On the Economics of Asset Management

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Abstract

Asset Management is about realizing value from physical assets. To do this, money has to be invested in physical assets (purchase, maintenance, consumables, etc.) thus producing a specific technical performance for each asset over its lifecycle. The technical performance then allows to realize value for the owner. This can be either a monetary value (e.g. for a production firm that can sell products) or a non-monetary value (e.g. for a utility that can provide a reliable electricity supply).

We examine the nature of physical assets as investment objects and derive some conclusions on optimal investment strategies. We develop a general model for physical assets as investment objects, simultaneously describing both the life cycle cost structure and the value realization under different operational policies. We show that physical assets are investments that have properties which distinguish them from classical financial investments such as bonds, stocks, or the like. In particular, the non-proportional relation of investment and value creation has important implications for the derivation of optimal investment strategies.

We apply the framework to the problem of budget allocation in a portfolio of physical assets. The model allows the calculation of the optimal allocation such that the total value creation is maximized. It turns out that the solution is similar to the well-known Equimarginal Principle. We also re-examine a classical optimization problem from the maintenance literature and show that the classical solution may lead to wrong results because assets are regarded in isolation instead as part of a larger system of investment options.

Since our approach combines both the cost and the value generation aspect of physical assets, and includes operational lifecycle policy decisions, it could form the conceptual basis for a new approach to asset management.

Keywords: Physical asset management, investment strategy, asset portfolio, value creation.

1. Introduction

In recent years, we observe a shift from maintenance management to what is now called (Physical) Asset Management. More and more researchers and practitioners are getting interested in the relatively new field of asset management. Historically, physical asset management has its roots in maintenance management. However, in many cases the term physical asset management is used to emphasize a wider perspective on the management of technical assets during their lifecycle, starting with the decision to purchase the asset, and including all activities along the lifecycle (see for example Amadi-Echendu 2010, Lloyd 2010, Campball and Jardine 2011, and references therein).

A major issue concerning an optimal life-cycle management of physical assets is the question how to invest in physical assets such that the benefit for the asset owner is maximal. Most of the classical approaches solve this problem by minimizing the life cycle costs for the management of each individual asset (Lloyd 2010, Hastings 2010). Moreover, the decisions are usually optimized irrespective of other investment options (i.e investments in other than physical assets) that could possibly yield profit for the owner. This approach of naïve single asset cost minimization may lead to erroneous conclusions and sub-optimal decisions regarding the management of physical assets

In this paper, we focus on physical assets under a general *investment perspective*: Assets are seen as objects that require financial investments, and, in return, deliver some value for the firm. We examine the nature of physical assets as investment objects and derive some conclusions on optimal investment strategies. In contrast to the classical literature, we explicitly consider the investment in physical assets in a context of multiple investment options. A firm always has different options of investing its money – investing in physical assets is only one of these options. Even if the total investment in assets is given, the allocation among different physical assets has still to be determined. So, the question has to be answered how much has to be invested in physical assets as opposed to the other investment options, and how the total investment in physical assets should be allocated to the different assets of a portfolio.

The decision on an optimal investment level is crucial. As we will show, this decision determines:

(a) a specific life cycle operation policy
(b) a specific level of the average cost rate
(c) a specific level of the average value creation rate

In other words, the decision on the investment level provides the basis for the optimization of the entire life cycle asset management.

The paper is structured as follows: In Section 2, we develop a general model of physical assets as objects that require financial investment and deliver some value. In Section 3, we re-examine the investment process itself. In Section 4, some conclusions on optimal investment strategies are derived. In Section 5 and 6, we show two applications of the theory. We show the difference of our proposed approach and the classical maintenance theory, and we show that the derived principles of investment can be used for managing asset portfolios.

2. General model of physical assets as investment objects

In this section, we derive a general model of physical assets as investment objects. We start with the basic question: What is a physical asset? Technically speaking, an asset is a system with some well-defined technical properties, for example a production machine, or an electrical transformer. However, in the framework of physical asset management, an asset is basically an object that creates some costs, and at the same time generates value for the owner by its usage in a specific business environment. More precisely, it is the technical performance of the asset, embedded in a business process, that generates the value for the owner. Any model of a physical asset should include both the cost generation and the value creation of the asset.

The value and cost generation do not only depend on the nature of the asset itself, but also on the policy with which the asset owner chooses to manage the assets (e.g how much to invest in maintenance, how long to use the asset).

