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Dynamics of depreciation and scrapping in business economics[1]

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Abstract

With the aim to bring in SD deeper into management education we compare the concepts of depreciation and scrappage used in the literature of SD on one side and business economics on the other. We demonstrate that the business economics concepts of straight-line depreciation and of sudden scrappage can be formulated within the SD methodology and software. The economic results are better in line with the textbooks of business economics than those given by the current SD equations. As a result we recommend using a pipeline delay instead of a third-order delay for modelling scrappage. The concepts of straight-line depreciation and sudden scrappage are then combined with the concepts of aging chains and co-flow in the framework of a simple model of a firm. The simulation results are in line with fundamental expectations of business economics. This will be the basis for our further work on a generic model of a firm which could meet both the didactical challenges of management education and the sophistication of modern System Dynamics.

[1] The authors wish so thank an anonymous referee for useful comments.

1. Introduction

One of the greatest goals of the founder of System Dynamics was to improve management education. Almost 50 years after the expression of this aim only a small minority of university professors or holders of a chair in Management are members of the System Dynamics Society or otherwise actively involved in the field. In Germany, less then 1% of the university professors in business economics are actively engaged in the field of System Dynamics (SD) and the situation has not improved over the last decade. We will not investigate the spectrum of reasons for this, but rather stress the different terminology used in business economics on one side and in System Dynamics on the other. For example, COYLE (1977, 248) writes that profit equals average income minus average costs. For a well-known management accountant professor (HORNGREN 1994, 61) operating profit and operating income are synonymous terms. Of course even in business economics authors often use different words for the same notion or concept. This complicates the introduction of SD into management education even more.

It is one objective of this paper to build bridges between different terminologies. This is a necessary precondition for our work on interactive learning environments (ILE) for education in the field of management accounting and control systems. We will focus on depreciation and scrapping. They are essential for the dynamics of investment and equipment. At the same time, depreciation is one of the basic cost elements and therefore an important determiner of profit. We try to understand these dynamics deeper by using the ceteris paribus approach together with the vintage approach.

The understanding of investment in an asset, its depreciation and scrapping in management literature can be summarised as stated below. Due to the investment of some amount of money, a piece of equipment is obtained which has the following attributes:

- an initial value equal to the price paid for the equipment,
- an economic life time during which the initial value depreciates,
- a maximal output per time unit called the capacity,
- a technical life time during which the capacity is more or less constant,
- a certain input of labour to produce the output,
- a certain input of material to produce the output.

Therefore, through an investment decision, three main costs of the product are incurred: depreciation, labour cost and material cost.

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In textbooks and in management education these attributes are usually discussed separately. The apparatus of co - flows known in SD is not applied. On the other hand, there are only a few contributions from the SD field that investigate depreciation and scrapping. Usually unit costs are applied. Through this approach, the value flows by which they are generated are assumed away. In FORRESTER's (1961) book and in

ZAHN's (1971) book, which presents the first complex SD model of a growing firm, depreciation and scrapping are not mentioned. In screening the papers from the last SD society conferences, the word combination "capacity expansion" was only found in a paper by LYNEIS (Quebec 1998) and in one by MOON, KIM and KIM (Wellington 1999), but the authors neither mentioned depreciation or scrapping. In other papers, these words were sometimes present, but equations were not. In the SD literature, we found clear statements about depreciation in the works of COYLE (1977), LYNEIS (1980), STERMAN (1980, 2000), REPENNING and STERMAN (1994), and SCHOENEBORN (2004). An explicit equation for scrapping is formulated by LYNEIS (1980). SCHOENEBORN (2001, 2004) also considers scrapping in his models. Last but not least we found an important contribution to the subject of linear depreciation in the contribution of DINGETHAL (2004) to this conference. KEENAN and PAICH (2004) also mention depreciation.

In the next section we compare these concepts with concepts of business economics, which we express in terms of SD. We demonstrate that the basic business economics' concept of straight-line depreciation can be captured in a SD equation. Then we investigate the consequences of the different concepts of depreciation and scrapping on profit and revenue. We compare the consequences of scrappage modelling by a third-order delay (after LYNEIS) and by a pipeline delay. Finally, we investigate the consequences of different time periods for depreciation and scrapping on the dynamics of profits. In the third section, these results are used to demonstrate how capacity expansion and the growth of a firm can be better understood within the perspective of co-flows and vintages. We combine the concepts of straight-line depreciation and instant scrapping with the vintage concept, which has been promoted in SD literature by STERMAN (in his new book under the name 'aging chains'), and with the concept of co-flows. Finally, we discuss some possibilities for the introduction of our approach into the generic model of a small firm.

Our intention in this paper is not to formulate a complex model that can be falsified in an empirical context. We wish to introduce greater clarity about the dynamic properties of basic management and accounting concepts which should be or are a part of any management education and a part of business dynamics models that handle investment and capacity expansion.

2. Depreciation and scrapping in business economics and in System Dynamics

We begin with a description of the business economics' view on scrapping and depreciation in the simplest possible way. We abstract from all complex and sophisticated phenomena or complications and assume moreover that all other things are equal (ceteris paribus assumption). In this paper we do not aim to completely survey depreciation methods or phenomena (f.e. current versus historical costs, moral obsolescence, and governmental regulations in different countries).

In business economics, the following concept for investment in equipment is used as the normal one.[2] At a certain time t_I the equipment is installed with a capacity of C

[2] There can be types of equipment with declining capacity. We do not regard them here.

units/period. With this capacity, this equipment can produce during a period which is called the technical life time (TL). At the end of this time (at t_S =TL+ t_I), the equipment is scrapped and the capacity is zero. This concept can easily be transformed in a SD picture (fig. 1) using two pulse rates at t_I and t_S. The equipment is installed at $t_I = 0$.[3] With TL = 10 (years), the equipment is scrapped at $t_S = 120$ (months). An example for this picture would be a taxi driver who buys a car and starts his business immediately. After an incident the car is scrapped. Note that C=const over the period TL.[4]

