MEMORIAL

Prof. Ivan Slimák, PhD.
(1932 – 2021)

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Professor Ivan Slimák played a pivotal role in implementing scientific research, education and engineering work in the field of metrology, precision mechanics, quality engineering and quality management. In 1974, he established curriculum Quality Engineering at the Technical University Košice, making Czechoslovakia one of the first countries with such a study program worldwide. Moreover, in 1980 he started and co-organised 16 international conferences, "Quality of Work, Production and Life", in Piešťany. Professor Slimák introduced Statistical Process Control and Total Quality Management systems in many Czechoslovak and later in Slovak companies. He lectured at conferences in the USA, Austria, China and was the founder of a nonprofit organisation, The Slovak Union for Quality (Q-Impulz).

He received recognition from the:

- European Organisation for Quality - EOQ for the introduction of higher education in the field of production quality in Czechoslovakia and doctoral students supervision (1995, 1996).
- Slovak Society for Quality - SSK for lifelong contribution to quality (2015).
- Slovak Society of Standards, Metrology and Testing - ÚNMS for lifelong contribution to quality and metrology (2014).

He was one of the founders of The QIP journal (1995)

Honour his memory!

Study on Likelihood-Ratio-Based Multivariate EWMA Control Chart Using Lasso

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ABSTRACT

Purpose: When applying exponentially weighted moving average (EWMA) multivariate control charts to multivariate statistical process control, in many cases, only some elements of the controlled parameters change. In such situations, control charts applying Lasso are useful. This study proposes a novel multivariate control chart that assumes that only a few elements of the controlled parameters change.

Methodology/Approach: We applied Lasso to the conventional likelihood ratio-based EWMA chart; specifically, we considered a multivariate control chart based on a log-likelihood ratio with sparse estimators of the mean vector and variance-covariance matrix.

Findings: The results show that 1) it is possible to identify which elements have changed by confirming each sparse estimated parameter, and 2) the proposed procedure outperforms the conventional likelihood ratio-based EWMA chart regardless of the number of parameter elements that change.

Research Limitation/Implication: We perform sparse estimation under the assumption that the regularization parameters are known. However, the regularization parameters are often unknown in real life; therefore, it is necessary to discuss how to determine them.

Originality/Value of paper: The study provides a natural extension of the conventional likelihood ratio-based EWMA chart to improve interpretability and detection accuracy. Our procedure is expected to solve challenges created by changes in a few elements of the population mean vector and population variance-covariance matrix.

Category: Research paper

Keywords: average run length; likelihood ratio test; L1 penalty function; multivariate control chart; statistical process control

1 INTRODUCTION

Exponentially weighted moving average (EWMA) multivariate control charts are used when small changes occur continuously. Many applications of EWMA multivariate control charts have been applied to various fields such as quality control and the healthcare sector (e.g., Morton et al., 2001; Yu et al., 2011). In the case of multivariate control charts, Hotelling' s T^2 control chart (Hotelling, 1947) for detecting changes in the mean vector was originally used. However, the control chart does not always detect small changes, so research regarding multivariate EWMA control charts to constantly detect small changes, has become popular. For example, Lowly et al. (1992) proposed a multivariate EWMA (MEWMA) control chart for detecting changes in the mean vector, and Hawkins and Maboudou-Tchao (2008) proposed a multivariate exponentially weighted moving covariance matrix (MEWMC) control chart for detecting changes in the variance-covariance matrix. Additionally, to identify changes in both the mean vector and the variance-covariance matrix, Zhang, Li and Wang (2010) proposed a control chart based on the likelihood ratio, using exponential weighted moving average estimators of the mean vector and covariance matrix, termed the ELR control chart.

Conversely, when applying EWMA multivariate control charts to multivariate statistical process control, in many cases only some of the elements of the controlled parameters change. As a result, various multivariate control charts based on Lasso (Tibishirani, 1996) have been proposed for detecting changes quickly in similar situations. For example, the Lasso-based multivariate EWMA (LEWMA) control chart (Zou and Qiu, 2009), which assumes that a few elements of the mean vector change, and the Lasso multivariate EWMC (LEWMC) control chart (Maboudou-Tchao and Diawara, 2013), which supposes that a few elements of the variance-covariance matrix change, apply Lasso to MEWMA and MEWMC control charts, respectively.

The purpose of this study is to propose a novel multivariate control chart, which assumes that a few elements of the mean vector and the variance-covariance matrix change. Specifically, we aim to achieve this by applying the Lasso to the ELR control chart. The application of Lasso not only improves the accuracy of change detection, but also the ease of interpretation in identifying the variables that affect the change. Subsequently, we evaluate the performance of the proposed procedure by using real data analysis and Monte Carlo simulation.

The remainder of this paper is structured as follows. In Section 2, we describe the ELR control chart according to the existing studies and present an overview of the analysis. In Section 3, we propose a novel multivariate control chart by applying the Lasso to the ELR control chart. In Section 4, we evaluate the

proposed multivariate control chart, mainly in terms of interpretability, using real data analysis. In Section 5, we evaluate the proposed multivariate control chart in terms of change detection accuracy by applying Monte Carlo simulation. Finally, in Section 6, we present the conclusions and scope for future research.

2 EXISTING RESEARCH

In this section, we discuss the ELR control chart (Zhang, Li and Wang, 2010) as per existing research and describe the analysis process.

As described in Section 1, the ELR control chart is a type of EWMA multivariate control chart. In the case of multivariate control charts, a situation in which a controlled process is stable is referred to as "in control". Contrarily, a situation in which a controlled process is unstable is termed "out of control". In general, the purpose of EWMA multivariate control charts is to determine whether a controlled process is in or out of control, whenever new data is observed.

When the process is in control in the ELR control chart, it is assumed that the p-dimensional vector $\boldsymbol{x}$ follows the p-dimensional multivariate normal distribution $N_p(\boldsymbol{\mu}_0, \boldsymbol{\Sigma}_0)$, where $\boldsymbol{\mu}_0$ and $\boldsymbol{\Sigma}_0$ refer to the population mean vector and the population variance-covariance matrix, respectively. As a result, it is assumed that both parameters are known. Therefore, using the matrix $\boldsymbol{A}$ so that $\boldsymbol{A}\boldsymbol{\Sigma}_0\boldsymbol{A}^T = \boldsymbol{I}_p$ and $\boldsymbol{u} = \boldsymbol{A}(\boldsymbol{x} - \boldsymbol{\mu}_0)$, we obtain $\boldsymbol{u} \sim N_p(\mathbf{0}_p, \boldsymbol{I}_p)$ if a process is in control, where $\mathbf{0}_p$ is the p-dimensional zero vector and $\boldsymbol{I}_p$ is the p-dimensional identity matrix. However, when the process is out of control, $\boldsymbol{u}$ follows the general p-dimensional multivariate normal distribution $N_p(\boldsymbol{\mu}, \boldsymbol{\Sigma})$, where, $\boldsymbol{\mu} \neq \mathbf{0}_p$ or $\boldsymbol{\Sigma} \neq \boldsymbol{I}_p$.

Under these assumptions in the ELR control chart, we determine whether a process is in control or out of control at time $t (t = 1, 2, \cdots)$. Then, if $\boldsymbol{u}_t$ is the p-dimensional observable at time $t (t = 1, 2, \cdots)$, this problem can be formulated in the framework of statistical hypothesis testing: "null hypothesis: $\boldsymbol{\mu} = \mathbf{0}_p$ and $\boldsymbol{\Sigma} = \boldsymbol{I}_p$" versus "alternative hypothesis: $\boldsymbol{\mu} \neq \mathbf{0}_p$ or $\boldsymbol{\Sigma} \neq \boldsymbol{I}_p$." Therefore, if the null hypothesis is accepted, the process is estimated as in control, and if the null hypothesis is rejected, it is considered out of control. The test statistics for change detection are as follows.

First, we define the sample mean vector and the sample covariance matrix, weighted according to $\lambda\ (0 \leq \lambda \leq 1)$ in Equations (1) and (2), where $\boldsymbol{w}_0 = \mathbf{0}_p, \boldsymbol{S}_0 = \boldsymbol{I}_p$. In EWMA-type control charts, it is recommended that a small value of $0.1 \sim 0.2$ be used as the value of λ (Wang, Yeh and Li, 2014). Therefore, in this paper, the value of λ is fixed at 0.1 for the subsequent real data analysis and the Monte Carlo simulation.

$$\boldsymbol{w}_t = (1 - \lambda)\boldsymbol{w}_{t-1} + \lambda \boldsymbol{u}_t \tag{1}$$

$$\boldsymbol{S}_t = (1-\lambda)\boldsymbol{S}_{t-1} + \lambda(\boldsymbol{u}_t - \boldsymbol{w}_t)(\boldsymbol{u}_t - \boldsymbol{w}_t)^T. \quad (2)$$

Next, we define a special log-likelihood function in which the sample mean vector and the sample variance-covariance matrix of the multivariate normal distribution for samples of size $t(t = 1, 2, \cdots)$ are replaced by $\boldsymbol{w}_t$ and $\boldsymbol{S}_t$, respectively, as follows:

$$l(\boldsymbol{\mu}_t, \boldsymbol{\Sigma}_t) = \mathrm{Tr}\left[{\boldsymbol{\Sigma}_t}^{-1}\{\boldsymbol{S}_t + (\boldsymbol{w}_t - \boldsymbol{\mu}_t)(\boldsymbol{w}_t - \boldsymbol{\mu}_t)^T\}\right] + \log\det(\boldsymbol{\Sigma}_t). \quad (3)$$

Then, the ratio of Equation (3) with its constrained maximum likelihood estimator under the null hypothesis plugged in and Equation (3) with its unconstrained maximum likelihood estimator plugged in, namely:

$$ELR_t = \mathrm{Tr}(\boldsymbol{S}_t) - \log\det(\boldsymbol{S}_t) + \|\boldsymbol{w}_t\|_2^2 - p \quad (4)$$

is the test statistic, where $\mathrm{Tr}(\cdot)$ and $\det(\cdot)$ denote the matrix trace and the determinant, respectively, and $\|\cdot\|_2$ denotes the L2 norm of the vector. Subsequently, we will refer to the test statistic in Equation (4) as the chart statistic, following the conventions of multivariate control charts.

