Economic reasoning for Asset Health Management Systems in volatile markets

Katja Gutsche[1]

[1]*Hochschule Ruhr West, Mülheim a.d.R., 45473, Germany*
katja.gutsche@hs-ruhrwest.de

ABSTRACT

With respect to the growing demand in asset reliability, availability, maintainability, safety and productivity (RAMS-LCC) diagnosis and prognostic asset health management (PHM) systems provide more detailed asset health information which allows improved maintenance decision-making. This gives the opportunity for a more efficient, safer system operation (e.g. aircraft, production facilities) and therefore a more competitive enterprise. Of course, the implementation and use of PHM causes recurring and non-recurring costs, which have to be at least covered by the savings due to benefits achieved by cost avoidance through better asset health knowledge. The economic justification is essential for a positive decision upon the installation of PHM. This becomes more complex as the benefits depend on the operation circumstances which then are strongly influenced by the market situation. The market situation is strongly determined by the market demand, number of competitors and speed of technological changes. As these parameters are especially relevant in the producing industry, this shall be the system of choice in this paper. The question to be raised is how much the economical attractiveness of PHM systems correlates with an increase in market impermanence as to be seen globally in most market segments.

1. INTRODUCTION

Asset health plays a tremendous role for the production efficiency as well as system safety and therefore for the competiveness of especially asset intensive enterprises. Asset intensive enterprises are characterized by a higher number of industrial facilities needed for the production process which in addition are generally cost-intensive in investment. This becomes even more important in a global economy where profit margins decrease and customer satisfaction has to be constantly on a high level. In addition, there are technical changes as there is an

- Increase in automation,
- Increase of system and asset chaining,
- Increase of asset complexity,
- Increase in availability requests.

As a consequence, the relevance of health management systems is further increasing.

Their economic benefits have been outlined in several publications as e.g. (Banks & Reichard & Crow & Nickell, 2005), (Banks & Merenich, 2007), (Feldmann & Sandborn & Taoufik, 2008), (Al-Najjar, 2010). (MacConnell, 2007) lists the following as the major benefits:

1. Maintenance time savings,
2. Failure reduction,
3. False alarm avoidance,
4. Availability improvement – increase mean time between maintenance actions,
5. Spare and supply savings.

There is no doubt that in sum prognostic and health management (PHM) decreases the efficiency loss caused by maintenance management driven by time or organizational restrictions rather than the use of detailed asset health knowledge, mostly expressed using wear-out stock. Wear-out stock (compare DIN 13306) defines the health of an asset. It indicates the degradation speed to the point where it can no longer operate in a safe and proper way. The wear-out stock (WS) is assumed to be high at the beginning (Time t = 0) of system use (WS_0) and decreases due its use. Unless maintenance actions are undertaken the WS decreases to a critical value (WS_{min}) where the asset can no longer be maintained and has to be replaced in order to work properly again. If the maintenance management is done purely on a time base with no regard to the current system degradation status, the value creation through the productive system gets diminished. Figure 1 shows the reason for efficiency loss in traditional time-based maintenance management. Maintenance actions are undertaken far before the limit wear-out stock (WS_{min}) is reached because of no clear asset health data. The asset lifetime becomes reduced. In sum the premature undertaking of maintenance reduces

- the potential time of use (T),
- the potential output (e.g. production units)

and increases

- the number of maintenance activities.

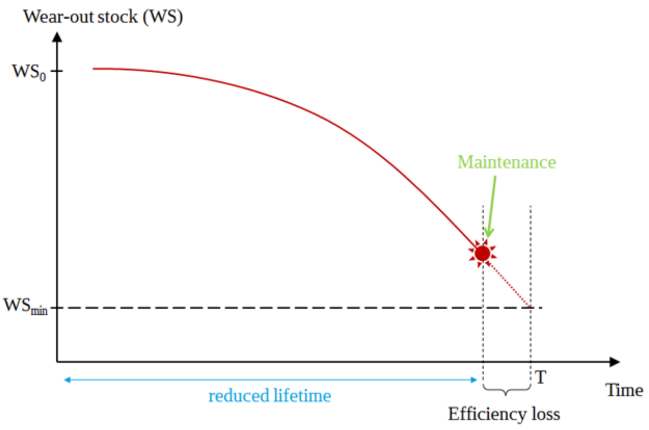

Figure 1. Maintenance efficiency loss

Besides the optimization of preventive maintenance tasks the use of PHM also improves the failure time line (figure 2). This is because either there is a pure prevention of failure or there is a reduction of downtime because of detailed asset health information. Firstly with the asset health information the time till maintenance work starts gets reduced due to faster fault identification. Secondly the information from PHM systems decrease the time needed to actually refit.