Below we first define the meaning of cost and value in the present context, and then relate these two aspects of asset management to the third important aspect: the operation policy.

2.1 Value and Costs

There is some risk of confusion with the term "value". Often, when speaking of the value of a technical asset, this term denotes the book accounting value, which is derived from the purchase price minus the write-offs. However, this book value is quite different from the business value. In the context of the current paper, the term value is used for denoting the business value, i.e. the reason why the asset has been purchased and installed in the first place. This value may be the ability of generate revenues in the case of a production machine, or the ability of transport electrical energy in the case on an electrical power line.

Also, the notion of value as used in this paper has nothing to do with “At which price can we sell the piece of equipment on the market?”, which is another frequently used definition of value. In many cases, physical assets cannot be sold after the installation, or only at prices that are much lower than the purchase price. This is especially true for infrastructures: A buried water pipe cannot be dug out and sold, and an electrical power line has nearly no material value. So while there might be no market value of the asset itself, it still can have a large value for the business.

The actual meaning and definition of “value” depends on the context and the business strategy of the asset owner. In a dynamic manufacturing environment, for instance, the value of a machine may be an increased production rate. It also might be added flexibility. For a public infrastructure, the value of an asset might be defined as the ability to deliver a specific supply quality. In all cases, however, the value is created during the usage of the asset during its life cycle, so essentially we have a value stream or value creation rate.

The value itself may be monetary (e.g. an increased production rate has a monetary value for the firm) or non-monetary. Our model will be formulated for the general case and does not require the value to be monetary. We assume that a definition of value is given, and the relation between the technical performance of an asset and its value generation is known. In practice, this is a mathematical function that may include many different aspects, including technical ones. In Heitz and Sigrist (2013), some examples are given.

Note that the business value depends not only on the asset itself, but also on the technical and business environment of the asset. A production machine, for example, can have a high value if the items that are produced with this machine can be sold with a high profit. The same machine has no value at all when the market collapses and the produced items cannot be sold any more. In the following, we assume that the technical and business environment are given.

The cost side is typically easier to assess. The costs include all costs elements during the lifecycle, beginning with the acquisition and installation costs, continuing with maintenance and other life-cycle costs such as energy costs, failure costs, and so on, and ending with the costs for disposing the asset, or reselling it.

Note that both cost and value generation rates may change over time. For example, we typically have a cost peak at the beginning of the lifetime when the initial investment costs have to be made. Failure costs appear in late stages of the life cycle. As for the value generation, typically the value generation decreases over time due to aging. Also, changes in the general business environment may have drastic effects on the value generation, for example in the case where the technical performance of the asset has no longer a market value.

In the framework of this paper, we take a lifecycle perspective, and consequently average over the entire lifetime when considering costs and value generation. We denote the average costs rate with c, and average value creation rate with v. Note that the unit of c is “money per time unit” (e.g. $/year), while the unit of v is “created value per time unit” which may be expressed in non-monetary units.

2.2 Cost/Value generation and Operations Policy

It is important to note that both costs and value creation are not a property of the asset itself but depend on the operations policy. Different operation policies lead to quite different cost and value rates. An important part of the operation policy is the usage time. A longer usage time reduces the annual capital costs, while the average failure rate increases, thus reducing the average value creation rate simultaneously. Thus, both costs and value generation are affected by changes of usage time. This also applies to different ways of performing maintenance activities during the life cycle of the asset, or any other operational decisions.

This is a rather important insight because since the owner has many options of how to operate an asset, we cannot assign cost and value to the asset itself, but rather to the asset *under a specific operation policy*. This means that an asset should be seen as an object possessing different cost/value pairs, where the owner has to choose one of them. This leads to our model that describes an asset as a set of cost-value pairs. Figure *1* provides a schematic description of a single asset within this model, where each operation policy is shown as a point in a two-dimensional cost-value space. Note that there may be a continuum of operation policies (e.g. usage times can be choosen continuusly), but for the sake of clarity we use discrete policies here. Each policy i generates a specific average value creation rate v_i and leads to an average cost rate c_i.

The fact that both costs and value creation of physical assets depend on the way of how the asset is operated is in contrast to many classical financial assets. For example, the return of a bond or a stock does not depend on activities of the owner during the time he possesses the bond.