3 PROPOSED PROCEDURE

In this section, we propose a novel multivariate control chart (hereinafter referred to as LELR control chart), which applies the Lasso to the ELR control chart. In the proposed procedure, we perform change detection on the *p*-dimensional observation variable $\boldsymbol{u}_t$ at time $t(t = 1, 2, \cdots)$, similar to the ELR control chart, based on the framework of statistical hypothesis testing: "null hypothesis: $\boldsymbol{\mu} = \boldsymbol{0}_p$ and $\boldsymbol{\Sigma} = \boldsymbol{I}_p$" versus "alternative hypothesis: $\boldsymbol{\mu} \neq \boldsymbol{0}_p$ or $\boldsymbol{\Sigma} \neq \boldsymbol{I}_p$." However, if the null hypothesis does not hold, we assume that a few elements of the mean vector and covariance matrix changed, where the chart statistics (test statistics) for change detection are as follows.

First, similar to the ELR control chart, we define the sample mean vector and the sample covariance matrix, weighted according to λ $(0 \leq \lambda \leq 1)$ in Equations (1) and (2).

Next, we define the penalized log-likelihood function, which is a special log-likelihood function defined in Equation (3) plus a regularization term, as follows:

$$l_{\rho_1,\rho_2}(\boldsymbol{\mu}_t, \boldsymbol{\Sigma}_t) = l(\boldsymbol{\mu}_t, \boldsymbol{\Sigma}_t) + \rho_1 P(\boldsymbol{\mu}_t) + \rho_2 P(\boldsymbol{\Sigma}_t), \quad (5)$$

where ρ_1 and ρ_2 are non-negative constants, and $P(\boldsymbol{\mu}_t)$ and $P(\boldsymbol{\Sigma}_t)$ are regularization terms for the parameters $\boldsymbol{\mu}_t$ and $\boldsymbol{\Sigma}_t$, respectively. In this paper, we discuss the case in which a Lasso-type regularization term is adopted, although

there are Lasso (Tibishirani, 1996), adaptive Lasso (Zou, 2006), and SCAD (Fan and Li, 2001) regularization terms for $P(\boldsymbol{\mu}_t)$ and $P(\boldsymbol{\Sigma}_t)$.

As a result, the ratio of Equation (3) with its constrained maximum likelihood estimator under the null hypothesis plugged in and Equation (3) with its unconstrained maximum likelihood estimator plugged in, namely:

$$LELR_t = \mathrm{Tr}\left(\widehat{\boldsymbol{\Sigma}}_t\right) - \log\det\left(\widehat{\boldsymbol{\Sigma}}_t\right) + \|\widehat{\boldsymbol{\mu}}_t\|_2^2 - p \tag{6}$$

is the chart statistic, where $\widehat{\boldsymbol{\mu}}_t$ and $\widehat{\boldsymbol{\Sigma}}_t$ are the unconstrained maximum likelihood estimators of Equation (5).

Note that in Equation (5), if we choose adaptive Lasso as $P(\boldsymbol{\mu}_t)$ and estimate the parameters with ρ_2 as zero, the chart statistic is consistent with the chart statistic in the LEWMA control chart (Zou and Qiu, 2009). Similarly, if we choose Lasso as $P(\boldsymbol{\Sigma}_t)$ and estimate the parameters with ρ_1 as zero, the chart statistic is consistent with the chart statistic in the LEWMC control chart (Maboudou-Tchao and Diawara, 2013). Therefore, the chart statistic of the proposed procedure is a natural extension of the chart statistic of LEWMA and LEWMC control charts in the case in which both the mean vector and the covariance matrix change. However, the optimal solution of Equation (5) cannot be obtained analytically, while it is difficult to optimize $\boldsymbol{\mu}_t$ and $\boldsymbol{\Sigma}_t$ simultaneously. For this reason, we use the following estimation algorithm to optimize $\boldsymbol{\mu}_t$ and $\boldsymbol{\Sigma}_t$.

In our optimization algorithm, we update the optimal solutions that correspond to the estimated values of $\boldsymbol{\mu}_t$ and $\boldsymbol{\Sigma}_t$ until the values converge. That is, the update formula for $\widehat{\boldsymbol{\mu}}_t$ and $\widehat{\boldsymbol{\Sigma}}_t$ with $i = 1, 2, \cdots$ are defined as follows:

$$\widehat{\boldsymbol{\mu}}_t{}^{(i+1)} = \underset{\boldsymbol{\mu}_t}{argmin} \left\{(\boldsymbol{w}_t - \boldsymbol{\mu}_t)^T \widehat{\boldsymbol{\Sigma}}_t{}^{(i)^{-1}} (\boldsymbol{w}_t - \boldsymbol{\mu}_t) + \rho_1 \sum_{j=1}^{p} \left|\mu_{t(j)}\right|\right\}, \tag{7}$$

$$\widehat{\boldsymbol{\Sigma}}_t{}^{(i+1)} = \underset{\boldsymbol{\Sigma}_t > 0}{argmin} \left\{\mathrm{Tr}\left[\boldsymbol{\Sigma}_t{}^{-1}\left\{\boldsymbol{S}_t + \left(\boldsymbol{w}_t - \widehat{\boldsymbol{\mu}}_t{}^{(i+1)}\right)\left(\boldsymbol{w}_t - \widehat{\boldsymbol{\mu}}_t{}^{(i+1)}\right)^T\right\}\right] + \log\det(\boldsymbol{\Sigma}_t) + \rho_2 \left\|\boldsymbol{\Sigma}_t - \boldsymbol{I}_p\right\|_1\right\}, \tag{8}$$

where $\left|\mu_{t(j)}\right|$ is the absolute value of the *j*-th element of $\boldsymbol{\mu}_t$ and $\|\cdot\|_1$ is the sum of the absolute values of each element of the matrix. The initial value of $\widehat{\boldsymbol{\Sigma}}_t$ is $\boldsymbol{S}_t$. Note that, by using an estimation algorithm such as per Wang, Yeh and Li (2014), we can apply a modified algorithm of Bien and Tibshirani (2011) to solve the Equation (8), which simplifies the implementation of the algorithm. In addition, the stopping rule is $D_{KL} < \varepsilon$, where D_{KL} is the Kullback-Leibler divergence (Kullback and Leibler, 1951) for $N\left(\widehat{\boldsymbol{\mu}}_t{}^{(i)}, \widehat{\boldsymbol{\Sigma}}_t{}^{(i)}\right)$ and $N\left(\widehat{\boldsymbol{\mu}}_t{}^{(i+1)}, \widehat{\boldsymbol{\Sigma}}_t{}^{(i+1)}\right)$, and ε is the infinitesimal quantity.

Finally, note that if $(\rho_1, \rho_2) = (0, 0)$, the proposed procedure is consistent with the ELR control chart. Therefore, if we set appropriate regularization parameters, the proposed procedure achieves equal or greater accuracy than the ELR control chart. However, in this study, the optimal regularization parameter is determined as an open question, and the discussion proceeds assuming that the value is known. In addition, in subsequent numerical experiments, the optimal parameters are determined in preliminary experiments.

4 REAL DATA ANALYSIS

In this section, we evaluate the proposed procedure mainly in terms of interpretability, using real data analysis.

4.1 Experimental Settings

The experimental settings are as follows. The comparison target is the ELR control chart. The data used (Hawkins and Maboudou-Tchao, 2008) are four consecutive measurements of mean systolic blood pressure, mean diastolic blood pressure, mean heart rate, and overall mean arterial pressure for 24 periods. Because this data follows the change point from the first period, it is important to determine how quickly changes can be detected. Further, the population mean vector and the population variance-covariance matrix prior to the change point is known. Refer to Hawkins and Maboudou-Tchao (2008) for the details of the data.

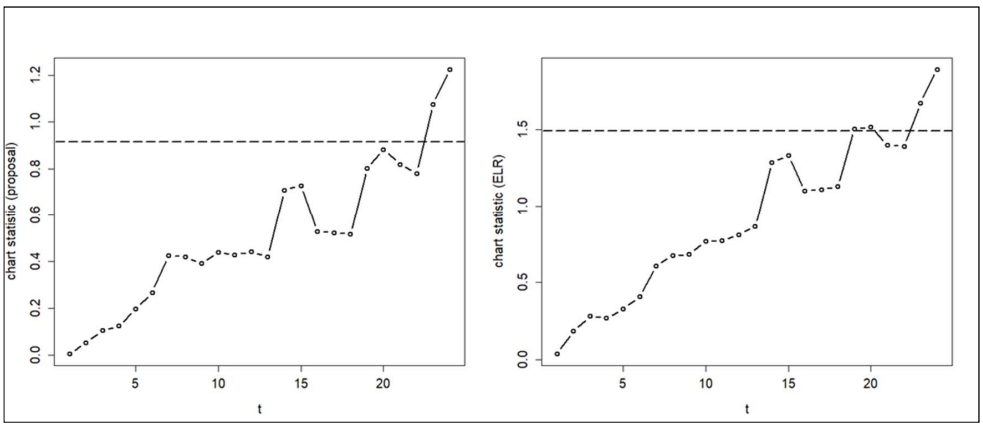
We use the average run length (ARL), which represents the period exceeding the control limit line as an evaluation criterion, where ARL under the null hypothesis is referred to as In Control ARL (IC-ARL), and ARL under the alternative hypothesis is termed Out of Control ARL (OC-ARL). We set IC-ARL = 200 and the control limit line. In addition, we examine the change of the chart statistic in the proposed procedure and the ELR control chart, where the regularization parameters for the proposed procedure are $(\rho_1, \rho_2) = (0.1, 0.1)$. The value of λ in Equations (1) and (2) is 0.1 for both the proposed procedure and the ELR control chart.