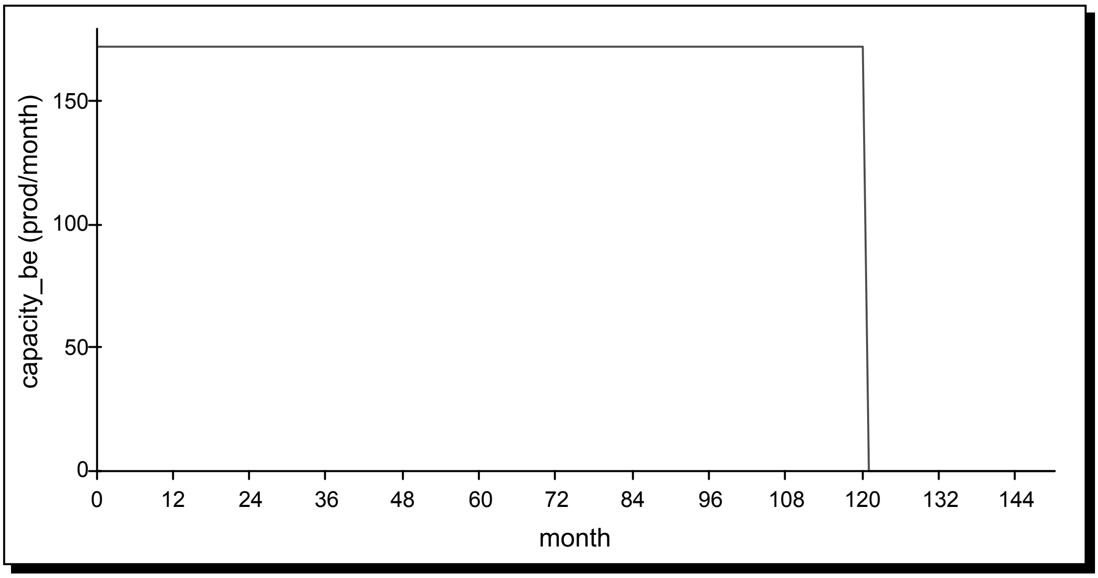

Figure 1: Investment, capacity, scrapping and technical life time

Whereas in this simplest of cases investment and scrapping occur instantly, depreciation is a more continuous valuation process. "In most cases, the amount allowable for depreciation is the original cost of (initial investment in) the asset."[7] In the case of the straight-line depreciation method from this amount I and the computed book values BV every year, an equal amount of depreciation D is deducted.

BV (t) = BV (t – 1) - D,
where
D = I/TU, t= 2(1) TU and BV (1) = I.

TU is the useful life time of the asset or the depreciation period. For the moment, we assume TU = TL = 10 (years). At the end of the depreciation period the terminal disposal price should be zero (BV (TU) = 0).

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3 This pulse rate cannot be seen because it overlaps with the ordinate in this figure and the other figures.
4 We abstract here from cases where the capacity is declining. In practise repairs can secure a constant capacity or even increase it.
7 HORNGREN (1994, 721).

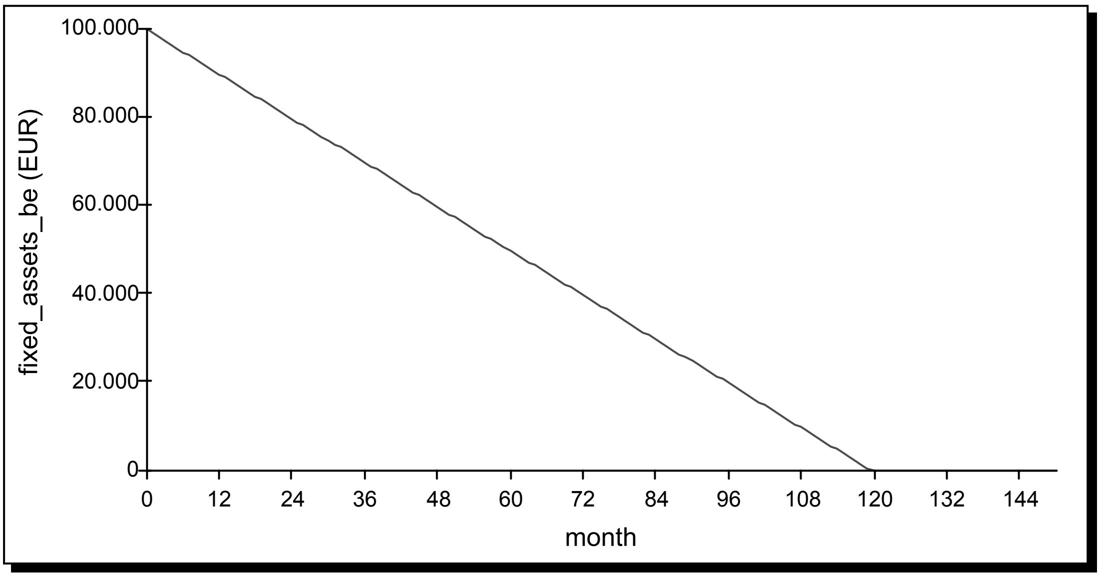

Figure 2: Book value of fixed assets with the straight-line depreciation method

In the case of the double-declining balance (DDB) depreciation method the book value BV of the previous year is multiplied by the DDB rate (= 2/TU):

BV (t) = BV (t – 1) *2/ TU,
where
t= 2(1) TU and BV (1) = I.

The DDB method never fully depreciates the existing book value. Therefore a firm has to switch after a few years to the straight-line depreciation method.[8] In this sense it is the more general depreciation method and teaching of depreciation in management courses begins with this method. We simplify our analysis and restrict it to the usage of the straight-line depreciation method. This is for teaching purposes. Firms prefer the accelerated depreciation pattern in the first years and then switch to straight-line depreciation in order to bring the book value to zero as it is demanded by law.

In SD literature depreciation is treated in various ways and different authors use different equations. For a business economist, depreciation is a "non-cash cost"[9]. In contrast to this, COYLE (1977, 248) speaks of a depreciation cash flow[10] and formulates the equation:

DCFL.K = DR*WDV.K

with the depreciation fraction DR and the written down value WDV. Neither a technical life time nor a useful life time nor scrapping is mentioned.

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8 DINGETHAL (2004) considers this case.

9 HORNGREN (1994, 723)

10 On page 335 he asserts that depreciation is one source where cash comes from. However on the diskette to COYLE's (1996) book we find now the correct statement that depreciation does not involve money.

LYNEIS (1980, 1988) and STERMAN (1980, 2000) are more explicit about depreciation.
STERMAN (1980, 21) uses the equations
K.K = K.J + (DT)(KAR.JK-KDR.JK)
KDR.KL = K.K/ALK
with the capital arrival rate KAR (capital units/year), the capital discard rate KDR (capital units/year)[11], the capital K (units) and the average life of capital ALK (years).