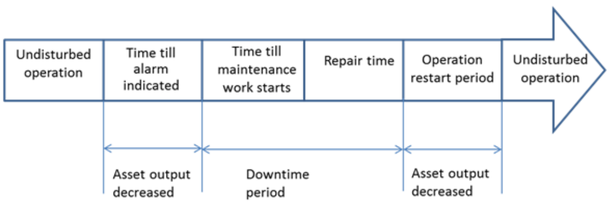

Figure 2. Failure time line

Apart from these numerous positive effects of PHM, there are also challenges which have to be managed, as there are e.g.:

- A large amount of special data is generated by the PHM.
- Mostly selection and interpretation of most relevant data is not done by the system.
- Decision making becomes more complex for the maintenance person in charge.

These challenges are listed at this point but will not be further analyzed at in this paper.

2. MOTIVATION

The economic attractiveness of PHM systems depends on the result of a cost-benefit analysis. This depends on the difference between the cost savings and the additional costs due to their implementation and use (section 1).

PHM has a notable effect on the asset availability which can be measured through (Wheeler & Kurtoglu & Scott, 2010) (Al-Najjar, 2010) (figure 3):

- Reduction in (unplanned) stoppages,
- Increase in mean time between maintenance actions,
- Reduction of labor mean-time-to-detect,
- Reduction of repair times,
- Reduction of maintenance induced failures

and has therefore a positive effect on the direct and indirect maintenance costs which are mainly dependent on the maintenance time parameters as well as needed number of spare parts, cases of secondary damage and work accidents.

Figure 3 demonstrates the potential effect of the implementation of PHM systems (scenario 1) compared to their non-use (scenario 0) on the asset availability level (increasing) and the maintenance costs (decreasing).

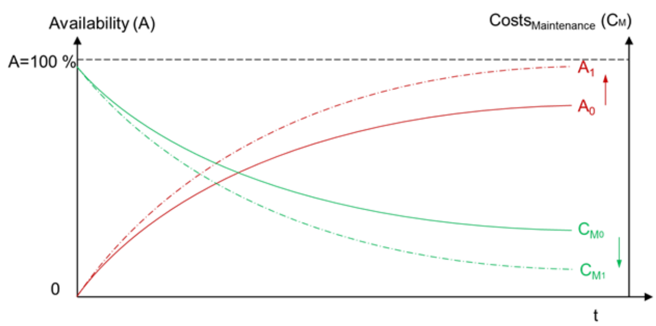

Figure 3. Effect of PHM implementation

Seen from a life-cycle perspective PHM causes development, implementation, operation and maintenance expenses. Moreover prognostics may also cause false alarm but this shall not be looked at in this paper.

Table 1 lists the major potential costs and benefits of a PHM system application. Especially in the beginning investments have to be made before actually using the system for asset health monitoring. The investment expenses are determined by the software and hardware components, the installation and testing complexity as well as the needed staff training. During the period of PHM system use there are cost positions due to the data management and its maintenance. The potential benefits have been outlined in detail in the sections before and shall only be listed at this point.

Costs	Benefits
Software	Reduction in failure rate*
Hardware	Reduction in downtime
Training	Decrease in quality rejections*
Installation & testing	Reduction in spare parts*
Data management*	Reduction in accident compensations*
PHM system maintenance & updates	Decrease in lifetime loss

Table 1. Costs and Benefits of PHM (*value dependent on operation circumstances)

Their actual value is variable due to probabilistic behavior of assets and their failure regime, the technical characteristics of the PHM (self-learning etc.) and their usability. Apart from these uncertainties which have to be taken into account when deciding on PHM, the overall result of the implementation of PHM depends on the operation intensity:

How tight is the operation schedule for the asset to be monitored with regard to the customer needs?

The relevant operation circumstances in producing industries can be expressed in

- Available realization time (e.g. time until product delivery),
- Number of waiting jobs,
- Number of shifts/ operation intensity.

These parameters change more often due to more market volatility. Market volatility is defined as the magnitude of short-term fluctuation in a time line compared to its mean value or a defined trend curve.

Figure 4 shows the development of the German Gross Domestic Product (GDP) adjusted for prices between 1951 and 2008. It illustrates that the economic cycles became shortened; hence the markets are more volatile. This has major effects on the manufacturing industry and in consequence on the operation circumstances and finally on the cost-benefit result of the use of PHM systems.