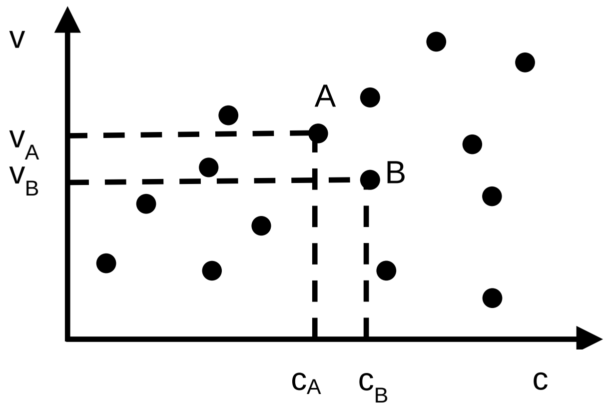

Figure 1. Model of a physical asset as set of different cost/value combinations. Each possible operation policy is denoted by a point in the two-dimensional cost-value space. For example, the policy A leads to average annual costs c_A and average annual value creation v_A.

As an example, we consider an asset that costs 1 M$ for purchase and installation, and has a maximal lifetime of 22 years, if no maintenance is made. Alternatively, a maintenance program can be carried out which reduces the decay of the value generation rate and thus leads to a longer lifetime. This maintenance policy generates cost of 60 k$/yr. The value generation rates of both policies are displayed in Fig. *2*. In this example, the value generation rate is normalized, assigning a value rate of 1 for a new asset.

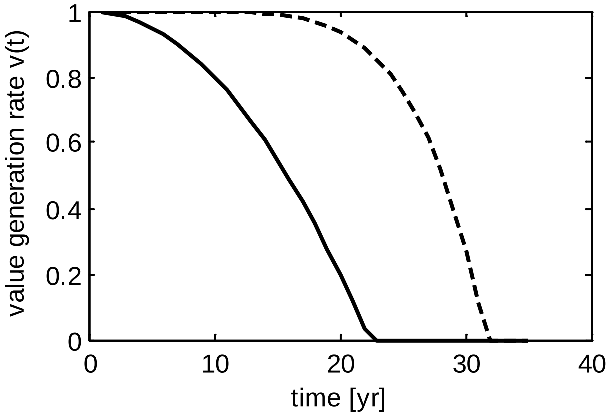

Figure 2.Value creation rate v(t) over the lifetime. Solid line: without maintenance. Dashed line: with maintenance.

In addition to the maintenance policy, the usage time has to be specified as well. In fact, the choice of the usage time of an asset is one important parameter of the operation policy. In Fig. *3*, the resulting plot of v (average value creation rate) against c (average cost rate) is shown for different usage times. Each point corresponds to a specific usage time, while the marker distinguishes between the two maintenance policies.

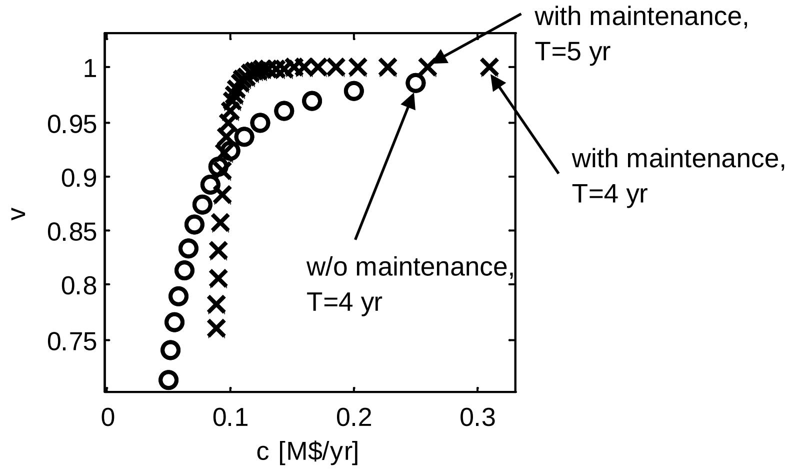

Figure 3. Display of different operation policies in the c-v space. Circles correspond to the case without maintenance, while x correspond to the case with maintenance. Each marker corresponds to a specific combination of usage time and maintenance policy

The cost-value plot shows the performance of the asset in terms of cost and value creation: high cost rates c correspond to a high value creation rate, because a high c means a short lifecycle, and vice versa. It can furthermore be seen that the two operation policies behave quite differently. There is a region where more value is being created with the maintenance program (for average annual costs higher than roughly 0.1 M$/year), where there is another region where the maintenance program essentially leads to an inferior investment performance. For example, if one would like to spend only 0.09 M$/yr on the asset, then the maintenance program does not make any sense. This budget constraint would lead to a usage time of roughly 33 yrs, and an average value creation of 0.8, while in the case of skipping the maintenance program altogether, the same budget would lead to an average annual value creation of 0.91, with a usage time of about 11 years.