The outflow is a physical flow with the dimension "units"and not a value flow as with depreciation and it is taken from the actual and declining level. As in the case of the double-declining balance (DDB) depreciation method, a declining level is divided by a life time. By multiplication with the price of capital PK ($/capital unit), STERMAN (1980, 40) also formulates implicitly an equation for the depreciation D which corresponds to the straight-line depreciation method:

D = PK.K*K.K/ALK
STERMAN (2000, 805) also uses a discard rate but now the capital stock is divided by the average life of capacity. "Production capacity is the rate of output …".

Discard Rate = Capital Stock / Average Life of Capacity.

LYNEIS treats depreciation and scrapping in a more detailed way. He uses the following equations for depreciation[12]:

BVFA.K=BVFA.J + (DT)(INVEST.J – DEPR.J)
BVFA=CE*CPUCE
where

BVFA	= book value of fixed assets ($)
DT	= delta time, simulation solution interval (days)
INVEST	= investment ($/day)
DEPR	= depreciation ($/day)
CE	= capital equipment (units/day)
CPUCE	= cost per unit of capital equipment ($/unit/day)

DEPR.K = BVFA.K / TDEPFA[13]
TDEPFA = 2400
where

DEPR	= depreciation ($/day)
BVFA	= book value of fixed assets ($)
TDEPFA	= time to depreciate fixed assets (days)

The book value of fixed assets is initialized to equal capital equipment CE multiplied by the price per unit of capital equipment CPUCE. Afterward, the book value is increased by investment and decreased by depreciation. LYNEIS (1980, 1988, 264) states: "Equation 117 approximates straight-line depreciation for the company that replaces

[11] In our case the capital arrival rate is assumed to be a pulse and zero afterwards.
[12] LYNEIS (1980, 1988, 264, 265)
[13] SCHOENEBORN (2004, 94, 101) uses the same approach.

assets as they depreciate”.[14] This is an important difference to the business economics approach, which assumes investment to be a pulse in the beginning and zero afterwards to get the pure behaviour of depreciation. In real companies, equipment is replaced only if the life time has ended and if it is scrapped. Moreover, the equation of LYNEIS computes depreciation from book value BVFA.K that is a declining variable.[15] SCHOENEBORN (2004) uses the same equation, which we will refer from now on as the SD concept of depreciation. This is similar to the double-declining balance (DDB) depreciation method. In contrast to this, the straight-line depreciation method gives a constant amount of depreciation each year and uses only the original cost for depreciation.

We compute now the resulting book value of fixed assets with this equation. In this analysis we abstract from any new capital arrivals, i.e. we set STERMAN’s KAR.JK or LYNEIS INVEST.J to zero in all subsequent time periods. We are interested only in the effect of this depreciation concept on the book value of just one original investment. We use an understanding that is known also as the net present value (NPV) concept in business economics. NPV calculates for just one investment the sum of a single cash outflow and the discounted cash inflows in all subsequent years. Figure 3 shows the results of the SD concept of depreciation for the book value of fixed assets.

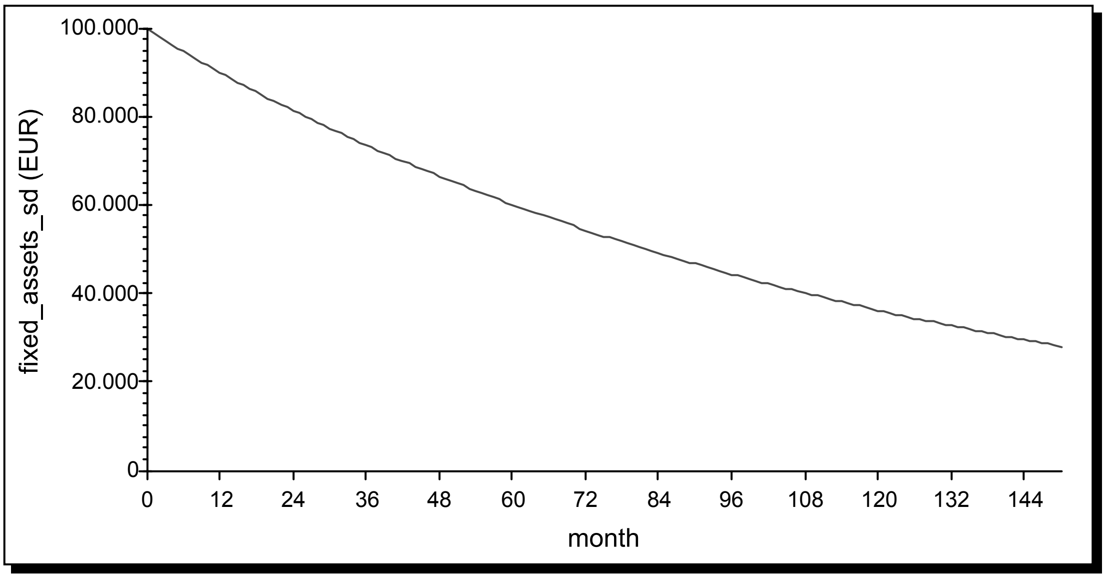


Figure 3: Book value of fixed assets with the SD concept of depreciation [16]

Figure 4 shows the small models built in POWERSIM which were the basis for the previous figures. In order to get an equal amount of depreciation using POWERSIM for every period, we had to change the usual equation for straight-line depreciation. We divide the book value by the remaining depreciation period.

[14] We have seen before that business economics has a different understanding of straight-line depreciation.

[15] STERMAN follows the same concept when computing the capital discard rate KDR in non-monetary units.

[16] According to LYNEIS, STERMAN and SCHOENEBORN.

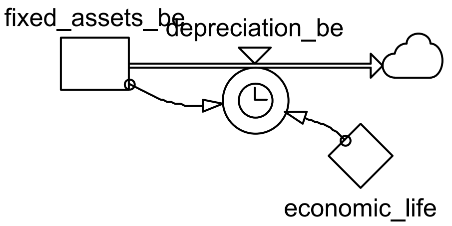
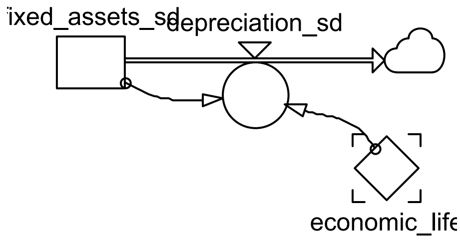
<table>
<tr><th>Model and equations in business dynamics</th><th>Model and equations based on SD-literature</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>init fixed_assets_be = 100000
flow fixed_assets_be = -dt*depreciation_be
unit fixed_assets_be = EUR
aux depreciation_be = IF(fixed_assets_be>0 , fixed_assets_be / (economic_life - TIME) , 0)
unit depreciation_be = EUR/month
const economic_life = 120
unit economic_life = month</td><td>init fixed_assets_sd = 100000
flow fixed_assets_sd = -dt*depreciation_sd
unit fixed_assets_sd = EUR
aux depreciation_sd = fixed_assets_sd/economic_life
unit depreciation_sd = EUR/month
const economic_life = 120
unit economic_life = month</td></tr>
</table>

