conclusion

The half-life model provides a useful tool to shape the non-financial cost drivers of a company towards a competitive level. In combination with the experience curve, the financial impact of continuous improvement projects can be evaluated.

However, the evidence given by the results of both the half-life model and the experience curve depends on the stability of the organizational structures in a company. In the case that relevant changes in the operational structure are carried out (e.g. by process reengineering or by a change in the management) the cost, time, and quality parameters used as input variables by both models will change. Thus, the half-life times and the learning rates would have to be re-determined. Therefore, the applicability is limited to processes with fixed structures. A further problem with the application of the half-life model is the focus on just one single parameter of performance. In some cases, existing interdependencies between different performance measures need to be accurately determined, e.g. (among others) cost, time and quality parameters might change due to continuous improvement projects. Therefore a too narrow-sighted focus might result.

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