2.3 Modelling a physical asset

As explained in the last subsection, we model a physical asset as a set of different operation policies, where each policy corresponds to an average cost rate c and an average value creation rate v. Such a description is helpful for describing the properties of an asset in the context of asset management. It shows both costs and value creation of the asset, but does not require an a-priori decision about the operation policy (which, conceptually, is not a property of the asset itself, but rather a degree of freedom for the owner). All feasible operation policies may be and should be included in the cost-value plot in order to give a full overview on the options of using the asset in the given context.

For example, when we are faced with the task of comparing two different assets for the sake of deciding which one to purchase, the cost-value-plot is a convenient and appropriate way of showing the properties of the assets in an exhaustive way.

We argue that, indeed, this way of representing or modelling an asset is the most compact form possible for asset management, because it is clear that we need both costs and value creation of an asset for assessing it in the context of physical asset management. Since it is also obvious that both costs and value creation are a function of the operation policy, each asset must have different options and thus different cost-value combinations. Displaying them all together leads to a complete picture of what the nature of the asset is.

3. Investing in physical assets

In this section, we want to investigate in a more thorough way what it means to invest in a physical asset. As we have seen in the last section, an asset in a specific business environment is an object that can be described as a set of different operation policy options, each one characterized by an average cost rate c, and an average value creation rate v.

Asset management as an investment decision problem consists of choosing one of these options. Obviously, there are options which do not make sense. For example, policy B in Figure *1* is more expensive than policy A, but results in a lower value generation. So, when faced with the decision problem of which policy to choose, we can sort out all policies that do not lie on the Pareto frontier (for an introduction in multi-criteria optimization and Pareto optimality, see e.g. Censor (1977) or Da Cunha and Polak (1967)). In Figure *4*(a), the Pareto frontier of the schematic asset of Figure *1* is shown. Each policy on the Pareto frontier is Pareto-optimal: There is no other policy in the whole set of policies that generates more value with lower costs. In Figure *4*(b), the Pareto frontier of the example asset of Figure *3* is shown.

Only policies on the Pareto frontier qualify as a possible choice for the investment. Choosing a policy on the Pareto frontier makes sure that, for the budget c of this policy, there is no other policy that generates more value. In this sense, the policies of the Pareto front are all optimal.

Choosing an investment option means deciding on a specific policy, that leads to a specific investment c. We may decompose this investment into a sequence of partial investments: We start with the leftmost policy (i.e. the policy with minimum annual costs), and increase the investment stepwise by adding annual budget.

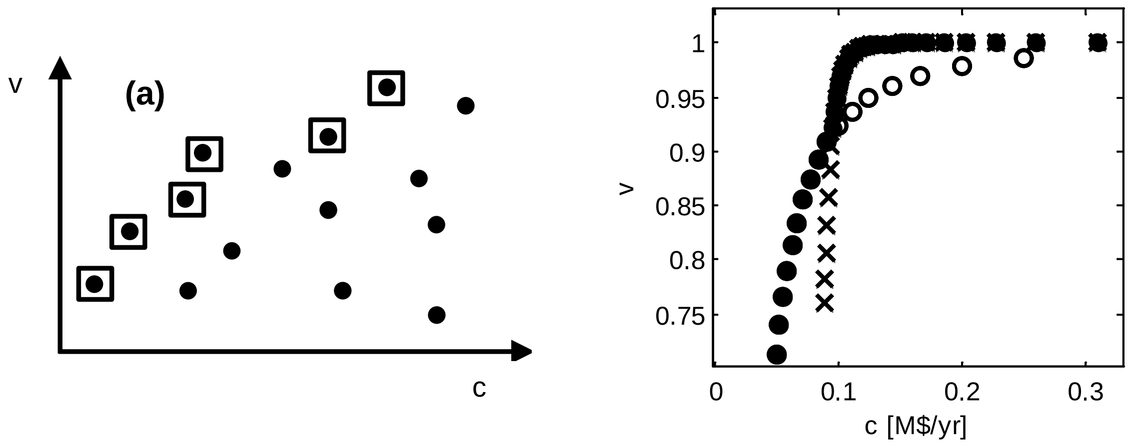

Figure 4. (a) The Pareto frontier of the asset of Figure 1: The dominating policies are denoted by surrounding squares. (b) Pareto frontier of the asset of Figure 3, denoted by black filled circles.