Figure 4: Model structures in POWERSIM for the calculation of depreciation

The equations for scrappage are formulated by LYNEIS (1980, 1988, 327) as follows:

CES.KL = DELAY3I (CEA.JK, TSCE, CE.K, CEI)
TSCE = 2400
CEI = CCOR * (1 + CEGM)
where

CES	= capital equipment scrappage (units/day/day)
DELAY3I	= third-order delay with user-specified initial value
CEA	= capital equipment arrivals (units/day/day)
TSCE	= time to scrap capital equipment (days)
CE	= capital equipment (units/day)
CEI	= capital equipment, initial (units/day)
CCOR	= constant customer order rate (units/day)
CEGM	= capital equipment growth margin (dimensionless)

This approach means that in every period capacity is scrapped. Figure 5 shows the results of a simulation with POWERSIM.

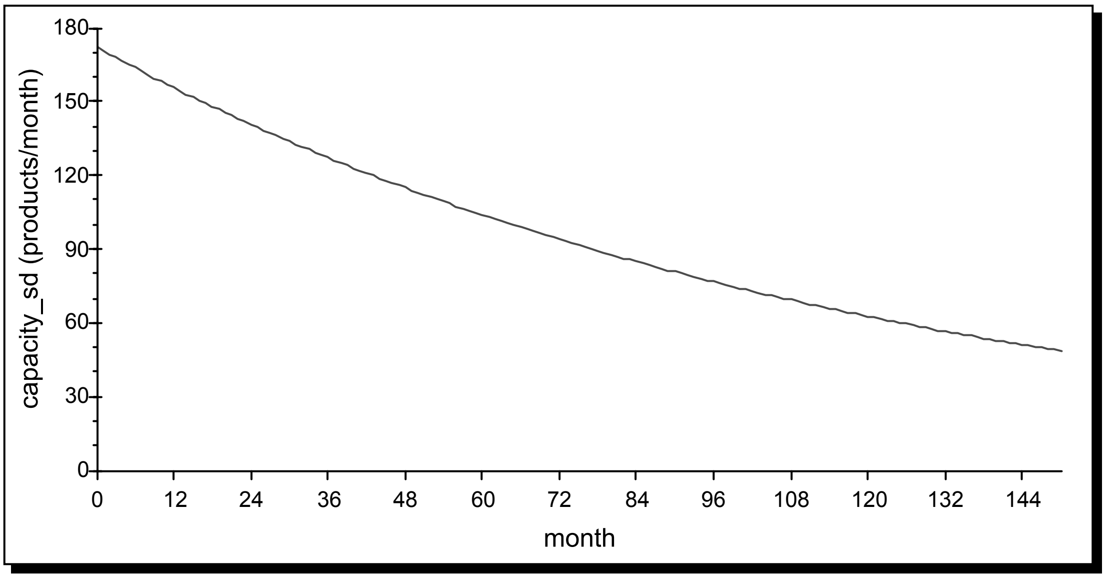


Figure 5: Scrapping on the basis of a third-order delay

At the end of this section we will compare scrapping on the basis of a third-order delay and a pipeline delay in more detail. The simulation results for both approaches in terms of revenue and profit are shown in the following figures 6 and 7.

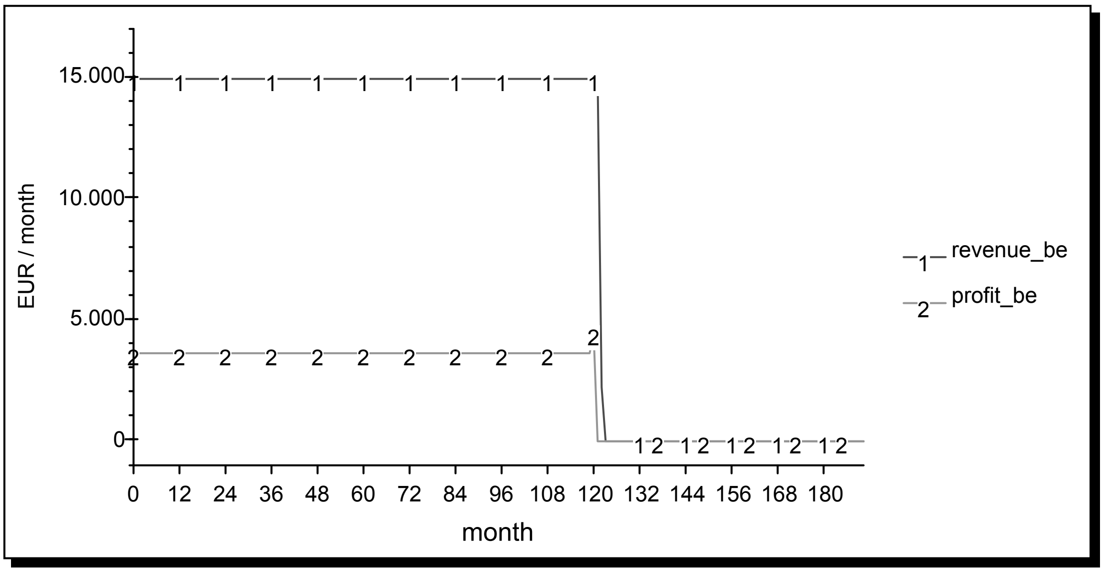


Figure 6: Revenue and profit based on the scrapping concept of business economics