4.2 Experimental Results

The experimental results are presented in Figure 1, which shows the control charts of (a) the change in the chart statistic of the proposed procedure, and (b) the change in the chart statistic of the ELR control chart.

In Figure 1a, it is observed that the points of the 23rd and 24th periods exceed the control limit line in the proposed procedure. On the other hand, Figure 1b shows that the points of the 19th, 20th, 23rd, and 24th periods exceed the control limit line in the ELR control chart.

Next, we show the changes in the mean vector and the variance-covariance matrix in periods 23 and 24, which were outside the control limit line in the proposed procedure:



(a) Proposed procedure (b) ELR control chart

Figure 1 – The Changes in Chart Statistic

$$\widehat{\boldsymbol{\mu}}_{23} - \mathbf{0}_4 = (0.000, -0.402, 0.140, 0.048)^T,$$

$$\widehat{\boldsymbol{\Sigma}}_{23} - \boldsymbol{I}_4 = \begin{pmatrix} -0.333 & 0.000 & 0.000 & 0.380 \\ 0.000 & 0.000 & 0.114 & -0.293 \\ 0.000 & 0.114 & -0.475 & -0.081 \\ 0.380 & -0.293 & -0.081 & 1.335 \end{pmatrix}, \tag{9}$$

$$\widehat{\boldsymbol{\mu}}_{24} - \mathbf{0}_4 = (0.000, -0.425, 0.060, -0.248)^T,$$

$$\widehat{\boldsymbol{\Sigma}}_{24} - \boldsymbol{I}_4 = \begin{pmatrix} -0386 & 0.000 & 0.000 & 0.376 \\ 0.000 & -0.048 & 0.110 & -0.207 \\ 0.000 & 0.110 & -0.461 & 0.000 \\ 0.377 & -0.207 & 0.000 & 1.494 \end{pmatrix}. \tag{10}$$

These results show that in the proposed procedure, we are able to estimate certain elements as an exact value of zero and to identify the changing variables. For example, we observe shifts in mean diastolic blood pressure, mean of heart rate and overall mean arterial pressure, and a greater variance in overall mean arterial pressure. By applying Lasso, we confirm that the proposed procedure improves interpretability while maintaining the same accuracy as the ELR control chart.

5 MONTE CARLO SIMULATION

In this section, we evaluate the proposed procedure mainly in terms of change detection accuracy by Monte Carlo simulation.

5.1 Simulation Settings

The simulation settings are as follows. First, the comparison target is the ELR control chart. Next, we prepare four sets of data for the different types of changes. Specifically, we generate multivariate normal random numbers (11) - (14) corresponding to the cases where (A) only the mean vector changes, (B) only the covariances of the covariance matrix changes, (C) only the variances of the covariance matrix changes, and (D) the mean vector and the covariance matrix change.

$$N_{10}\left(\boldsymbol{\mu} = \begin{pmatrix} \boldsymbol{v} \\ \mathbf{0}_k \end{pmatrix}, \quad \boldsymbol{\Sigma} = \boldsymbol{I}_{10}\right) \quad (t = 1,\ 2,\ \cdots), \tag{11}$$

$$N_{10}\left(\boldsymbol{\mu} = \mathbf{0}_{10}, \quad \boldsymbol{\Sigma} = \begin{pmatrix} \boldsymbol{P} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{I}_k \end{pmatrix}\right) \quad (t = 1,\ 2,\ \cdots), \tag{12}$$

$$N_{10}\left(\boldsymbol{\mu} = \mathbf{0}_{10}, \quad \boldsymbol{\Sigma} = \begin{pmatrix} \boldsymbol{Q} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{I}_k \end{pmatrix}\right) \quad (t = 1,\ 2,\ \cdots), \tag{13}$$

$$N_{10}\left(\boldsymbol{\mu} = \begin{pmatrix} \boldsymbol{v} \\ \mathbf{0}_k \end{pmatrix}, \quad \boldsymbol{\Sigma} = \begin{pmatrix} \boldsymbol{R} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{I}_k \end{pmatrix}\right) \quad (t = 1,\ 2,\ \cdots), \tag{14}$$

where $\boldsymbol{v}$ is the $(10-k)$-dimensional vector with each element of δ. In addition, $\boldsymbol{P}$ is a $(10-k)\times(10-k)$ square matrix with off-diagonal elements of δ, $\boldsymbol{Q}$ is a $(10-k)\times(10-k)$ square matrix with diagonal elements of $1+\delta$, and $\boldsymbol{R}$ is a $(10-k)\times(10-k)$ square matrix with diagonal elements of $1+\delta$ and off-diagonal elements of δ. In Equations (11) and (13), we change the value of k in the range of $0 \le k \le 9$, and in Equations (12) and (14), we change the value of k in the range of $0 \le k \le 8$ and perform simulations. The regularization parameters of the proposed procedure are set to $\rho_1 \in \{0,\ 0.01, 0.1\}$ and $\rho_2 \in \{0,\ 0.01, 0.1\}$, while the optimal parameter is selected by preliminary experiments from nine combinations. The value of λ in Equations (1) and (2) is 0.1 for both the proposed procedure and the ELR control chart.

We use ARL as an evaluation criterion, as well as real data analysis. In this simulation, we set IC-ARL = 200 and the control limit line. In addition, we evaluate the mean of OC-ARL for 5000 simulations, in which a smaller OC-ARL is preferable.

5.2 Simulation Settings

We indicate the results of this experiment by $\delta = 0.1$ in Figure 2–5. In each figure, the solid line refers to the change in OC-ARL of the proposed procedure, and the dotted line indicates the change in OC-ARL of the ELR control chart. However, for each value of k in the proposed procedure, we describe the best performing results among the nine combinations of regularization parameters. We obtained the same results for $\delta = 0.5, 1.0$.

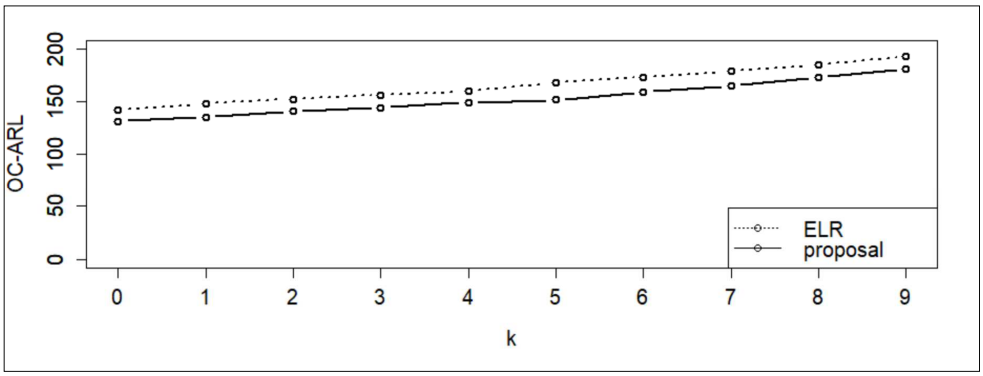


Figure 2 – Comparison of OC-ARL for the Proposed Procedure and the ELR Control Chart (Only the Mean Vector Changes)

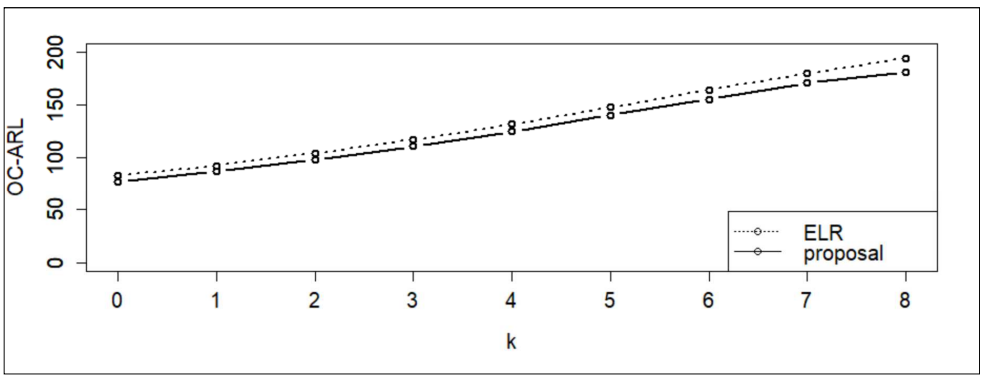


Figure 3 – Comparison of OC-ARL for the Proposed Procedure and the ELR Control Chart (Only the Covariances of the Covariance Matrix Changes)

From Figure 2-5, it is observed that in all situations in Equations (11) - (14), the proposed procedure shows greater accuracy than the ELR control chart. Although the proposed procedure assumes that both the mean vector and the covariance matrix change, we can execute change detection without any problems, even in a situation where only one changes.

It is noted that regardless of the number of changing elements, the proposed procedure shows greater accuracy than the ELR control chart. The proposed procedure assumes a situation in which a few elements change. In the data

generation method assumed in this simulation, the effect of Lasso's shrinkage estimation may have resulted in satisfactory accuracy, even in situations in which many elements change. In this simulation, the change is fixed at δ for all elements, but it should be noted that if different values are set for each element, the shrinkage estimation may not function well, and the accuracy may be inadequate.