In Figure *5* (a), we start with policy A, with corresponds to an initial investment. Note that policy A may be the origin (c,v)=(0,0) if it is an option not to have the asset at all. The second partial investment might, in principle, lead from A to B, to C, or to any other policy. In order to get the maximum return for this second investment, one should choose the partial investment that generates the maximum added value per invested dollar. This requirement leads to the selection of the partial investment leading to policy B. The third partial investment leads to policy D, after which it is policy F that is chosen (see Figure *5* (b)).

So, if there is no budget restriction, the requirement to invest the money such that the maximal return is generated for each partial investment leads to a subset of policies on the Pareto frontier, which we call the optimal-investment frontier. The stepwise investment leads to a sequence of partial investments investments Δc_i (i=1,2,…) which each generate an added value contribution Δv_i.

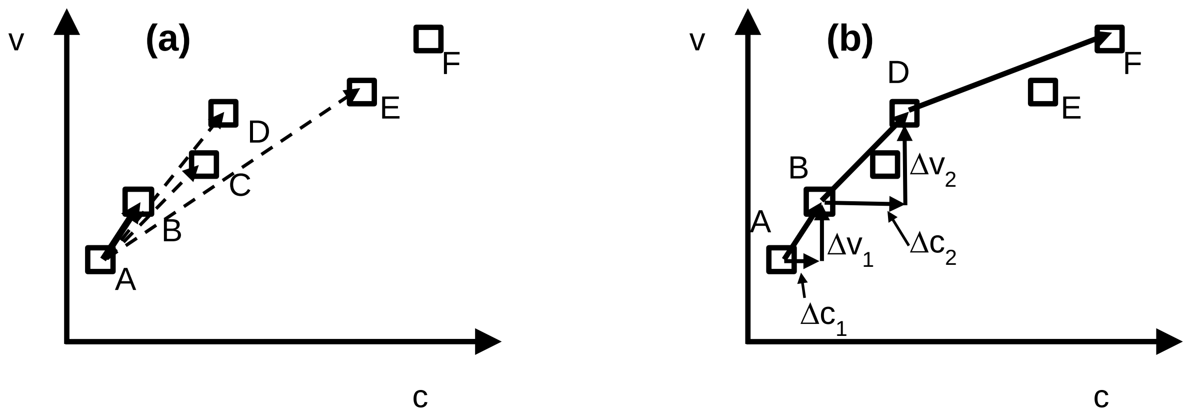

Figure 5. An investment in a physical asset may decomposed in a sequence of partial investments. (a) After the initial investment for policy A, the second investment step may lead to any other policy. However, policy B yields the maximal added value per invested dollar. (b) Sequence of optimum partial investments with decreasing returns.

We call the ratio of added value and partial investment the Marginal Cost Effectiveness MCE (cmp. e.g., Uddin et al, 2013).

$$MCE_i = \frac{\Delta v_i}{\Delta c_i} \qquad (1)$$

Note that, in general, MCE is not a dimensionless quantity such as the return-on-investment (ROI). It has a physical dimension which is value unit/cost unit. For example, in the case of supply infrastructure, the value may be measured in terms of supply quality. Here, MCE has the unit SupplyQuality/$. More specifically, the MCE of a partial investment denotes the added supply quality per additionally invested dollar.

Note that the sequence of partial investments has strictly decreasing MCEs. So, when interpreting a physical asset as an investment object, we may conclude:

> *A physical asset is an investment object that can be modelled as an object with a minimum investment, followed by a sequence of partial investments with decreasing MCEs. Investing in a physical asset can be regarded as a process of sequentially allocating more and more money to the asset up to a specific level. The final investment level determines*
> *(a) a specific operation policy*
> *(b) a specific annual cost level, c, and*
> *(c) a specific level of value creation v*

This perspective on physical assets as investment objects lead to two important observations.