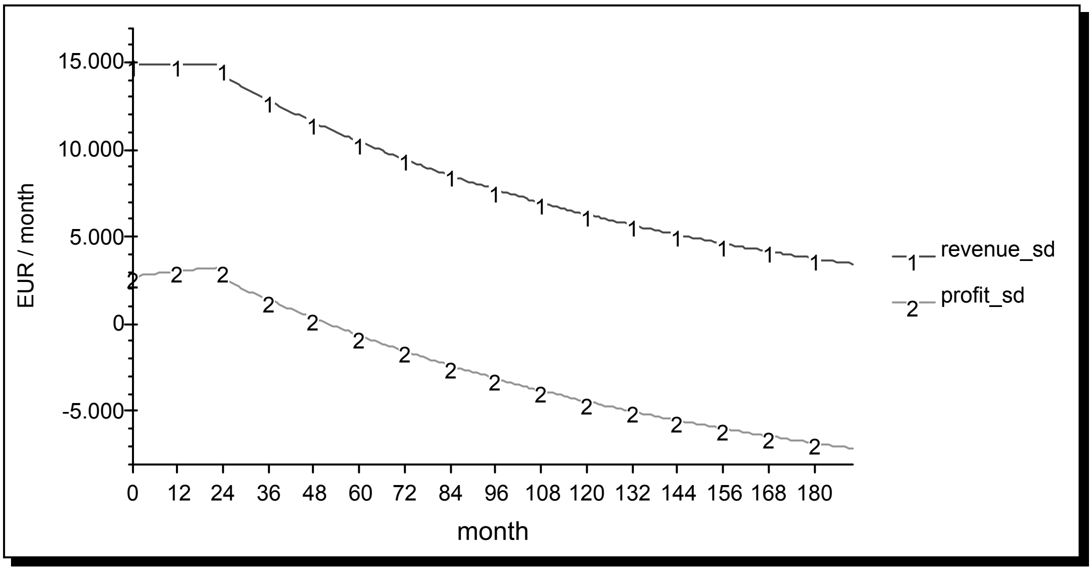


Figure 7: Revenue and profit with scrapping on the base of a third-order delay

Up to this point we assumed that TL = TU. This seems to be also the general assumption in SD literature. In practical life we observe that TL can be much longer than TU. Equipment is used for production even if it is fully depreciated and its book value is zero. We assume now that TL is longer than TU and equals 15 years. Depreciation is zero beginning with the month 120. By using such a policy after TU = 10 (years) the profit grows by 22%. In figure 8 this behaviour is compared to the profit development according to the third-order delay equations of LYNEIS (in the lower curve).

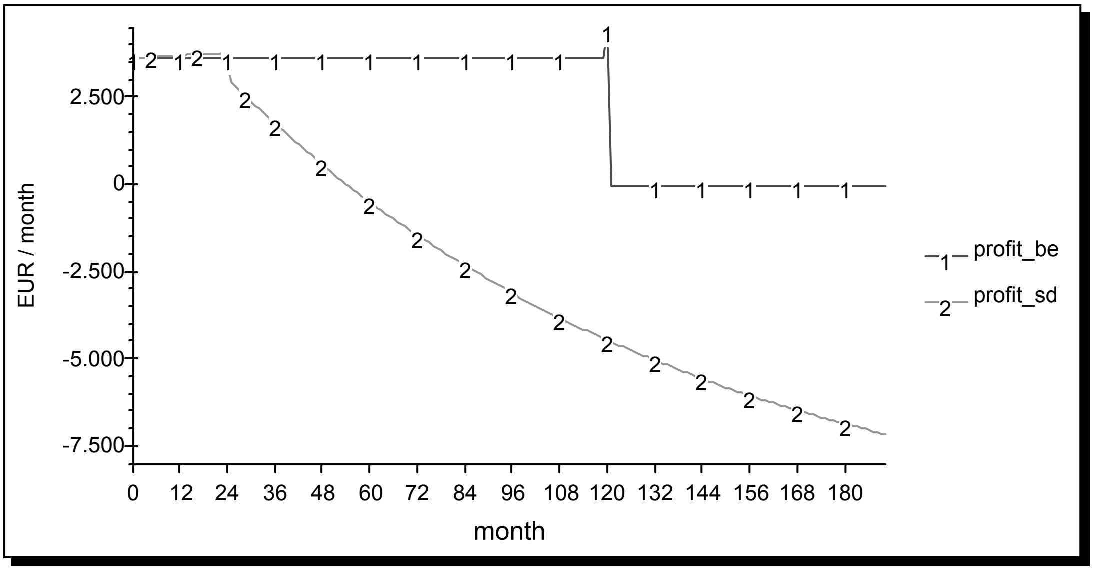


Figure 8: Profit behaviour with a pipeline delay and usage of written off equipment (upper curve) and with a third-order delay (lower curve)

Finally we compare the consequences of a pipeline delay and a third-order delay on capacity in more depth. Every two years the equipment is scrapped and renewed. Here scrappage and renewal have duration of 1 month each. After each period new capacity is ordered which is equal to a changed product demand. For both cases (pipeline delay and third-order delay) equipment with the same capacity is ordered. In the case of a pipeline delay the capacity equals always the demand. In the case of the modelling with a third-order delay capacity is scrapped continuously. Therefore the capacity does not meet the demand in the first period (hence less revenue and profit). Then we have overcapacity in the beginning of the second period and not enough capacity in the second half of that period. Figure 10 is a zoomed part of figure 9. In our opinion, it seems better to model scrappage with a pipeline delay.