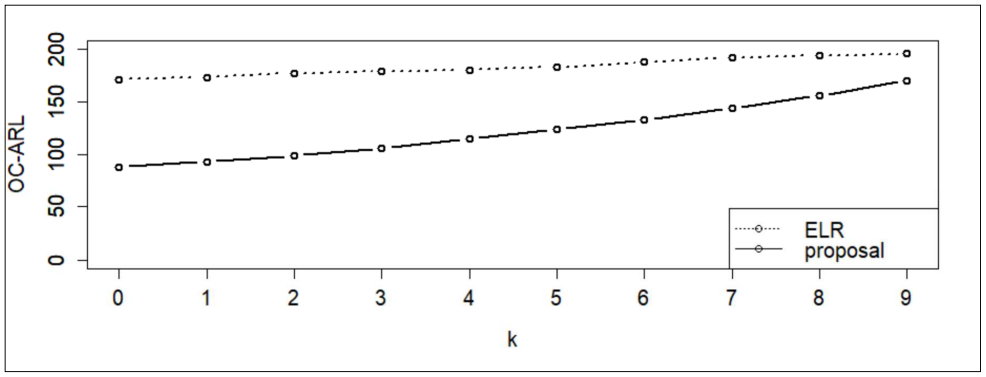


Figure 4 – Comparison of OC-ARL for the Proposed Procedure and the ELR Control Chart (Only the Variances of the Covariance Matrix Changes)

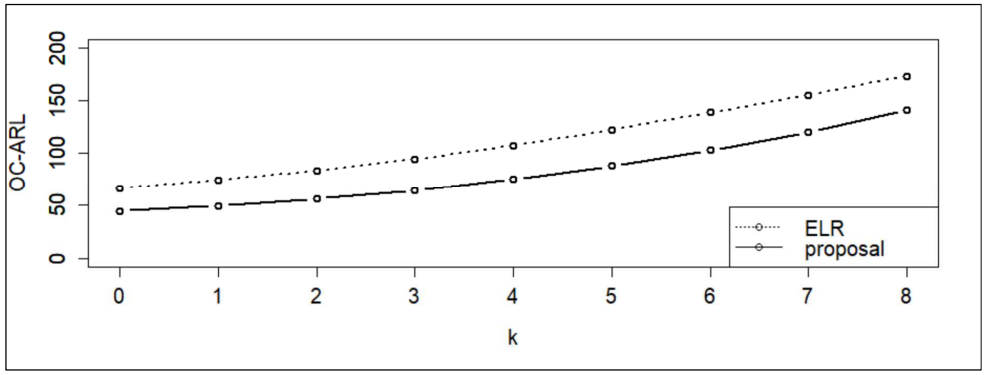


Figure 5 – Comparison of OC-ARL for the Proposed Procedure and the ELR Control Chart (the Mean Vector and the Covariance Matrix Change)

6 CONCLUSION

In this study, we adopted the ELR control chart, which is one of the EWMA-type multivariate control charts, and proposed a novel multivariate control chart by applying Lasso. Specifically, we suggested a multivariate control chart based on a log-likelihood ratio with sparse estimators of the mean vector and the variance-covariance matrix, assuming a situation in which a few elements of each parameter change. Subsequently, through real data analysis, we showed that it is possible to identify which elements of the mean vector and the variance-covariance matrix have changed by confirming each of the sparse estimated

parameters. Additionally, through Monte Carlo simulations, we showed that the proposed procedure outperforms the ELR control chart regardless of the number of elements that change in the parameters. Additionally, we showed that the proposed procedure can be applied to situations where both the mean vector and the variance-covariance matrix change, and situations where only one of them changes.

The scope for future research is as follows. In this study, we discussed the appropriate regularization parameters. As described in Section 5, the proposed procedure indicates equal or improved accuracy compared to the ELR control chart, if appropriate regularization parameters are set. Contrarily, it is necessary to determine the regularization parameters from the observed data for practical purposes. Whether cross-validation and various information criteria can be applied to determine the regularization parameters, should also be verified. In addition, we conducted the experiment with the value of λ fixed at 0.1 in Sections 4 and 5. We would like to discuss how to determine the value of λ. Finally, although different statistics are used, pGLR chart (Wang, Yeh and Li, 2014) that is an application of Lasso to GLR chart, can detect the change of the mean vector and the variance-covariance matrix, as well as ELR chart. It would prove valuable to compare the proposed procedure with these control charts.

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Effects of Systematic Changes in Commodity Arrangement on the Satisfaction of Supermarket Customers

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ABSTRACT

Purpose: The paper investigates if relocation of goods at supermarkets, practised to boost sales, bothers customers and improves financial results of the stores. To explore this, a questionnaire-based poll was run, using questions, such as "Do you mind if commodity is not permanently in the same place?", or "While searching, do you buy anything you did not indend to buy?". Various relations are also observed. For instance, are opinions on product relocation related in any way to age of customers? The study suggests most customers are not satisfied with changes in product location, yet the practices lead to higher sales. It turns out the business principle – only satisfied customers spend more – may not be so true. In the study, some new questions also arose and were evaluated, such as the question "Which management activities have a positive effect on customers?".

Methodology/Approach: The paper relies on statistical testing, specifically on the chi-square test of independence and a test of differences in the relative frequency of occurrence of diverse phenomena. Real, empirical data are utilized.

Findings: The analysis showed that most customers dislike looking for goods, and many of them buy items that they did not intend to purchase. Thus, a paradox occurs when entrepreneurs dissatisfy customers, yet they register higher profits.

Research Limitation/Implication: The results concern a specific scientific field – microeconomic behavioural patterns at supermarkets.

Originality/Value of paper: The research presented in this paper is focused on the Czech Republic where it has not been undertaken to date. Work of this kind is not cited in the scientific literature, however.

Category: Technical paper

Keywords: commodity location; customer satisfaction; contingency tables

1 INTRODUCTION

It is a common practice of many supermarkets to alter systematically the placement of their products so that customers are forced to glance at other items while going after an originally planned purchase. This practice is expected to boost sales. The aim of the presented research, which generally concerns human factors (HF) in quality management, is to learn whether searching for goods discomforts customers and whether customers really buy items they did not originally plan to buy. A confirmation of both the dissatisfaction and higher expenses would mean that the theory about satisfied customers spending more might not be generally valid. From a practical point of view, one could also ask the question of how far negatively perceived business activities can go before customers switch to competition, or how such practices can be compensated with other activities. Therefore many other relations of this sort can also studied.

The research presented in this paper is focused on the Czech Republic where it has not been undertaken to date. Work of this kind is also not mentioned in the scientific literature. Conclusions based on the research may be of interest when compared with experience from foreign supermarkets, especially when their owners and management run subsidiaries in Central and Eastern Europe.

In the past, researchers set diverse objectives focused on various business fields, gathered data from different states and employed and compared various mathematical and statistical tools. A large portion of the papers is dedicated to HF in business management (Hendrick, 1980). These articles dealt with a wide spectrum of questions ranging from more general ones, such as those related to understanding customer behaviour (Perugini and Conner, 2000; Tauber, 1972), to special issues including confidence of customers (Gefen, 2000), knowledge of relations and security (Belanger, Hiller and Smith, 2002; Jarvenpaa, Tractinsky and Vitale, 2000; Koufaris, 2002). Some very specific subjects were covered, as well – for example, purchase of clothes on the internet (Goldsmith and Goldsmith, 2002; Liang and Huang, 1998). Much attention is also paid to e-commerce where the subject of interest are measuring satisfaction (Chang, Torkzadeh and Dhillon, 2004), understanding customers (Donthu and Garcia, 1999; Limayem, Khalifa and Frini, 2000), relations between e-commerce and traditional commerce (Eastin, 2002; Farag, Krizek and Dijst, 2006), specifications of e-commerce in selected countries (Sim and Koi, 2002), issues of buying goods on the internet (Verhoef and Langerak, 2001; Walczuch and Lundgren, 2004), effects of internet promotional material on sales (Vijayasarathy and Jones, 2000; Peterson, Balasubramanian and Bronnenberg, 1997) and many others.

Various statistical methods have been used in the research, and the methods were compared to other techniques (Fabrigar et al., 1999; Hansen, Jensen and Solgaard, 2004; Widaman, 1993). Since much of the work draws on questionnaires, the question of acquiring data samples and processing them is of importance too (Krizek, Li and Handy, 2005; Ory and Mokhtarian, 2007), as is

the methodology of composing questionnaires (Ellard and Rogers, 1993; Baumgartner and Steenkamp, 2001; Babbie, 1998). Theoretical models of the explored relations have also been designed (Dijst, Farag and Schwanen, 2008). Papers fairly often compare different sales strategies and reasons why they are preferred (Chen, Gillenson and Sherrell, 2002; Childers et al., 2001; Li, Kuo and Russell, 1999; Shang, Chen and Shen, 2005). Articles serving as a compendium and presenting a complex overview of these problems (Cao and Mokhtarian, 2005) are also of practical importance.

2 METHODOLOGY

In a related research work (Dočkalová, 2016) carried out at the Department of Quality Management of VŠB – Technical University of Ostrava, hundreds of randomly selected supermarket customers were polled. The selection consisted of 36.7% of men and 63.3% of women. There is generally a higher probability of women being polled because they visit supermarkets more frequently, being usually the ones in charge of home economics. Regarding educational level, 28.3% of the polled customers had no secondary education, 34.4% had a secondary education and 34.4% were university graduates.

Six age categories were also created: less than 20 years of age (3.9% of respondents), 21-30 years of age (17.8%), 31-40 years old (27.9%), 41-50 years old (22.1%), 51-60 years old (16.9%) and 61 years of age or older (11.4%). The most populous group of all were women aged 31-40 years (18.8%). In all but one group – that of the respondents under 20 years of age, women dominate, the most striking dominance being in the group of 50-61 years of age (25% men, 75% women).

The respondents filled out a questionnaire containing nine questions and offered answers of the type *yes*, *no*, *I do not care*. Subsequently, the following was evaluated using statistical methods that involve testing significance of differences in relative frequencies of responses, analysis of means for proportions (Wludyka, Karen and Copeland, 2005) and testing independence in contingency tables:

- Do the response frequencies differ significantly, or are they the same?
- Which responses occur with an above-average frequency, average frequency and below-average frequency?

Is the type of response related to education, age or sex of the respondents?

3 POLL RESULTS

The results of the analysis of questionnaires are presented in section 3.1 in a unified manner: a question is stated together with possible answers, the result of the test on significant differences in responses (p-value) is presented afterwards, and an evaluation of the responses is done together with a comment. Section 3.2

presents the analysis of relations between the responses and sex, education and age. The evaluation is described in a greater detail for questions one and two which are the main objective of the research.