The first observation is that there is a second fundamental difference of an investment in physical assets and investment in classical financial assets. Financial assets such as saving accounts, bonds, stocks, futures, etc., all have a linear return characteristic: Doubling the investment sum means doubling the return, and the return is always proportional to the investment height. This is no longer valid for physical assets. Here, the higher the investment level, the lower the return-on-additional-investment, assuming that we always choose optimal-investment policies. This means that, in contrast to classical financial assets, the absolute height of the investment has to be taken into account, and the return on investment in terms of value generation is a function of the investment level. Describing the investment object with simply a relative ROI (such as ROI=5%) is not appropriate. This is a very far-reaching property of investment in assets, which will become clearer in the application examples of the next sections.

The second observation is that an asset still has different possible levels of investment, from which one has to be chosen. The asset itself does not predetermine the investment level – it is a decision made by the asset manager how high the (annual) investment will be. The investment level is mainly determined by the decision on the usage time, but other decisions on the operation policy may be important as well (see Figure *4*). In general it holds that the higher the investment, the higher is the generated value. Let's consider again the case of public supply infrastructure. Here, the higher the annual investment, the higher the value which is created for the citizens in terms of supply quality (provided, of course, that for each investment level the optimal operational policy is chosen). However, the higher the investment, the smaller is the added value per additionally invested dollar.

Note that there may exist a policy with a maximal value generation. In this case, there is a maximal investment level that should not be exceeded since this would lead to a lower value generation. However, such a policy does not always exist. In many practical cases, there is an infinite number of policies with ever increasing value, though often limited. The asset displayed in Figure *3* is an example.

Using this model of a physical asset as investment object, different important problems in physical asset management can be solved. In the next two sections, we discuss two important applications.

4. Application: Optimal allocation of an annual budget in a portfolio of physical assets

In the first application example we demonstrate that our model provides the basis for a novel method for the solution of budget allocation problems that are central to asset management.

We consider a firm with a portfolio of physical assets. We assume that the firm has a given annual budget B that can be used for financing the asset portfolio. Assets are replaced by identical assets after their usage time, where the usage time of each single asset as well as other operational policy decisions are control parameters. Furthermore, we assume stationary business conditions. The goal is to maximize the value generation of the asset portfolio.

Such a case is typical for public infrastructures such as water or electricity supply. Often, the annual budget has been determined in a political process, and has to be considered as a fixed quantity. The task of the asset manager is to invest this budget in an optimal way such that the most value is generated. The value is typically measured by some sort of measure of supply quality, for example with KPIs such as SAIFI (system average interruption frequency index), SAIDI (system average interruption duration index), or the like.

We assume for simplicity that the total value generation consists of the sum of individual value contributions, one for each asset. The total costs are assumed to be the sum of individual asset costs:

$$v_{tot} = \sum_i v_i \qquad c_{tot} = \sum_i c_i \tag{2}$$

Each asset i has an investment characteristic as explained above, with a set of policies defining the optimal-investment frontier, and each asset has a minimum investment level m_i. We assume that

$$B > \sum_i m_i \quad . \tag{3}$$

The goal is to find the optimal allocation of the total budget to the different assets, such that the total generated value is maximized, given the boundary condition

$$c_{tot} \le B \quad . \tag{4}$$

This is a classical integer optimization problem. It can be shown that a near-optimal solution can be obtained by the following sequential procedure:

1. Allocate the minimum investment level m_i to each asset i. Reduce the available budget by $\sum_i m_i$
2. For each asset: calculate the MCE for the partial investment leading to the next investment level on the optimal-investment frontier.
3. Find the asset with the highest MCE. Say this is asset j.
4. If the available budget is greater than the necessary amount for the partial investment of asset j, then
   a. Increase the investment in asset j by this partial investment
   b. Reduce the available budget by this amount
   c. Go to Step 2.

   If the remaining budget is smaller than the necessary amount for the partial investment of asset j, take the asset with the next smaller MCE and go to start of step 4.
   If there is no partial investment that can be done with the available budget, then stop.

For the case of a continuous optimum-investment frontier, the optimum solution is given by the Equimarginal Principle, also known as Gossen's Law (Gossen 1983). The Equimarginal Principle states that the optimum allocation is characterized by the fact the derivative $\frac{dv}{dc}$ is equal for each asset.

Note that the problem of optimal allocation is an investment problem, but it cannot be solved by optimizing each asset individually. The central issue is not to find an individually defined optimal investment level for each asset. In contrast, the optimal investment levels are found by comparing different partial investment options (for the different assets) and choosing the best one. The basic property which is used is the concavity of the optimal-investment frontier, i.e. the fact that returns are decreasing with increasing investment.