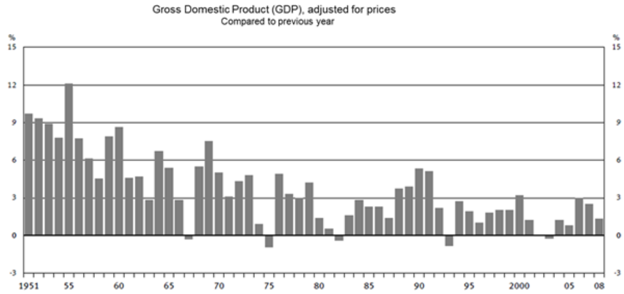

Figure 4. Market volatility (Statistisches Bundesamt, 2009)

3. Economic reasoning in volatile markets

Whereas the costs listed in table 1 stay relatively stable no matter how the operation circumstances change (data management expenses increase due to more data volume), the value of the potential benefits increases with a decrease of available realization time and an increase in waiting jobs and operation intensity.

3.1. Value of availability

The value of a gain in availability changes depending on the operation circumstances. This value correlates with the failure costs. Failure costs are

- Costs of decreased output before and after downtime,
- Costs due to the downtime period (downtime costs) (see figure 2),
- Opportunity cost,
- Loss in asset value.

(Biedermann, 2008) outlines that the failure costs correlate with the percentage of downtime of overall asset lifetime and the level of use of the producing asset capacity (figure 5). In case of a constant percentage of downtime the failure costs decrease when the use of asset capacity use decreases. Illustrated with an example:

A manufacturing plant either works a) 24 hours/day (100% use of asset capacity) or b) 18 hours/day (75% use of asset capacity). The output per hour is 1unit worth 500 €. In case of a failure lasting one working day (downtime) the loss in production (failure costs) is in a) 24 * 500€=12.000€ and in b) 18 * 500€=9.000€.

The level of use of the asset capacity is one parameter describing the operation circumstances. As the level of capacity use depends on the operation intensity which is depending on the market demand (high demand – high use level), the cause-effect chain can be summed up in the following way:

market situation ↓→ use of asset capacity ↓→ failure costs ↓ → value of availability↓

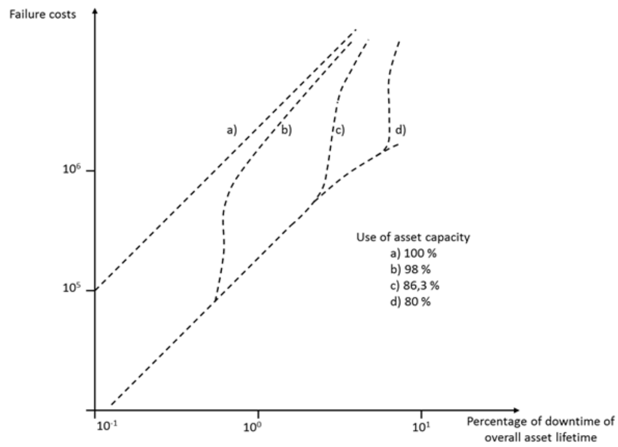

Figure 5. Value of non-availability in producing industries (failure costs) (Biedermann, 2008)

3.2. Volatility gap in availability savings

With a change in market there is a positive or negative effect on the manufacturing industry. The change in product demand directly influences the manufacturing asset. Depending on the positive or negative change in the market, the asset work load increases due to a higher product demand and decreases when there is a decline in market demand. These scenarios are outlined in figure 6, upper part. During an economic upturn the asset is used to its maximum. The asset work load is adjusted when there is less demand for the product or service. Corresponding to the development in asset work load there is a change in availability savings (S_A) (figure 6, lower part). If the asset is always used to assumed high level and there is no change in market demand the value of savings through availability increase due to the use of PHM systems (S_{Anv}) is higher than when there are changes in market parameters, expressed by a higher volatility (S_{Av}).

Comparing these two scenarios a so-called volatility gap in savings through the use of PHM systems evolves.