3.1 Differences in Responses

Each respondent received a questionnaire with nine questions so that a statistical evaluation of differences in opinions, or relative frequencies of occurrence of given responses, could be performed. The results are contained in this section. Table 1 contains frequencies of provided responses and the p-value for the test of equality of relative frequencies.

Question 1: Do you mind if goods are not permanently located in the same place?

Possible answers: yes/no/I do not care

Result: The hypothesis of equal relative frequencies of occurrence of the responses was rejected (p-value = 0.000). Comparing the responses to the question, it was obvious that most customers are bothered by continuous relocation of commodity (73.7% of them said *yes* compared to 12.9% saying "*no*", while 13.3% "*did not care*").

Comparisons of relative frequencies can be performed in the Statgraphics software using the option Compare/Two Samples/Hypothesis Tests/Binomial Proportions for the case of two frequencies or the option Compare/Multiple Samples/Comparison of Proportions for the case of more than two relative frequencies. The tested statement is the hypothesis H_o: $\pi_1 = \pi_2 = \ldots = \pi_k$, where π_i is the relative frequency of the *i*-th response in the corresponding population.

Further, the analysis-of-means graph was exploited to find out which of the response frequencies differ significantly from the average. Significantly different are the responses the proportion of which either exceeds the so-called upper decision line UDL or is below the lower decision line LDL (Nelson, Wludyka and Copeland, 2005). Regarding this question, the graph shows that the "*yes*" response has an above-average frequency, whereas the "*no*" and "*I do not care*" responses have significant below-average frequencies. This procedure is used for all nine questions, although the graph is depicted only for the first two questions.

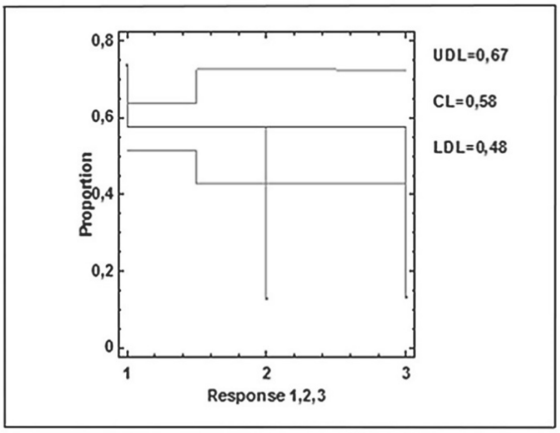

Figure 1 – Analysis-of-Means Plot for Question 1

Question 2: Do you buy anything you did not intend to buy while searching?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0001). Although most customers are bothered by the need to look for relocated commodity (50.6%), they also buy goods they originally did not want to purchase. Only 11.6% of them follow strictly their original shopping plans, whereas 37.6% shoppers buy additional items only occasionally, depending on what they spot during the shopping process. Using the graphical method, the number of "*yes*" responses is significantly above average, the number of "*no*" responses is located significantly below average and the "*sometimes*" response is not significantly different from the average number.

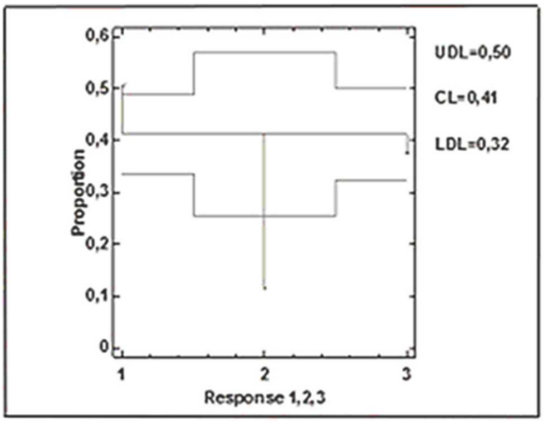

Figure 2 – Analysis-of-Means Plot for Question 2

Question 3: Do you think supermarkets change location of goods intentionally to increase sales?

Possible answers: yes/no/I do not know

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value=0.0001). Overall, 79.5% of customers believe that relocation of goods is intentional. Only 4.5% of them does not think so and 15.9% does not know.

Question 4: Do you return to such supermarkets?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0). Although a majority of customers is discontent with searching for goods, a high percentage of them (73.7%) returns to the stores. Only 3.8% of them goes elsewhere and 22.4% visits occasionally a different supermarket. The proportion of those who return is significantly above average, whereas the frequency of the other two responses is below average.

While exploring opinions on goods relocation, unplanned purchases and potential migration to competitive stores, other possible factors which might affect customers positively or negatively were also observed. These factors are taken into account in questions 5-9.

Question 5: Do you mind inaccessibility of shop assistants at supermarkets?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0013). It was explored whether customers mind if there is nobody to get advice from if need be while shopping. The inaccessibility is viewed as a problem by 46.1% of customers, while 19.4% do not mind and 34.4% of shoppers only sometimes regard it as a problem. The graphical evaluation of the responses shows that the "*yes*" answer is well above average, the "*sometimes*" response has an average occurrence and the "*no*" response is below average, regarding the frequency of their occurrence. Therefore it is worth considering an additional number of shop assistants. Their presence is appreciated particularly when they are well-informed, kind to customers and can even remember regular visitors to their supermarket.

Question 6: Do you visit supermarkets due to discounts?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0090). Discounts regularly benefit 43.1% of customers, they are not exploited by 20.7% of customers and they are sometimes sought after by 36% of customers. The number of clients who regularly seek discounts is not significantly above average, even though their number is the highest. The first and third responses are average in number, based on the graphical evaluation. The number of those who do not seek discounts is significantly below average.

Question 7: Are you affected by scents at supermarkets?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0). Pleasant scents were considered a factor that might increase interest in bakery products. The most frequent answer is no (55.5%) and this number is significantly high, judged by the graphical method. Scents have a positive effect on 25% of customers only and sometimes on 19.4% of them. The last two numbers are significantly below average.

Question 8: Are you positively affected by music at supermarkets?

Possible answers: yes/no/sometimes

Result: The hypothesis of equal relative frequencies of the responses is rejected (p-value = 0.0). As in the case of scents, music does not influence most customers (50.3%). It does have a positive effect on 30.1%, which is an average number, sometimes it has a positive effect in 19.4% of cases, which is a below-average number.

Question 9: Are you content with commodity arrangement at supermarkets?

Possible answers: yes/no/I do not care

Result: The hypothesis of equal relative frequencies of the responses is accepted (p-value = 0.091). The most frequent response is the "*I do not care*" response (40.5%), which however is an average number according to the analysis-of-means graph. An average number also concerns the responses yes and no. Thus, question 9 is answered equally in all three response categories. As is shown in Table 1, this is the only case when the responses are equally represented, regarding the population number of their occurrence. Table 1 summarizes the tests of equal occurrence of various responses.

Table 1 – Results of the Tests of Equal Occurrence of Responses

Question	*Answer*	*Frequency*	*Relative f.*	*%*	*P-value*
1	Yes	227	0.737	73.70	0.00
	No	40	0.1299	12.99	
	No care	41	0.1331	13.31	
2	Yes	156	0.5065	50.65	0.00
	No	36	0.1169	11.69	
	At times	116	0.3766	37.66	
3	Yes	245	0.7995	79.55	0.00
	No	14	0.0455	4.55	
	I do not Know	49	0.159	15.90	

Question	*Answer*	*Frequency*	*Relative f.*	*%*	*P-value*
4	Yes	227	0.737	73.70	0.00
	No	12	0.0389	3.890	
	At times	69	0.224	22.4	
5	Yes	142	0.461	46.10	0.0013
	No	60	0.1948	19.48	
	At times	106	0.3441	34.41	
6	Yes	133	0.4318	43.18	0.009
	No	64	0.2078	20.78	
	At times	111	0.3604	36.04	
7	Yes	77	0.25	25	0.00
	No	171	0.5552	55.52	
	At times	60	0.1948	19.48	
8	Yes	93	0.3019	30.19	0.00
	No	155	0.5032	50.33	
	At times	60	0.1948	19.48	
9	Yes	104	0.3377	33.77	0.091
	No	79	0.2565	25.65	
	No care	125	0.4058	40.58	

3.2 Relation of Responses to Sex, Education and Age

Only differences in frequencies of occurrence of the responses have been evaluated so far. Since the answers may be different depending on sex, age and education of the respondents, an analysis has been carried out on how the three categories affect the opinions. The effects were evaluated using the chi-square test of independence. The tested hypothesis is: the two observed variables are independent.

The contingency tables are shown for the most important questions one, two and four. For the other questions, comments on the test results are presented without the tables.

Question 1: Do you mind if goods are not permanently located in the same place?

Table 2 – Sex: Response Contingency Table

	Yes	*No*	*No care*
Male	73	18	22
Female	154	22	19

Since the p-value = 0.0159 is less than the significance level alpha of 0.05, we reject the hypothesis that the rows and columns are independent. The observed rows are related to the columns. Women seem to be bothered more than men when they must look for goods they want to buy. At the 0.01 significance level, however, the dependence cannot be confirmed.

Table 3 – Education: Response Contingency Table

	Yes	*No*	*No care*
Elementary	59	13	15
Secondary	79	13	14
Tertiary	89	14	12

Since the p-value = 0.6068 is greater than alpha = 0.05, we cannot reject the hypothesis that the rows and columns are independent at the 0.05 significance level. The row categories may bear no relation to the column categories. Education seems to be unrelated to the relocation of commodity.

Table 4 – Age: Response Contingency Table

	Yes	*No*	*No care*
< 20	4	4	4
21-30	38	11	6
31-40	60	12	14
41-50	57	5	6
51-60	41	5	6
> 60	27	3	5

The p-value equals 0.0487. Since the p-value is roughly at 0.05, and there is no connection between the two variables at 0.01 significance level, one cannot conclude that age is related to the opinion on goods relocation.

Question 2: Do you buy anything you did not intend to buy while searching?