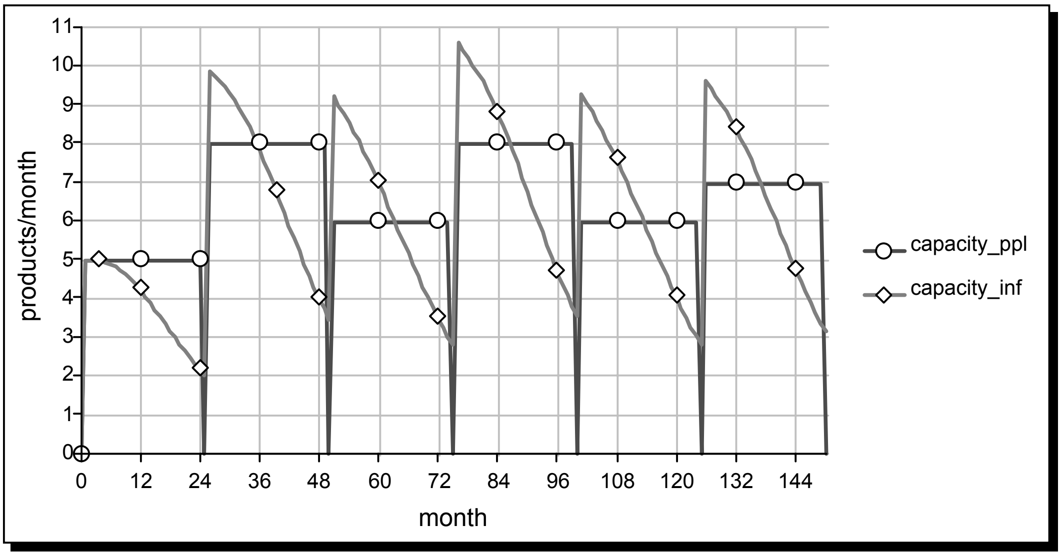


Figure 9: Consequences of a pipeline delay and a third-order delay on capacity

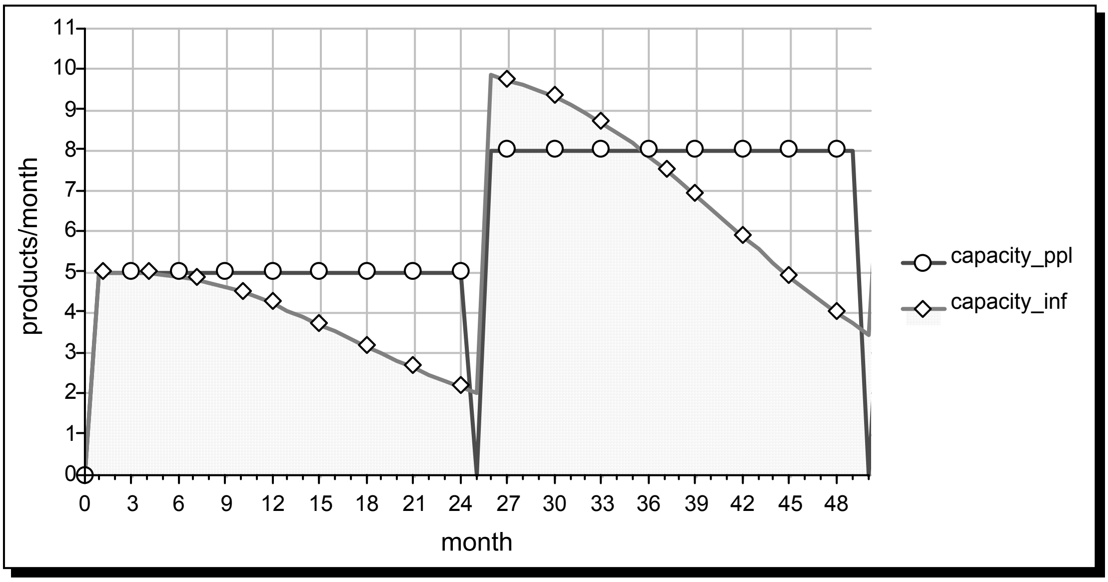


Figure 10: Consequences of a pipeline delay and a third-order delay on capacity (detail)

3. Capacity expansion in a vintage perspective

After having analysed the concept of pure depreciation of an initial piece of capital equipment we now turn to capacity expansion again in the simplest possible way. This means we now introduce investment in new equipment during the lifetime of the old one. LYNEIS (1980, 1988, 265) already saw the possibility of a more detailed model with "individual asset levels for each different age category of fixed assets". This is exactly what bookkeeping in a normal company does register. But up to now we find in companies no mathematical models of these dynamics. Vintage models have been developed within macroeconomic literature.[17] Some authors in System Dynamics literature have adopted that approach.[18] The interest in vintage models for firms was only recently refreshed by STERMAN (2000) and supported by the possibilities of software packages like POWERSIM© and VENSIM©. STERMAN now uses a different terminology. He speaks of aging chains. At the same time System Dynamics has developed the modern concept of co-flows.[19] Based on both concepts we formulate a model the structure of which is described in figure 11. This model was constructed only for management education purposes and does not claim broader empirical relevance. The equations are noted in Appendix A. We use the following assumptions:

- The firm already exists and has a small capacity in the at the start.
- The policy of the firm requires minimisation of order backlog. This means that the firm invests in new capital equipment if the capacity reaches its upper limit.
- Every vintage of capital equipment is connected with a certain capacity, a given price or book value and a given amount of personnel to operate the equipment.
- The orders grow as linear functions.
- New equipment is immediately available, there are no delivery times.
- When a vintage of equipment is scrapped its capacity will be replaced by new equipment. Non-essential members of the workforce leave the firm.
- One machine needs one worker and produces one product per hour (velocity of the machine).
- The capacity results from this velocity and the available working time.
- The available working time is 173 hours per month.
- New personnel is immediately available
- Personnel costs grow in one year by 2 %.
- Maintenance times grow with the age of the equipment.
- Material is delivered just in time.
- One unit of material is needed for one product.

Each vintage of machines (respective equipment) is characterised by a certain book value, a given capacity and a given number of workers to operate the equipment. It is connected with a co-flow of these attributes. In general, there is also a certain amount of material input to the machine which can be modelled as a co-flow. In this paper we abstract from this attribute and model it as an input of material needed for one product. We use in the model 1 array for every month in order to register the aging of vintages.

[17] STERMAN (1980) gives a short survey.

[18] STERMAN (1980), MATTHES und SCHWARZ (1982), MATTHES und SCHWARZ (1983), KOZIOLEK, MATTHES und SCHWARZ (1988).

[19] See again STERMAN (2000).

With TL = 10 (years) we have 120 arrays for capacity and workforce each. The depreciation period TU is 5 years. So we have 60 arrays for the book value of fixed assets.

The simulation with this model gives a behaviour which a business economist is familiar with (figure 12). We assume that the already existing firm has a certain capacity in the first two years. Then the demand reaches the limit of the capacity and the firm invests in equipment. This brings an immediate increase in capacity. The same happens in the years 2011 and 2018. The upper curve has some jumps because we assume there are some smaller repairs during the lifetime of the equipment. The lower curve shows the assumed linear growth of demand (orders) and the resulting growth of the production output.