The allocation problem is one of the central problems of physical asset management, and the current asset management literature seems to have limited solutions for it (Uddin et al. 2013, Colin at al. 2010). However, with our modelling approach, this problem can be solved easily.

The authors have performed several case studies with public infrastructure operators in the last years. It could be shown that large improvements can be realized by optimally allocating the budget according to the described method, compared with classical asset management strategies.

It should be noted that the simplifying assumption on the additive structure of the value function can be relaxed. However, it is beyond the scope of this paper to describe the approach in this more complex case.

5. Application: Optimal usage time for ageing assets

In another application of our framework, we re-examine a classical problem of maintenance management and show that the well-known classical solution can yield a sub-optimal result.

We consider a manufacturing machine generating an annual profit of p under the assumption of no failures. Due to ageing, however, the machine shows an increasing failure rate over time, which gradually reduces the profit due to the associated failure costs. The task is to determine the optimal lifetime T of the machine. A too short lifetime is associated with high capital costs, where a too long lifetime is associated with high failure costs. The optimal lifetime is in between these extremes.

The classical approach is to calculate the average total costs per time unit as a sum of capital costs and failure costs. This cost rate c(T) is a function of the usage time T:

$$c(T) = \frac{1}{T}\left(C_0 + C_f \int_0^T h(t)\, dt \right) \tag{5}$$

(C_0 denote the purchase and installation costs, C_f the costs per failure, and h(t) the failure rate), and to minimize this total cost rate c with respect to T:

$$c(T) = \min . \tag{6}$$

Obviously, using the optimal T leads to the highest total profit per time unit, which is given by the difference of p-c(T). In Fig. *6*, the classical cost minimization approach is shown for an example with C_0=10, C_f=1, and a linearly increasing failure rate of $h(t)=0.1 \cdot t/yr^2$. It can be seen that the minimum of the total costs is obtained at a usage time of 14.1 yr. With this usage time, a cost rate of 1.42/yr is obtained, consisting of capital costs of 0.71/yr and failure costs of 0.71/yr.

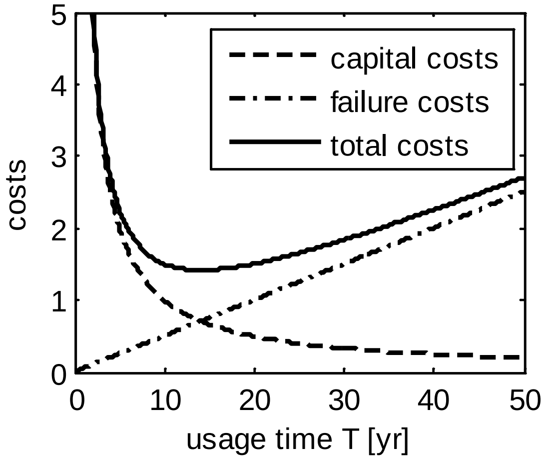

Figure 6. Classical cost minimization for an ageing manufacturing machine

We now reformulate this classical problem in our framework of cost and value. The value of the manufacturing machine for the owner is the actually made profit, which is the theoretical production profit p minus the failure costs. As for the costs, we use the capital costs.

$$\begin{aligned} v(T) &= p - \frac{1}{T}\left(C_f \int_0^T h(t)\, dt \right) \\ c(T) &= \frac{C_0}{T} \end{aligned} \tag{7}$$

We assume that p=1.5/yr.

In Fig. *7*, a part of the cost-value function is shown. Note that since T is a continuous variable, we do not have discrete operation policies but rather a continuous cost-value function. The solution of Eq. (6) is characterized by

$$\frac{dv}{dc} = 1 \tag{8}$$

as can be shown easily. And, indeed, the derivative at the point with $c = 0.71$ is equal to one (see Fig. *7*). We thus see that in a cost-value framework, choosing the derivative equal to 1 leads to the classical solution.