Table 5 – Sex: Response Contingency Table

	Yes	*No*	*Sometimes*
Male	44	23	46
Female	112	13	70

The observed rows seem to be related to the columns, since p-value = 0.0002. The hypothesis of no relation between the two factors is rejected. Women make an unplanned purchase more often than men (57.4% of women vs. 38.9% of men) despite the fact that they dislike commodity relocation more than men.

Table 6 – Education: Response Contingency Table

	Yes	*No*	*I do not care*
Elementary	46	15	26
Secondary	53	14	39
Tertiary	57	7	51

The observed rows may bear no relation to the columns. Unplanned purchases have no relation to education: p-value = 0.075.

Table 7 – Age: Response Contingency Table

	Yes	*No*	*No care*
< 20	8	2	2
21-30	29	5	21
31-40	51	7	28
41-50	31	12	25
51-60	25	7	20
> 60	12	3	20

The observed rows may bear no relation to the columns. The inclination to buy unplanned items is not related to age: p-value = 0.1853.

Question 3: Do you think that supermarkets relocate goods purposefully?

Evaluations: a) the relation sex – response: the p-value = 0.5354, which means that we cannot reject the hypothesis that the rows and columns are independent. A relation between sex and the opinion that supermarkets relocate commodity purposefully has not been proved; b) the relation education – response: the p-value = 0.0154. Since the p-value is less than 0.05, we can reject the hypothesis

that rows and columns are independent; c) the relation age – response: the p-value = 0.0003. Since the p-value is less than 0.01, we can reject the hypothesis that rows and columns are independent. There seems to be a relation between age and the opinion on purposeful commodity relocation.

Question 4: Do you return to such supermarkets?

Table 8 – Sex: Response Contingency Table

	Yes	*No*	*Sometimes*
Male	86	6	21
Female	141	6	48

Since the p-value = 0.33 is greater than 0.05, we cannot reject the hypothesis that the rows and columns are independent at 5% significance level. The inclination to return to supermarkets where goods are relocated from time to time does not have a significant relation to the sex status.

Table 9 – Education: Response Contingency Table

	Yes	*No*	*No care*
Elementary	63	5	19
Secondary	83	5	18
Tertiary	81	2	32

The observed rows may have no relation to the columns, as the p-value = 0.2206. The opinion on changing the supermarkets is not related to education.

Table 10 – Age: Response Contingency Table

	Yes	*No*	*No care*
< 20	9	0	3
21-30	43	1	11
31-40	64	4	18
41-50	45	6	17
51-60	36	1	15
> 60	30	0	5

The observed rows seem unrelated to the columns: the p-value = 0.3354. The opinion on changing the supermarket is not related to age.

For the other questions, the conclusions are stated without contingency tables.

Question 5: Do you mind if sales force is unavailable at supermarkets?

Evaluations: a) the relation sex – response: the p-value = 0.0014, which means, even at 1% significance level, that we can reject the hypothesis of independence of the rows and columns. Age seems to be related to the type of response to unavailability of sales personnel. In the category of men, 44.3% of respondents mind the absence of sales force, whereas 30% do not mind and 25.7% is bothered by this situation only sometimes. In the category of women, 47.7% do mind, 13.8% do not mind and 38.5% mind only sometimes; b) the relation education – response: the p-value = 0.2405. This leads to the conclusion that we cannot reject the hypothesis of the rows and columns being independent. Education does not affect the opinion on absence of sales force; c) the relation age – response: the p-value = 0.0519. At the 10% significance level, this would mean that there is a relation between age and the opinion on absence of sales force, at the 5% level, however, the test is rather inconclusive.

Question 6: Do you visit supermarkets due to discounts?

Evaluations: a) the sex – response relation: since the p-value = 0.2081 is greater than 0.05, we cannot reject the hypothesis that the two categories are independent. Men and women take the same approach to discounts at supermarkets; b) the education – response relation: the p-value = 0.0468. Visiting supermarkets due to discounts is related to education. Discounts are sought after mostly by people with secondary education (52.9%), the least by people with tertiary education (33%); c) the age – response relation: the p-value = 0.4863, and so the opinions on discounts seem unrelated to age.

Question 7: Are you affected by scents at supermarkets?

Evaluations: a) the sex – response relation: the p-value = 0.0013. The tested hypothesis of independence of the two categories is rejected. Women are affected by scents more than men; b) the education – response relation: the p-value = 0.4003. The effect of scents is not related to education; c) the age – response relation: the p-value = 0.0927. Age does not seem to be related to the perception of scents at supermarkets at the 5% significance level.

Question 8: Are you positively affected by music at supermarkets?

Evaluations: a) the sex – response relation: the p-value = 0.3288. Music at supermarkets does not affect men and women differently; b) the education – response relation: the p-value = 0.4465. The effect of music on customers is not related to education; c) the age – response relation: the p-value = 0.2194. Music at supermarkets is not related to age.

Question 9: Are you content with commodity arrangement at supermarkets?

Evaluations: a) the sex – response relation: the p-value = 0.176. The way goods are arranged at supermarkets has the same effect on women and men; b) the education – response relation: the p-value = 0.2606. Opinions on commodity arrangement are not related to education; c) the age – response relation: opinions on commodity arrangement are not related to age, since the p-value = 0.3458.

4 CONCLUSION

This study had two objectives: to find out how supermarket customers perceive relocation of goods, which is practised to boost sales, and to observe whether such practices do increase sale. It turns out that most customers dislike looking for goods (74%), and many of them (50%) buy items that they did not originally intend to purchase. Thus, from a theoretical point of view, a paradoxical situation occurs when entrepreneurs intentionally pursue activities that dissatisfy customers, yet they register higher profits. All this despite the usual assumption, given by general business management principles, that only satisfied customers return and spend more. This principle is still valid, but not in absolute terms. If a customer isn't satisfied with key business features, he or she will switch to another supermarket, if there is such a possibility. From our experience, key features include mainly commodity prices and quality. The time of purchase and difficulties given by the search for shopping items do not rank among the key features that give rise to changing the supermarket. According to our study, customers (73%) will not change their supermarket because goods is relocated from time to time. Most of the polled customers (85%) have encountered the practice of commodity relocation. While analysing customers' opinions on the aforementioned issues, other facts were also observed such as relations of these opinions to education, sex and age of the customer, or whether music and scents, i.e. positive business activities, generally speaking, have an effect on customers.

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What Determines Firm's Innovation? The Case of Catching-up CEE Countries

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ABSTRACT

Purpose: The purpose of the paper is to recognize significant innovation determinants on firms' product, process, and overall innovation activity.

Methodology/Approach: The source of data for the analysis is the Community Innovation Survey 2012-2014. If the company has implemented the relevant innovation activity, they acquire a value of 1, or, if the company has not performed a certain activity in the period, they reached 0. As the variables are binary, the logistic regression analysis was used.

Findings: Based on the results from the analysis, we defined the proper determinants of firms' innovation activities but unfortunately, firms are not able to achieve innovative outputs, specifically within CEE countries. This is due, among other things, to several factors such as different conditions in individual countries, different innovation policies at the national as well as company level, managerial approach (aversion) to risk, mistrust between the various actors, and many others. A typical example is the impact of internal R&D on firm innovations. While in the case of product innovations we found a significant positive impact, in the case of process innovations the impact was negative

Research Limitation/Implication: We performed on outdated data and we did not make a comparison with countries from Western Europe.

Originality/Value of paper: The paper analyses innovation determinants and it is importance for innovation activities within the CEE countries.

Category: Research paper

Keywords: product innovation; process innovation; CEE countries; knowledge

1 INTRODUCTION

Knowledge and innovation have been recently determined as a strategic resource of competitive advantage in today's global and intensive business environment (Nielsen, 2010; Mahdi, Nassar and Almsafir, 2019). Moreover, firms realized that acquiring external knowledge, as a vital factor of economic growth, is an efficient way to ensure the achievement of their goals (Che et al., 2019; Asimakopoulos, Revilla and Slavova, 2020). Subsequently, it helps to gain a sustainable competitive advantage in the marketplace (Barkhordari, Fattahi and Azimi, 2019). Therefore, we can see a shift from closed to open innovation models that provide firms a number of various resources and other advantages connected with the firm's openness. However, there are significant differences between firms and countries and their readiness to become more open. While a number of Western European countries successfully applied various models based on Chesbrough's open innovation concept (see e.g. Chesbrough, 2017; Bogers, Chesbrough and Moedas, 2018), Central and Eastern European (CEE) countries struggled. There are several reasons for this phenomenon.

On the one hand, Western countries (e.g. Germany) belong to the group of countries that are able to develop their innovation potential, reach high positions in the inter-European firm comparison due to their innovation performance, and represent the global leaders in competitiveness, not only in the context of the knowledge economy (Prokop and Stejskal, 2019a). On the other hand, despite the fact that the communist regime in CEE countries collapsed, the firm's and its employees' mindset within CEE countries might still be affected by the ideologies and cultural specifics from the past (Ivanova-Gongne et al., 2018). In terms of scientific publication counts in the Web of Science, post-communist countries are still lagging far behind their EU counterparts (Jurajda et al., 2017). Moreover, firms within these catching-up CEE countries are affected by several negative effects, such as lock-in or not-invented-here (NIH). The dependence of the lock-in effect is among the concepts that seek to explain the decline of the region's economic development how highly productive regions could lose competitiveness (MacVaugh and Schiavone, 2010). On the other hand, not-invented-here syndrome describes as an employee's generally has difficulties with externally introduced ideas and developments and are not able or they are not willing to accept external knowledge sources (Kathoefer and Leker, 2012).

