Is There an Optimal Level of Digitalization?

by

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ABSTRACT

The topic "Industry 4.0 & Digitalization" spans across almost all company areas and processes today. Manager strive to increase efficiency by implementing related applications and by automating process steps. Therefore, conventional financial instruments are often used in order to calculate the productivity of single digital solutions. For supporting the decision-making process, the focus is often (only) on the question of whether the digitalization of a process is economically feasible or not. A comprehensive mathematical model to calculate the cost-efficient portion of digitalized and manual processes within a business process has not yet been developed. Obviously, this would be highly appreciated since many companies worldwide are pursuing a so-called hybrid strategy with partially automated production processes and selective use of digital technologies. The focus of the present paper is on the question, how it is guaranteed that the solution found actually leads to the minimum costs.

Keywords: Digitalization, Process Management, Cost Efficiency, Optimization Model.

INTRODUCTION

The digitalization or digital transformation of companies is often determined as the fourth industrial revolution (Industry 4.0). Starting from the third industrial revolution, which was characterized above all by the increasing use of information technology (IT) in companies, Industry 4.0 stands for the comprehensive digital networking of processes in the company (Kagermann et al. 2013). As a result, the entire value chain can be operated autonomously, i.e. without human intervention. Digitalization is not limited to industrial processes, but also includes control and administration processes.

As empirical studies show, especially larger companies combine digitalization with the automation of business processes (Bitkom 2018). Routine tasks are being digitized at ever shorter frequencies. People are being replaced by machines to save costs and minimize errors. From a technical point of view, there seems to be no limits for the substitution of human workforce. According to the motto "Everything that can be digitized will be digitized" (Carly Fiorina, CEO HP), today all business areas are under "digitalization pressure". But, what are the criteria or parameter that support an economically rationale decision?

An important precondition for the digitalization or automation of business processes is the collection and networking of data. Only a few years ago people (employees) primarily determined and evaluated process-related data. Today, this work is increasingly being carried out by machines, e.g. computers, using Artificial Intelligence (AI) (Hirsch-Kreinsen 2015). On the one hand, this means that more and more things can be networked on the Internet, the so-called Internet of Things (IoT). On the other hand, there is a progressive fusion of the physical and virtual world leading to so-called cyber-physical systems (CPS). Both of these factors accelerate the intelligent automation of processes.

Around a quarter of industrial companies have highly automated production lines in which Machine-to-Machine (M2M) communication is already implemented, including Machine Learning for autonomous optimization of production processes. In contrast, almost half of the companies still produce manually, on the basis of individual, non-networked production steps. The remaining companies are pursuing a so-called hybrid strategy with partially automated production processes and selective use of digital technologies. Such a range of applications can be observed in many OECD countries (Spath et al. 2013).

From business perspective, the focus on Industry 4.0 & Digitalization is primarily driven by efficiency considerations (Schumacher et al. 2016). In empirical surveys, up to three quarters of interviewed companies response that process automation using digital applications will primarily contribute to increasing sales and saving costs (Capgemini 2014). At the same time, the respondents outline that they have considerable difficulties in measuring and calculating these values (Bitkom 2018).

The relevant assessment models are based on the comparison of alternative solutions that have to be defined in advance. The optimal solution is found by "scoring" or "calculating" the costs and benefits of individual alternatives (Ross 2002, Dürr 2013). To determine the optimal degree of digitalization of a given process, all possible variants resulting from the combination of manual and automated process steps must be calculated. This procedure appears to be less efficient, esp. in complex processes with many individual steps. In addition, it is not guaranteed that the solution found actually leads to the minimum costs.

COST-ORIENTED OPTIMIZATION MODEL

Target Function

We consider a linear process with p process steps to produce an output (product or service). Therefore, m manual i.e. partly automated process steps and d digitalized i.e. fully automated process steps are required. For a given planning period the optimal combination of both kinds of process steps has to be calculated (Günther 2020: Introduction of basic model). The following is true:

$$p = m + d \qquad [1]$$

with

p … Total number of process steps

m … Number of manual process steps

d … Number of digitalized process steps

For the manual and digitalized process steps different costs are relevant. The following cost coefficients c_m and c_d refer to one completed process step. Only process-related costs are considered. The process cost c_p for one completed process, including all process steps, will be represented by the following cumulative function:

$$c_p = c_m \cdot m + c_d \cdot d \qquad [2]$$

with

c_p … Cost of one completed process

c_m … Cost of one manual process step

c_d … Cost of one digitalized process step

The cost coefficient c_m is given and constant for all steps m. The cost coefficient c_d is calculated on the basis of the investment cost for research and development of the digital solution and its depreciation. Variable costs are not considered since they are not important for digital transformation (Teichert 2018). According to the effect of fixed cost degression, the more often the digitalized process steps – after implementation of solution – are operated, the less the value c_d becomes. For this purpose, the investment cost C_i that occur for the digitalization of relevant process steps d / p, will be evenly distributed across the total number of process cycles n in the given planning period:

$$c_d = \frac{C_i \cdot \left(\frac{d}{p}\right)}{n} \qquad [3]$$

with

C_i … Total cost for digitalization of the process

n … Number of process cycles in planning period (equals output volume)

By plugging in the transposed equation [1] together with equation [3] into the cost equation [2], we derive the target function $c_p(d)$ for the given planning period:

$$c_p(d) = c_m \cdot (p - d) + \frac{C_i}{n \cdot p} \cdot d^2 \qquad [4]$$

with sub-functions:

$$c_{pm}(d) = c_m \cdot (p - d) \qquad [4.1]$$

$$c_{pd}(d) = \frac{C_i}{n \cdot p} \cdot d^2 \qquad [4.2]$$

Optimal Solution

The target function [4] is only dependent on variable d. All other variables are constant. In order to determine the cost optimum, the target function has to be minimized. By calculating the first derivative of the function with respect to d and setting it to zero we get the necessary condition for an optimum:

$$c_p(d)' = -c_m + \frac{2 \cdot C_i}{n \cdot p} \cdot \mathrm{d} = 0 \qquad [5]$$

Hence, the following relation is given: $|c_{pm}(d)'| = |c_{pd}(d)'|$. It follows that in the optimal solution the decrease of cost of digitalized processes equals the cost of manual processes in terms absolute value. By transposing the equation [5] with respect to d we are able to calculate the optimal number of digitalized process steps:

$$d_{opt} = \frac{c_m \cdot n \cdot p}{2 \cdot C_i} \qquad [6]$$

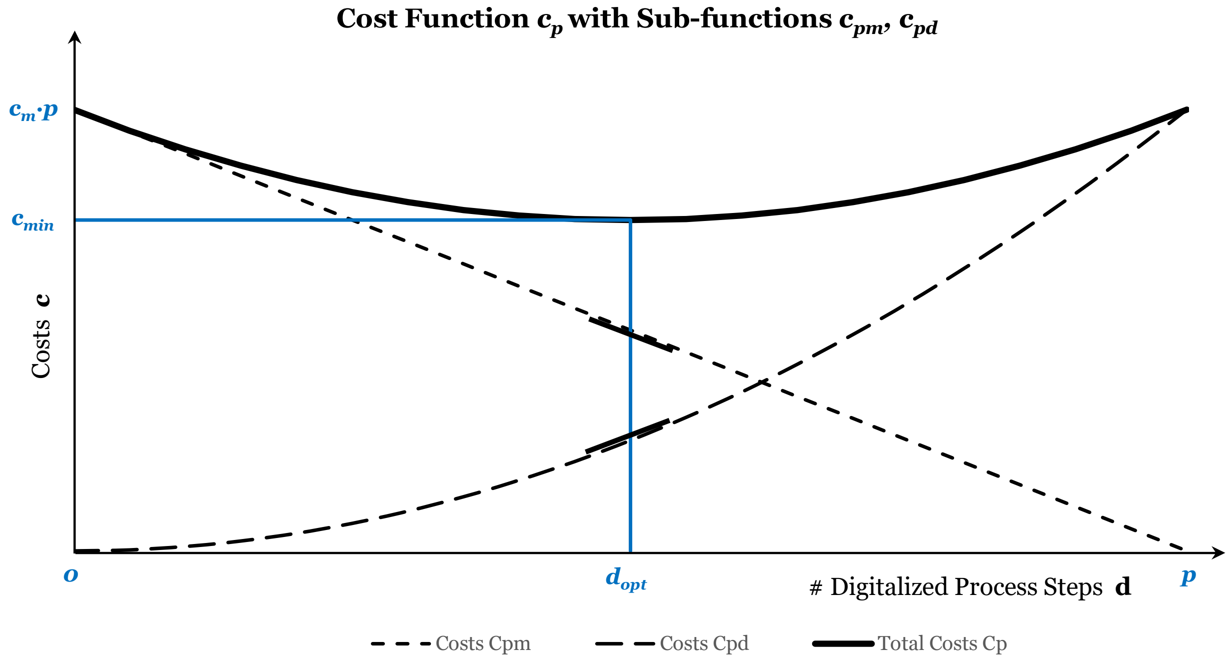


Figure 1: Optimization Model for Cost-efficient Digitalization

The cost function [4] together with the sub-functions for manual process steps [4.1] as well as digitized process steps [4.2] are shown in Figure 1. According to equation [1], the permissible range of values for the functions is given with $0 \leq d \leq p$. The resulting (total) cost function $c_p(d)$ is an upwardly opened parabola, which reaches its minimum at d_{opt}. At this point, the absolute increase of $c_{pm}(d)$ and $c_{pd}(d)$ is the same.

NUMERICAL EXAMPLE TO CALCULATE OPTIMAL COSTS

Model Application

For the demonstration of the developed optimization model we will conduct a numerical example.

Given:

Total number of process steps	$p = 10$
Number of process cycles in planning period	$n = 1{,}000$
Cost of one manual process step	$c_m = 1$ [MU]
Total cost for digitalization of the process	$C_i = 1{,}000$ [MU]

Solve for:

Optimal number of digitalized process steps	d_{opt}

Solution:

In order to determine the cost minimum we apply equation [6]:

$$d_{opt} = \frac{1 \cdot 1{,}000 \cdot 10}{2 \cdot 1{,}000} = 5.0$$

The optimal number of digitalized processes that will lead to minimal costs per process cycle is $d_{opt} = 5.0$. The optimal level of digitalization for $p = 10$ is *50%*. According to equation [1] the optimal number of manual processes can be directly determined with $m_{opt} = 5.0$, absolutely, and with 50%, relatively. With these values, the cost of one process cycle is minimal and can be calculated according to equation [4]:

$$c_p(d_{opt}) = 1 \cdot (10 - 5) + \frac{1{,}000}{1{,}000 \cdot 10} \cdot 5^2 = 7.50 \text{ [MU]}$$

with

MU … Monetary Units

From practical perspective the requirement is usually to provide an integer value as a solution. This is simply due to the fact that process steps are either purely manually operated using technical support or are completely digitalized, i.e. can be performed autonomously. In order to determine the (optimal) integer solution d_{optZ}, the calculated value d_{opt} has to be rounded to a whole number. Since we have a symmetric cost function, as outlined above, the mathematical crosscheck is not necessary if the greater or lower whole number nearest to d_{opt} leads to minimal costs.

In the example, we get the optimal integer solution – by chance – $d_{optZ} = d_{opt} = 5$, resulting in (minimal) costs c_{min} = 7.50 [MU]. Accordingly, the optimal whole number of manual process steps is $m_{optZ} = 5$.

Model Results

Based on the derived model to determine the optimal level of digitalization, we could identify three characteristic cases or model results within the given range of values $0 \leq d_{opt} \leq p$, which include processes that are (A) "Not digitalized", (B) "Partly digitalized", and (C) "Completely digitalized". In the following, the numeric example is provided of the three cases by using equation [6] for d_{opt} and in adherence to the requirement of finding an integer value solution d_{optZ}:

(A) $d_{optZ} = 0$: The digitalization of process steps is not efficient at all. According to the cost function all process steps should be conducted semi-automatic or manually, i.e. $m_{optZ} = p$. Due to the outlined rounding principle we preserve $d_{optZ} = 0$ if $d_{opt} < 0.5$. This occurs if the product of manual costs c_m, process cycles n and given process steps p is relatively small compared to the costs of digitalization C_i. Hence, for $d_{opt} < 0.5$ the condition $c_m \cdot n \cdot p < C_i$ must be true. In the example, we will meet this condition for $n < 100$ assuming all other values c_m, p and C_i remain constant.