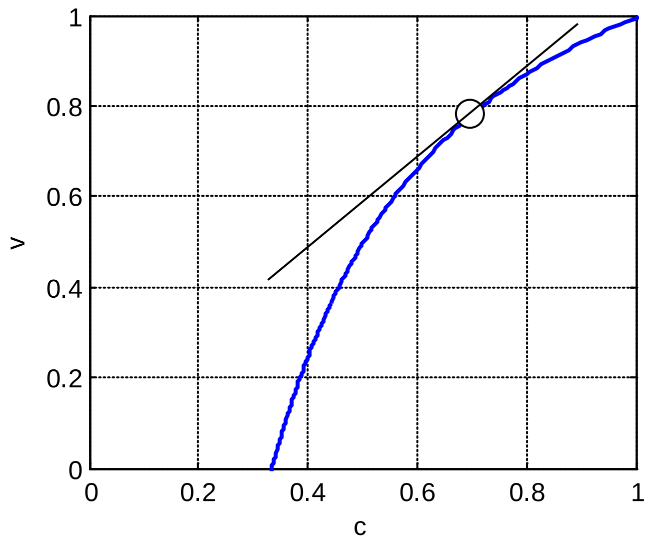

Figure 7. Cost-value plot for the manufacturing machine. The point with the minimum cost rate according to Eq. (4) is at $(c, \mathrm{v}) = (0.71, 0.79)$. *The derivative is 1 at this point.*

We might ask if this specific operation mode, determined by setting the derivative to a value of 1, is really the optimal point in a holistic perspective. Common intuition would suggest this is true. However, a closer look reveals that this is not the case.

The operation mode with $\frac{dv}{dc} = 1$ is characterized by the fact that the investment of the last dollar of capital costs (the last partial investment) leads to exactly one dollar additional net profit for the company. This means that, in terms of financial investments, the investment of this last dollar is a bad investment, because the MCE is exactly one, meaning a ROI of zero! As a financial investor, one would not invest this dollar in the manufacturing machine but rather in another investment object, let's say a bank account, where one would get back more than $1 at the end of the year.

We see that although a lifetime with associated capital costs of 0.71/yr leads to the highest net profit for the company, this is only true if the investment in the physical asset is the only investment option that is available. In practice, other investment options than the considered physical assets are always available. Thus, it would be in fact more profitable for the company to invest *less* money in the machine, and use the saved money for either other machines, or other productive resources in the company, or even in classical financial investments! Accordingly, the company should in fact run the machine *longer* than calculated in the classical cost-minimization approach.

For example, let us assume that there is a competing investment option characterized by MCE=1.1, corresponding to a ROI of 10%. Then, the investment in the investigated production machine would stop when the derivative approaches the value $\frac{dv}{dc} = 1.1$. This would lead to c =0.67 instead of c=0.71, which means that the investment in the production machine is decreased by about 6%! The saved money would be invested in the alternative investment option, thus generating more value.

Even if the difference in this simple example does not seem that big, this result is of high theoretical importance. It means that using the classical and established approaches of the maintenance literature may indeed lead to basically wrong conclusions on operation policies and sub-optimal investment decisions. The reason for this surprising and somewhat counter-intuitive result is the combination of the non-linear behaviour of the return-on-investment for physical assets, and the fact that other investment options are available.

It is beyond the scope of this paper to explore the implications of this observation in detail. However, the presented example suggests that much of the existing literature of maintenance optimization has to be revisited in the context of a broader perspective of investment theory of physical assets.

6. Conclusions

We have presented a general framework for modelling physical assets as a set of operation policies in a two-dimensional cost-value space. This reflects the basic nature of physical assets as investment objects which are meant to generate value for the owner. Our model can be seen as a straight-forward operationalization of the general idea of physical asset management. We have shown that this representation is useful for understanding the nature of an asset as investment object, which is defined by the relation between costs and value generation for the different feasible policies. This understanding is in turn essential for the attempt to optimize the life cycle management of physical assets. The model is formulated in general terms, allowing both monetary and non-monetary value definitions.

From our description of an asset we can directly derive optimal investment strategies that directly lead to optimum life cycle management policies. By combining standard methods of multi-dimensional optimization theory and classical investment optimization approaches, we can identify a subset of the operational policies which create the optimal investment frontier. Only policies on this frontier need to be considered as candidates for optimal policies. For a given investment level, the optimal operation policy can be determined.

An investment in physical assets in terms of covering the lifecycle costs can be conceptualized as a sequence of partial investments with decreasing returns. The non-linear behaviour of the return is a basic property of physical assets as investment objects, and distinguishes them from all classical financial investments.

When deciding on the level of investment, the marginal return, or marginal cost-effectiveness, is the decisive quantity. We showed that optimal investment strategies are governed by choosing between investment alternatives. The alternatives can be either inside an asset portfolio, or between physical assets on one hand, and other investment options of the firm on the other hand. Based on applicative examples, we demonstrated that the classical single-machine perspective of maintenance optimization literature may lead to suboptimal results, as this neglects these coupling effects.

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