Therefore, there are number of studies that focused on the CEE countries. For example, Stejskal, Mikušová Meričková and Prokop (2016) analyzed the case of cooperation within the Czech Republic in the process of product and process innovations creation. They showed that cooperation with universities and research institutes plays an important role. Odei, Stejskal and Prokop (2020) found out, in the case of countries from Visegrad Group (except Poland), that engaging in R&D was probable to improve product innovations by 48%, process, and organizational innovations by 27%, and market innovations by 22%. The study also shows that public subsidies for innovations from local, central, and EU sources significantly influenced firm-level innovations. Lastly, innovations in

these countries were also significantly and positively stimulated by certain firm characteristics such as size and ownership. Žítek and Klímová (2016) explored the ways how is knowledge involved in innovation processes and how knowledge flow within and between organizations in the Czech Republic. Kotkova Stříteská and Prokop (2020), in the case of 10 European countries, identified sustainable sources of competitive advantage that represent a way to achieve business goals. They proved that for innovative leaders, key innovation determinants (in-house R&D; market-related activities, including market research and launch advertising; design of goods or services) have a positive impact on produced innovations while for the innovation followers, the same group of innovation determinants has a negative influence.

However, possible disadvantage of the above-mentioned studies is the fact that they have primarily focused on selected countries and industries and made comparisons of them. These results are subsequently more difficult to apply in public policy-making across other countries. Moreover, practical recommendations based on the results of these studies may not accurately capture firms' needs in other sectors. For these reasons, we see an opportunity to build on these limitations of previous research. Therefore, the main motivation of our article is to verify the applicability of the results obtained for each country to a larger sample of countries and to provide relevant results that will be applicable across countries and industries, by using a random selection of firms across CEE industries to create aggregated data set. For the purpose of this study, we are using the same data sets as some of the previous studies provided by Eurostat – these are the data from the latest available Community Innovation Survey.

The rest of the paper is structured as follows. The next section covers the theoretical background. Third part provides the research methodology and the characteristics of the dataset. Subsequently, we show the research results. Following these parts, discussion and concluding remarks are included.

2 THEORETICAL BACKGROUND

Knowledge is nowadays seen as one of the key drivers of economic growth and represent conditions for successful innovation, patents, and the development of new technologies (Tchamyou, 2017; Asim and Sorooshian, 2019). Several authors (e.g. Nonaka and Takeuchi, 1995; Chergui, Zidat and Marir, 2018; Vasin et al., 2020) divide knowledge according to their nature into explicit and tacit. Explicit knowledge is open and could be easily interpreted and can be systematically categorized. It can be easily expressed and communicated using language, writing, illustration, mathematical formula, or digital recording in the form of written documents, such as reports or manuals (Hau et al., 2013). These knowledges can be stored in software as an information system in the form of data or hardware (Barcelo-Valenzuela et al., 2016). On the other hand, tacit knowledge is hidden knowledge in people's minds. These knowledges are not easily codified or articulated because are embedded in an individual's brain or

experiences, such as know-how or skills (Goffin and Koners, 2011). Moreover, tacit knowledge is highly personal and difficult to be transferred to another person by written word or verbal expression (Battistutti and Bork, 2017).

The knowledge economy as well as knowledge-based economy represent well-known theoretical concepts that work with knowledge. Mokyr (2002) defines the knowledge economy as a result of technological and scientific progress of the last two centuries and states that knowledge are significant element of economic and social growth. This growth helped to discover new technologies and new ways how to access knowledge through networks' creation with universities, research institutions, firms, and other partners. The knowledge economy is defined as a transformed economy that transfers investment into assets based on knowledge (research and development, design, software, human and organizational potential) and investment in physical assets (machinery, equipment, buildings, cars) and makes use of knowledge as the principal engine of economic prosperity (Brinkley, 2006; Tchamyou, 2017). According to Li, Tarafdar and Rao (2012), it is an important determinant of firm growth, survival, and economic performance. On the other hand, a knowledge-based economy is directly rooted in the production, distribution, and use of knowledge and information through the process of economic learning to catalyze and accelerate the sustainability of economic growth (Momeni, Elahi and Najafi, 2017; Minárik, Vokoun and Stellner, 2018). In the knowledge-based economy innovation systems, firms, organizations, and the government interact with one another and become actors in the cycles of knowledge conversion and innovation (Park, 2001). Moreover, knowledge-based view points out the role of knowledge as the main source for creation of strategic opportunities (Juknevičienė, 2017).

In the recent year, there were a huge debate on the sources of innovation and the role of open and closed innovation approaches. The closed innovation comes from the company's environment, which takes place within the company, uses internal recourses like know-how, technology, processes, etc. (Chesbrough, 2003; Manzini, Lazzarotti and Pellegrini, 2017). Otherwise open innovation concept is connected with the use of external knowledge sources. In addition, while innovations are not exclusively in the private sector domain separated from the public sector (Lavčák, Hudec and Sinčáková, 2019), innovation could be generated in co-operation/collaboration with various partners such as universities, research organizations, regional customers and/or suppliers, venture capitalists, and industry/cluster associations or business assistance centers (Ili, Albers and Miller, 2010; Dries et al., 2014). In this study, therefore, we build on the assumptions of open innovation theory.

Moreover, in the contexts of the knowledge and knowledge-based economy, as well as in the era of the growing importance of open innovation, there were a huge debate on the ways how to express and measure innovations and its determinants. On the one hand, authors dealt with an interesting question on how to express innovation as dependent (output) variable within analyses focused on the measuring of firm productivity and innovation performance (Carayannis and

Grigoroudis, 2014). According to Dziallas and Blind (2019) and Prokop and Stejskal (2019b), innovation could be measured by the number of patents, R&D budget, the number of new product ideas, and the percentage of ideas with commercialization potential. Otherwise, Janger et al. (2017) measured innovation output e.g. as the share of firms that have introduced innovations. On the other hand, while the level of innovation activities is influenced by several factors (independent variables), scholars focused on the factors that determine the level of innovation in a given company, state, or region. These are, for example, the size of companies (Zona, Zattoni and Minichilli, 2013), the innovation capacity of companies (Rohrbeck and Gemünden, 2011; Forsman 2011), risk aversion (Arundel, 2017), market situation (Liu and Atuahene-Gima, 2018), innovation environment (Wang et al. 2016; Lukovics et al., 2017), the volume of available knowledge (Sun, Liu and Di, 2020; Bacon, Williams and Davies, 2020), and many others.

Similarly, there were number of studies that focused on firms' innovation and its determinants within CEE countries in recent years. For example, in the case of Estonian and Lithuanian manufacturing firms, Prokop, Stejskal and Hajek (2018) showed that in Estonia, innovation activities are influenced by the following determinants: internal R&D expenditures, public funding from the government, cooperation with companies within the firm group, cooperation with customers, the establishment of subsidiaries outside Europe, and participation in a group of companies. On the other hand, in Lithuania, innovation activities are influenced by the following factors: public funding from the government, cooperation with companies within the firm group, the introduction of a new or improved process on the market, and the introduction of a new or improved product on the market. Hudec (2015) analyzed the innovation efficiency of the Visegrad Group (the Czech Republic, Hungary, Poland, and Slovakia) as well as their regions by considering R&D expenditures as inputs and patents as outputs. He observed that Visegrad countries do not belong to the best performers in innovation and competitiveness in the EU.

Moreover, Kraftova and Kraft (2018) examined relationships between economic performance and the pro-innovation factors which represent the intensity of R&D at the level of the national economy of the EU Member States. They found out that the most important influence on economic growth is the support of R&D by entrepreneurial subjects, followed by the degree of allocation of funds to higher education. Their research also shown that there is probably a certain degree of saturation for an increase in expenditures of R&D is associated with lower performance gains. Chlebovsky, Schüller and Škapa (2018) analysed how Czech firms, oriented on product innovations, are prepared in terms of their internal infrastructure for effective customized product solution development and delivery to their customers, in comparison with Austrian, German and Swiss firms.

Following above-mentioned studies on this topic, we build on the previous findings and to propose novel way of measuring firms' innovation performance

and its determinants in CEE countries, using a random selection of companies across countries. Moreover, we aim to analyze the influence of innovation determinants on firms' product, process, and overall innovation activity.

3 METHODOLOGY

The source of data for the analysis is the Community Innovation Survey 2012 – 2014 conducted by Eurostat. The Community Innovation Survey (CIS) is a harmonized survey and also a part of the EU's scientific and technological statistics, carried out every two years in the EU Member States. CIS is often used to analyze the innovation activities of companies. It contains 2,363 companies from the Czech Republic (CR), 510 companies from the Slovak Republic (SR), 472 companies from Estonia (EE), and 1,125 companies from Lithuania (LT). The companies represented various sectors of the economy. Note, this is the latest available version of CIS.

CIS questionnaire provides several information about firms' innovation activities. In this study, we used combinations of different innovation activities that are shown in Table 1. If the company has implemented the relevant innovation activity, they acquire a value of 1, or, if the company has not performed a certain activity in the period, they reached 0.

Table 1 – CIS Data On Innovation Activities

Variable (abbrev.)	*Description*
INPDGD	Introduction of new or significantly improved goods on the market in the period 2012-2014.
INPDSV	Introduction of a new or significantly improved service on the market in the period 2012-2014.
INPSPD	Introduction of a new or significantly improved method of production of goods or services in the period 2012-2014.
INPSLG	Introduction of a new or significantly improved method of logistics, method of delivery or distribution of inputs, goods or services in the period 2012-2014.
INPSSU	Introduction of new or significantly improved support activities for the main processes, such as maintenance systems or operations for purchasing, accounting, or computer technology in the period 2012-2014.

Notes: INPDGD – product innovation, INPDSV – service innovation, INPSPD – innovation of method of production of goods or services, INPSLG – innovation of methods of logistics, delivery or distribution of inputs, goods or services, INPSSU – innovation of support activities.

Based on the available data on firms' innovation, we created models for overall, product and process innovations as follows:

- *Overall innovation activities* – if the company performed at least one of the activities INPDGD, INPDSV, INPSPD, INPSLG, INPSSU then the output quantity of the model is equal to 1. If the company did not perform any of the activities, then the value of the output quantity is equal to 0;
- *Product innovation activities model* – if the company has performed at least one of the INPDGD, INPDSV activities, then the output value of the model is equal to 1; if the company has not performed any of the activities, then the value of the output quantity is equal to 0;
- *Process innovation activities model* – if the company has performed at least one of the activities INPSPD, INPSLG, INPSSU then the output quantity of the model is equal to 1; if the company has not performed any of the activities, then the value of the output quantity is equal to 0.