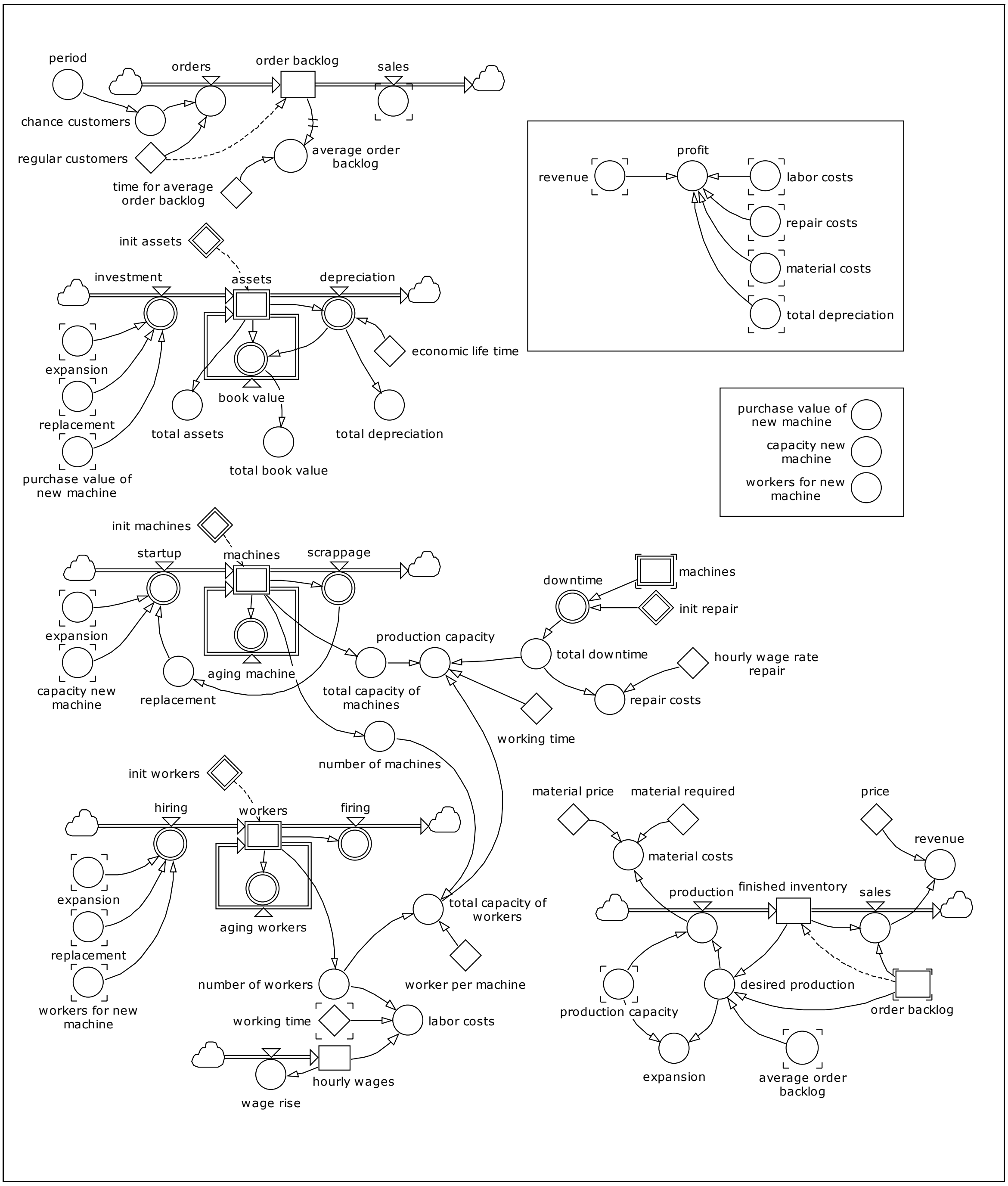


Figure 11: System Dynamics model of an aging chain of equipment connected with co-flows for every vintage.

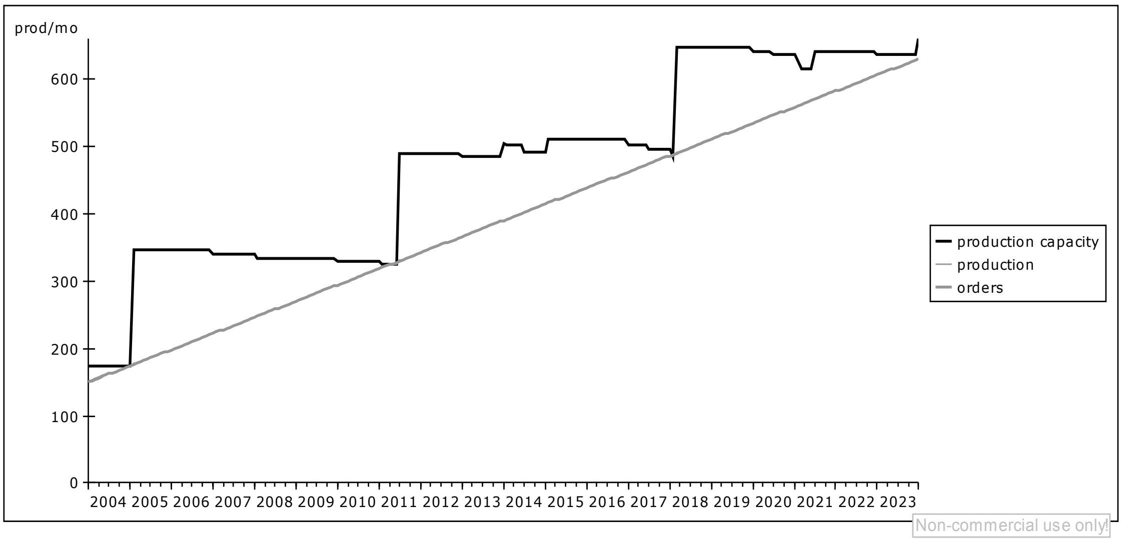


Figure 12: Growth of demand and the resulting expansion of capacity and output

The next figure 13 depicts important economic results. Assuming a constant product price we get linear growth of sales. The cost of material is a unit cost per product and grows, therefore, in a linear way too. Because of the discrete investments, we have jumps in the workforce which are needed for the operation of new equipment. This is accompanied by jumps in the labour costs and to the same effect the profit declines in these years. The book value of the equipment is decreased by straight-line depreciation and increased by investments into new vintages of equipment (figure 14).