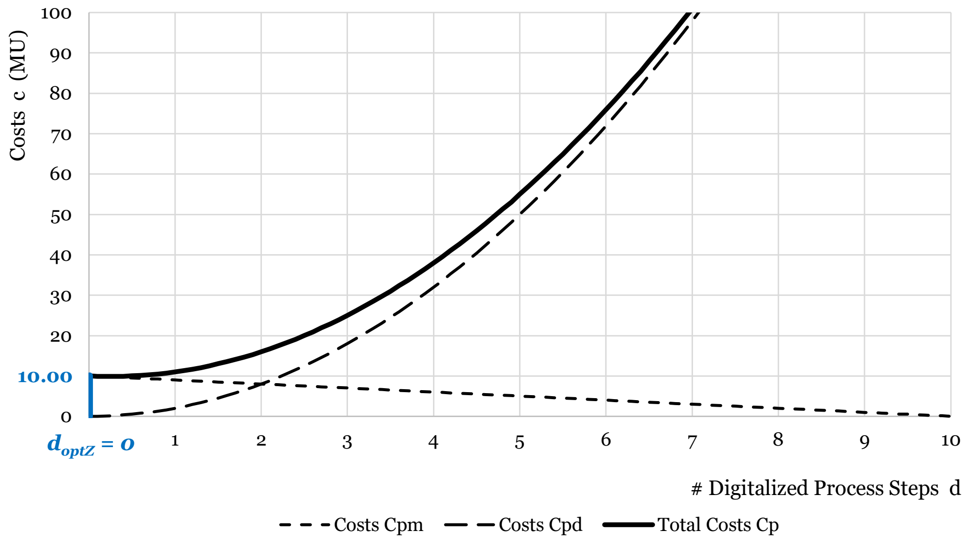
(B) $1 \leq d_{optZ} \leq p - 1$: In this situation, d_{optZ} process steps should be digitalized in order to achieve the cost minimum. At the same time, $m_{optZ} = p - d_{optZ}$ process steps should be manually performed. To meet the outlined condition for d_{optZ}, the following must apply: $0.5 \leq d_{opt} \leq p - 0.5$. According to equation [6] the relation of coefficients has to be within the following ratio: $C_i \leq c_m \cdot n \cdot p \leq C_i \cdot (2 \cdot p - 1)$. As can be seen in the example, this ratio is true for the given data of the numeric example. The calculated (integer) solution $d_{optZ} = 5$ is within the constraints of the ratio $1 \leq \mathrm{d_{optZ}} \leq 10 - 1$.

(C) $d_{optZ} = p$: All process steps are to be digitalized in order to achieve the cost minimum. From a cost perspective it is not efficient to retain any manual process steps, i.e. $m_{optZ} = 0$. This situation occurs if the product of manual costs c_m, process cycles n and total number of process steps p is relatively large compared with the costs of digitalization C_i.

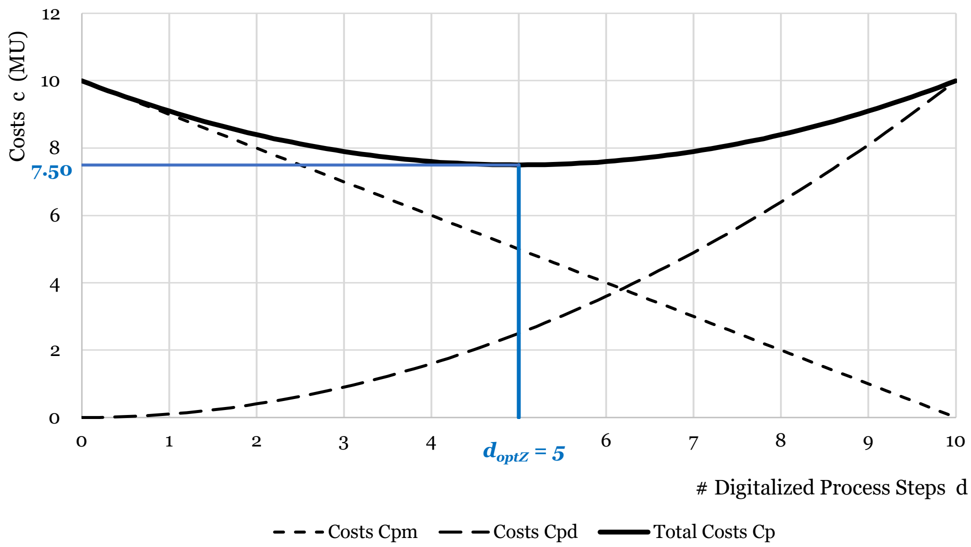
Hence, the following condition $c_m \cdot n \cdot p > C_i \cdot (2 \cdot p - 1)$ must be true, so that the following applies: $d_{optZ} = p$, i.e. $d_{opt} > p - 0.5$. In the example, it follows that $d_{optZ} = 10$ if $n > 1{,}900$ and all other values c_m, p und C_i remain constant.