As the saving in availability is directly linked to the benefits of PHM systems, the cause-effect chain in section 3.1. can be extended in the following manner:

market situation ↓→ use of asset capacity ↓→ failure costs ↓ → value of availability↓ → benefit of PHM systems ↓

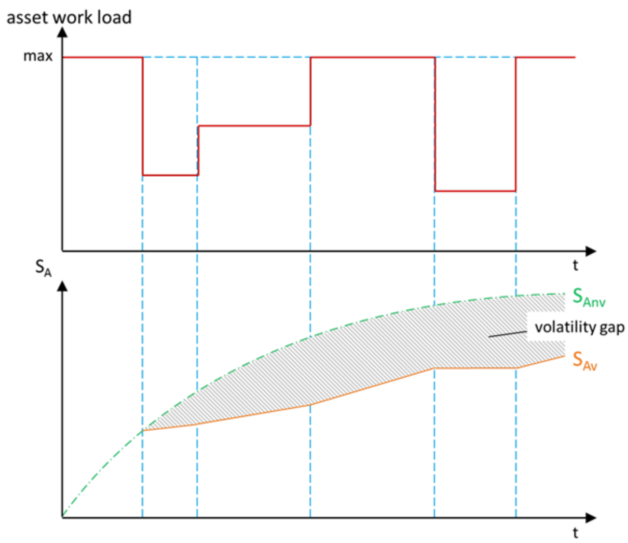

Figure 6. Effect of volatility on savings through availability increase SA

3.3. Numerical example

To highlight the importance of market effects on the economic attractiveness of PHM systems a numerical example will be outlined.

The following assumptions shall be made:

Use period [years]	10
fault time per year [% of operating hours]	1
value of downtime [€/per hour]	150
fault prevention rate through PHM system [%]	20

Table 2. Numerical example - assumptions

The volatility gap shall be shown by comparing the following two scenarios

Scenario A: constant operating hours of two shifts of 8 hours on 365 days per year = 5840 h/year = maximum use of asset capacity

Scenario B: Changing operating hours (see table 4, column 2).

Table 3 and table 4 show the potential availability savings through the use of PHM systems. As in scenario B the asset is not used to its full extend the sum of availability savings is lower than in scenario A (13.578 € < 17.520 €). The difference of 3942€ represents the volatility gap indicated in figure 6.

		sceanrio A		
Year	operating hours	fault periods per year [h]	fault reduction through phm [%]	Availability savings [€]
1	5840	58,4	11,68	1752
2	5840	58,4	11,68	1752
3	5840	58,4	11,68	1752
4	5840	58,4	11,68	1752
5	5840	58,4	11,68	1752
6	5840	58,4	11,68	1752
7	5840	58,4	11,68	1752
8	5840	58,4	11,68	1752
9	5840	58,4	11,68	1752
10	5840	58,4	11,68	1752
				17520

Table 3. Scenario A – maximum use of capacity, no volatility

		sceanrio B		
Year	operating hours	fault periods per year [h]	fault reduction through phm [%]	Availability savings [€]
1	5840	58,4	11,68	1752
2	5548	55,48	11,096	1664,4
3	5256	52,56	10,512	1576,8
4	4964	49,64	9,928	1489,2
5	4672	46,72	9,344	1401,6
6	4380	43,8	8,76	1314
7	4088	40,88	8,176	1226,4
8	3796	37,96	7,592	1138,8
9	3504	35,04	7,008	1051,2
10	3212	32,12	6,424	963,6
				13578

Table 4. Scenario B - changing use of capacity and market volatility

4. SUMMARY

The integration of a health management system is primarily based on the economic reasoning. PHM provides failure predictions, reduces the downtime, expands the maintenance intervals and therefore decreases the efficiency loss in maintenance and increases the system availability. However, PHM causes investment expenses and recurring costs for the PHM system sustainment. Whereas the latter are mostly independent of the market situation in which the operator uses the asset to fulfill customer demands, the potential benefits strongly depend on the operation circumstances (e.g. working shifts, time buffers within the production line, stock of semi-finished products).

As there is not only a higher level of competition within the markets but also more volatility (e.g. steel production) which strongly influences the operation circumstances, these dynamic effects have to be taken into account when deciding on the introduction of a PHM system.

This paper outlines the effect of market volatility on the economic reasoning of the use of PHM systems. Depending on the market situation the volatility gap describes the cost avoidance due to higher system availability. The value of cost avoidance then depends on the level of use of asset capacity.

In volatile markets modular PHM systems may be an option. These systems allow a downsizing. Instead of installing the all-embracing PHM system, modular systems offer the big advantage of being sizeable according to the actual operation constraints (e.g. number of sensors and interpreting algorithms). This allows a downsizing of recurring costs for the health management system and makes them more flexible with respect to the increase in market volatility.

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