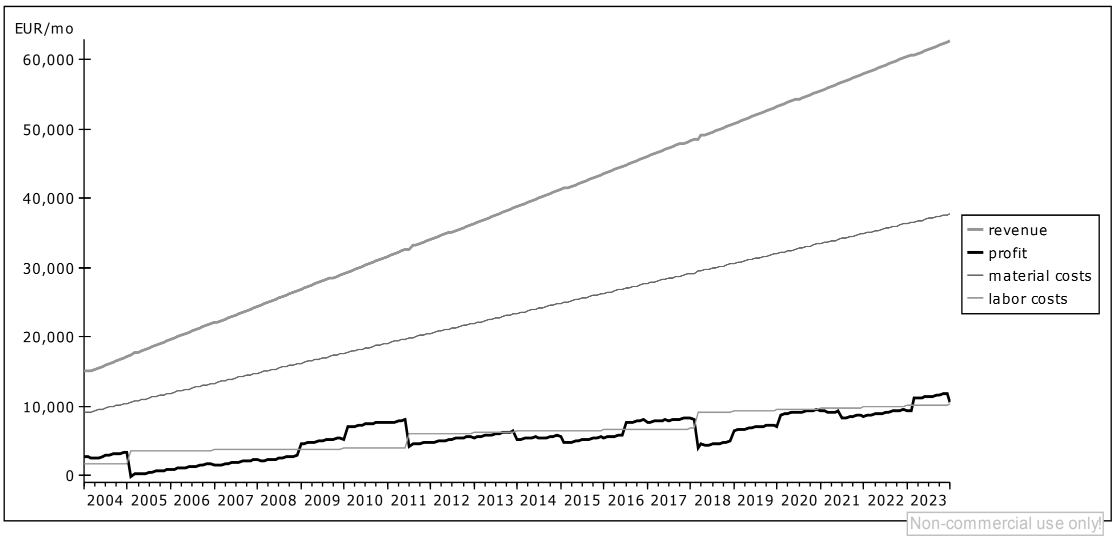


Figure 13: Behaviour of important economic variables

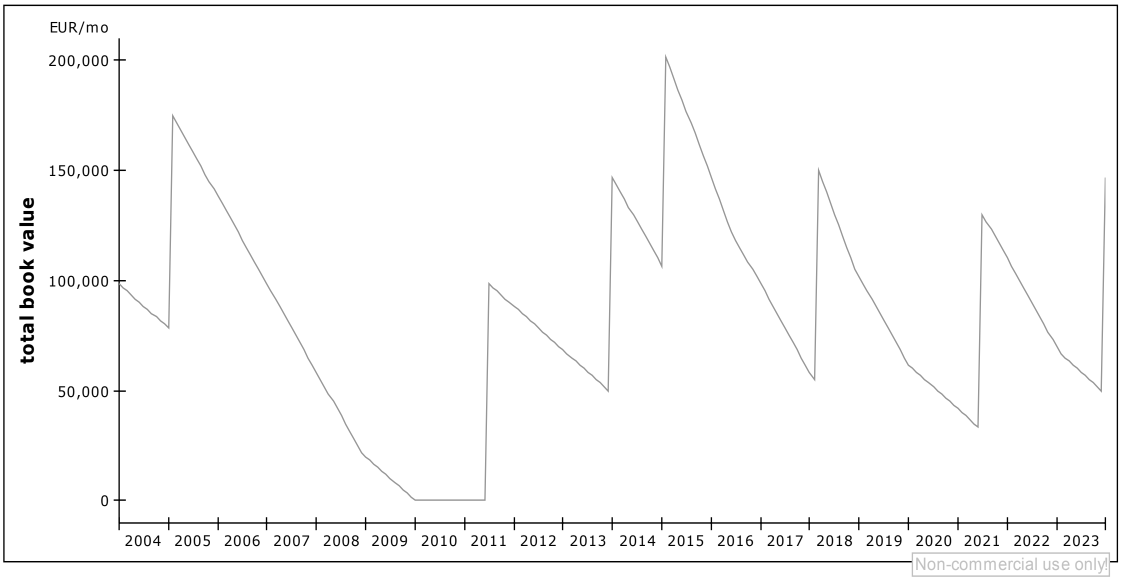


Figure 14: Book value of equipment

4. Discussion and proposals for further work

We have seen that basic concepts of business economics, especially depreciation and scrapping can be expressed in small SD models. This can help to introduce the SD methodology into management courses. Here it is appropriate to use the terms and concepts of basic business economics textbooks within SD models. The paper demonstrated this for the straight-line depreciation method. It is the basic depreciation method in two senses. First, teaching in management accounting usually starts with this method. Secondly, it is more general than the DDB method which cannot depreciate the existing book value fully. Therefore a firm must always switch to the straight-line depreciation method.[20] Unlike this usage in business economics, depreciation equations similar to the DDB method are preferred in SD literature. This reflects the well-known observation that most firms use accelerated depreciation (DBB) in the beginning. One should at least add the SD view on the straight-line depreciation method which we propose in this paper in SD models for management education.

Whereas depreciation diminishes the value of equipment over the whole depreciation period (the useful life time TU) scrapping affects the equipment only at the end of its technical life time (TL). It destroys (or sells) the equipment and brings the capacity almost instantly to zero. A good example for this is a blast furnace which is destroyed. Scrapping is rarely mentioned in SD literature. In the few cases which handle scrapping, it is modelled with a third-order delay. This has the effect of continuous scrapping which begins shortly after the installation of new equipment. Any buyer of a new car would eventually find that this is complete economic nonsense. Besides this we find with a third-order delay a remaining capacity even at the end of the technical life time. This concept resembles accelerated (DDB) depreciation and it leads to a missing capacity even before the end of the technical lifetime (and despite continuous repairs).

20 See also DINGETHAL (2004).

In the equations of STERMAN and LYNEIS (in section 2 above) this permanent scrapping is compensated with permanent investment into new equipment.[21] This approach does not correspond to the business economics understanding of scrapping and we cannot recommend it for management education. In contrast to a third-order delay, the application of a pipeline delay mirrors the understanding of business economics completely. The contrast between both delays can be seen in their consequences to revenue and profit.

In business economics and in SD literature it is often assumed that the depreciation period TU and the technical lifetime of equipment are identical or equal. Business practise knows otherwise. Sometimes equipment is scrapped even if it is not written off and in some cases it is advisable not to scrap equipment even if it is written off. The latter policy brings an immediate jump in the profit because the capacity is used and depreciation does not diminish the profit anymore. Under our assumptions this effect leads to a profit growth by 22%.

The concepts of straight-line depreciation and pulse-like scrapping also allow a convenient combination of the vintage concept (or aging chains) and the concept of co-flows. Both concepts are well known in the SD community but rarely used in management courses. Capacity expansion and the bookkeeping of equipment are fields where vintage thinking is common to business economics. Here one can open a door to bring more SD into management education. In section 3 we formulated a simple model which combines all the four concepts mentioned: straight-line depreciation, pulse-like scrapping, aging chains and co-flows. The simulation with this model gives a behaviour which a business economist is familiar with. Therefore it seems to be suited for adoption in management teaching or in high schools with a specialization in business economics. It also could be a module in an interactive learning environment (ILE) for courses in management or management accounting and control.

However we regard the model effort in this paper only as a starting point. The combination of the four concepts should be elaborated in greater detail. With concern for high school and management education we see the need for an interactive learning environment. A necessary step in that direction would be the introduction of the basic concepts outlined in this paper into a generic model of a firm. This model should depict the main concepts and causal loops that are taught in business economics, but usually without the SD approach. Our further work will combine the results of this paper with the generic model of SCHÖNEBORN and SCHWARZ (2002).

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[21] See also SCHWARZ and MAYBAUM (2000) for a detailed analysis of LYNEIS' model.

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