The three characteristic cases of the optimization model are depicted in Figure 2 in separate diagrams, in which only the parameter n is varied, i.e. Case (A) $n = 50$, Case (B) $n = 1{,}000$, and Case (C) $n = 1{,}950$.

Case (A): "Not Digitalized" (n = 50)



Case (B): "Partly Digitalized" (n = 1,000)



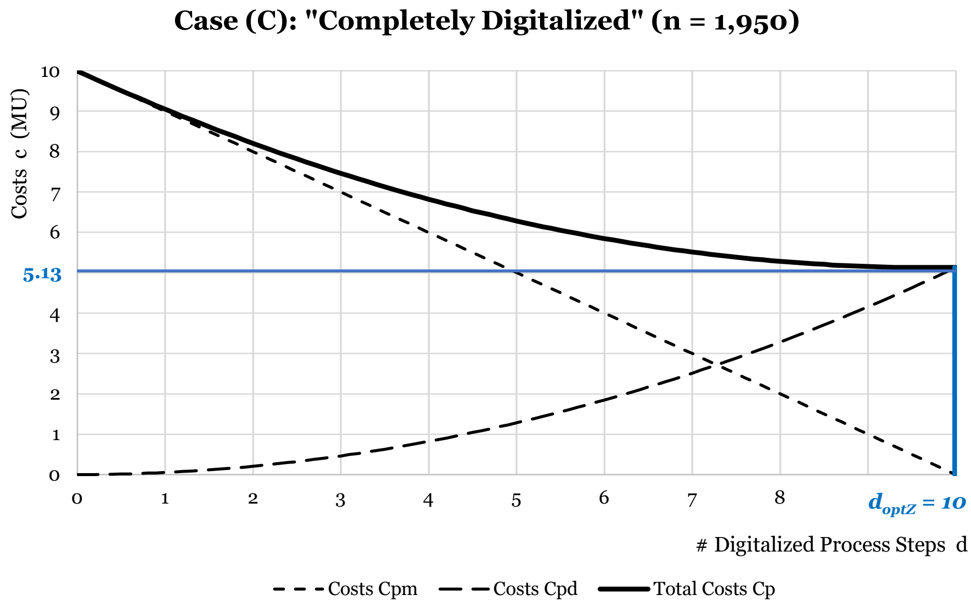


Figure 2: Characteristic Cases of the Optimization Model

CONCLUSION

From research perspective, a number of authors argue that Industry 4.0 shows the characteristics of a "digital evolution" rather than an "industrial revolution" (Becker et al. 2017). Although the technical requirements for the complete automation and networking of processes have already been met, many companies are pursuing the strategy of continuously developing existing structures and processes. The radical or disruptive change in the process architecture is the exception rather than the rule. It can be assumed that it will take a few more years until all manual activities are replaced by digital technologies. In this context, the decision-making process based on economic rationality is crucial.

In this paper, an optimization model is developed which – based on relevant input variables – allows the determination of the cost-efficient degree of digitalization of processes. The target function consists of two sub-functions taking into account the costs for manual and digitalized process steps. The minimum costs of the business process depend on the number of process repetitions, the investment costs for digitization, e.g. automation of single process steps, as well as the manual process costs. On the basis of this comprehensive model, all empirically observable cases, i.e. from purely manual work to fully digitized business processes, can be analyzed and/ or reviewed in respect of overall cost efficiency.

Due to the derived square target function, the mathematical model is very clear and easy to understand. As outlined, there is only one optimal solution. The critical cause-and-effectrelationships can be identified and mathematically described. Nevertheless, the level of abstraction is relatively high, especially from a business perspective, so that the complexity of organizations could not be completely taken into account. As with other theories, the cost model is subject to strongly simplifying assumptions, e.g. fixed planning period and constant cost rates. The economic benefit of digitization projects is determined in the form of opportunity costs, based on the saved costs for the manual execution of process steps.

All in all, the derived cost model is at the beginning rather than at the end of a theory-based view of digital transformation. The optimization formula is a relevant starting point for analyzing the efficiency of existing and/ or future process layouts in terms of optimal digitalization. In this context, characteristic cases or patterns of digitalization can be determined. Sensitivity analyses can help to localize and/ or verify the optimal solution. Further research may focus on the variation and dynamization of these model-related parameters, i.e. cost rates varying over time and/ or differ between single process steps. Finally, empirical research is needed to provide evidences for the usability and accuracy of the model.

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