Input (independent) variables are listed in Table 2. The selection of independent variables is based on the previous part of the paper, where they are identified based on a search of the literature. These variables are selected from the data available in the CIS survey.

Table 2 – List of Independent Variables

Independent variable	*Description of an independent variable*
Participation in the firm group GP	The company is part of a group. A group consists of two or more legally defined jointly owned enterprises. Each company in the group can serve a different geographic and product market.
Sales on the local market MARLOC	In the period 2012-2014, the company sold its products/services to the local and regional market.
Sales on the national market MARNAT	In the period 2012-2014, the company sold its products/services on the national market (in their country).
Sales on the EU market MAREUR	In the period 2012-2014, the company sold its products/services on the EU market.
Sales to other countries MAROTH	In the period 2012-2014, the company sold its products/services to other countries than are listed for MAREUR.
Internal research and development RRDIN	Research and development activities performed internally to generate new knowledge or solve scientific or technical problems (including own software development that meets this requirement).
External research and development RRDEX	The company has outsourced research and development to other companies or to public or private research organizations.
Acquisition of machinery, equipment, software and buildings RMAC	Acquisition of advanced machinery, equipment, software and buildings to be used for the production and introduction of new or significantly improved products or processes.

Independent variable	*Description of an independent variable*
Obtaining existing knowledge from other companies or organizations ROEK	Acquisition of existing know-how, copyrighted works, patented and non-patented inventions, etc. from other enterprises or organizations for the development of new or significantly improved products and processes.
Training, training for innovative activities RTR	In-house or contracted out training for your personnel specifically for the development and/or introduction of new or significantly improved products and processes.
Market introduction of innovations RMAR	In-house or contracted out activities for the market introduction of your new or significantly improved goods or services, including market research and launch advertising.
Design RDSG	In-house or contracted out activities to alter the shape, appearance or usability of goods or services.
Public financial support for local and regional institutions FUNLOC	Public financial support for innovative activities from local and regional institutions (regions, municipalities).
Public financial support from the government FUNGMT	Public financial support for innovation activities from the government (including government agencies or ministries). It includes financial support through tax rebates or deductions, grants, subsidized loans and loan guarantees.
Public financial support from EU FUNEU	Public financial support for innovation activities from the EU. It includes financial support through tax rebates or deductions, grants, subsidized loans and loan guarantees.

The methodological process consists from two crucial steps. *First,* similarly to previous above-mentioned studies focused on the case of CEE countries, we tested influence of selected determinants on firms' overall, product and process innovation outputs. *Second,* 400 companies across countries were randomly selected to verify the applicability of the results obtained for each country to a larger sample of countries.

As the variables are binary, the logistic regression analysis is used. The relationship between innovation (INN) output and its determinants (shown and specified in Table 4) could be defined as follows (Divisekera and Nguyen, 2018; Prokop, Stejskal and Hudec, 2019):

$$INN = \beta_0 + \sum_{i=1}^{m} \beta_i X_i + \varepsilon \quad (1)$$

where *INN* is an innovation output, x_i is a vector of variable s that influences the innovation output, β_i is a vector of corresponding coefficients and ε is an error term.

Data quality testing was performed and the data were tested for collinearity by using the Spearman correlation coefficient (rho). Results showed that the correlation between variables is significantly different from zero (rho ranges between $-1 \leq \text{rho} \leq 1$). Variance Inflation Factor (VIF) were also used to test

independent variables for collinearity (all models had VIF < 5, multicollinearity was not found).

4 RESULTS

Following part contains results of our research models, while Tables 3 and 4 include analyses of determinants influencing overall, product and process innovations in selected CEE countries. Results of randomly selected 400 firms across countries are shown in Table 5.

Table 3 shows that firms' overall innovation activities within the Czech Republic are influenced by sales on the national market, training for innovative activities, internal or contractual activities for the launch of a new or improved products or services, and internal or contractual activities related to product design. On the other hand, in the Slovak Republic, significant determinants are participation in the firm group, and sales to other countries. Significant positive determinants of product innovation activities in the Czech Republic are sales to other countries, internal R&D, external R&D, market introduction of innovations, and design. Surprisingly, the acquisition of machinery, equipment, software, and buildings has significant negative impact on firms' product innovation. In the Slovak Republic, significant positive determinants are participation in the firm group, internal R&D, obtaining existing knowledge from other companies or organizations, and market introduction of innovations.

In the analysis of significant determinants of process innovation activities in the Czech Republic, we found a positive impact of participation in the firm group, acquisition of machinery, equipment, software and buildings, training, training for innovative activities, and public financial support from the EU. On the other hand, sales on the national market have a significant negative impact. Significant positive determinants of process innovation activities are participation in the firm group and acquisition of machinery, equipment, software and buildings in the Slovak Republic. On the other hand, public financial support from the government has a significant negative influence.

Table 3 – Influence of Innovation Determinants on Firm's Innovation Activities in the Czech Republic And nn the Slovak Republic

Determinant	*Czech Republic*			*Slovak Republic*		
	Overall innovation activities p-value = 0.0000 Success rate: 75.0%	*Product innovation activities p-value = 0.0000 Success rate: 78.1%*	*Process innovation activities p-value = 0.0000 Success rate: 71.2%*	*Overall innovation activities p-value = 0.0054 Success rate: 72.6%*	*Product innovation activities p-value = 0.0000 Success rate: 82.3%*	*Process innovation activities p-value = 0.0001 Success rate: 70.9%*
	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i
Intercept	0.0000*** (1.5565)	0.3015 (0.2020)	0.0024*** (-0.5385)	0.0106** (2.2832)	0.2068 (0.6530)	0.5030 (-0.2681)
GP	0.3774 (0.1604)	0.2432 (-0.1372)	0.0016*** (0.3217)	0.0972* (0.6987)	0.0206** (0.6422)	0.0527** (0.4201)
MARLOC	0.3419 (0.1718)	0.5592 (-0.0708)	0.5284 (0.0676)	0.2554 (0.4566)	0.0822* (0.4854)	0.2075 (-0.2924)
MARNAT	0.0961* (-0.3994)	0.3257 (-0.1405)	0.0427** (-0.2918)	0.4393 (-0.4597)	0.1858 (-0.5222)	0.2515 (0.3548)
MAREUR	0.2745 (0.2198)	0.9551 (-0.0007)	0.7424 (0.0404)	0.1653 (-0.6601)	0.4391 (-0.2463)	0.2157 (-0.3339)
MAROTH	0.3091 (0.2065)	0.0077*** (0.3255)	0.3084 (0.1116)	0.0889* (0.7669)	0.0792* (0.5186)	0.2208 (0.2799)
RRDIN	0.8585 (0.0342)	0.0000*** (0.7704)	0.4930 (-0.0747)	0.2123 (0.5292)	0.0160** (0.7073)	0.9747 (-0.0073)
RRDEX	0.1228 (0.3745)	0.0054*** (0.4142)	0.0783* (0.2076)	0.7863 (0.1882)	0.9156 (0.0469)	0.9637 (0.0139)
RMAC	0.5272 (0.1202)	0.0021*** (-0.3983)	0.0000*** (0.9754)	0.2945 (-0.4743)	0.8846 (-0.0429)	0.0015*** (0.7303)
ROEK	0.1214 (0.5340)	0.0590* (0.3480)	0.2486 (0.1660)	0.1527 (0.9667)	0.0686** (0.7060)	0.8218 (0.0610)
RTR	0.0372** (0.4003)	0.7748 (-0.0341)	0.0000*** (0.4798)	0.3670 (-0.3534)	0.5169 (-0.1850)	0.3695 (0.2082)
RMAR	0.0000*** (1.3882)	0.0000*** (1.6176)	0.9823 (-0.0028)	0.4274 (0.4371)	0.0045*** (1.2395)	0.2163 (-0.3247)
RDSG	0.0780* (0.4688)	0.0000*** (0.9476)	0.9296 (0.0109)	0.8933 (0.0609)	0.5648 (0.2209)	0.3559 (-0.2448)
FUNLOC	0.1929 (0.6275)	0.6523 (0.1112)	0.8984 (-0.0264)	0.9999 (23.1410)	0.2477 (1.2849)	0.1416 (1.5950)
FUNGMT	0.8909 (0.0305)	0.7010 (-0.0544)	0.5998 (0.0627)	0.4256 (-0.5385)	0.6568 (-0.2408)	0.0223** (-0.9805)
FUNEU	0.8434 (0.0472)	0.4910 (0.1044)	0.0002*** (0.5040)	0.4758 (-0.4275)	0.5813 (-0.2503)	0.9005 (-0.0462)

Legend: the table shows the results of p-values and β_i coefficients (in round brackets) for the models of logistic regression in the Czech Republic and Slovak Republic * significant at significance level P <0.1; ** significant at significance level P <0.05; *** significant at significance level P <0.01.

Table 4 shows that 4 determinants have a statistically significant effect on the firms' overall innovation activities in Lithuania. These are acquisition of machinery, equipment, software, and buildings; market introduction of innovations; public financial support from the government, and public financial support from the EU. In the case of Estonia, overall innovation activities are significantly influenced by following determinants: participation in the firm group, sales on the national market, public financial support from local and regional institutions, public financial support from the government, and public financial support from EU. Significant positive determinants of product innovation activities in Lithuania are internal R&D, market introduction of innovations, and design. In Estonia, the significant positive impact has internal R&D, market introduction of innovations, acquisition of machinery, equipment, software and buildings, sales to other countries, and design.

In the case of process innovation activities in Lithuania, we found out training, training for innovative activities, and acquisition of machinery, equipment, software and buildings as significant positive determinants. However, the design has a significant negative impact on process innovation activities. In Estonia only the acquisition of machinery, equipment, software and buildings plays a positive significant role.

Table 4 – Influence of Innovation Determinants on Firm's Innovation Activities in Lithuania and Estonia

Determinant	*Lithuania*			*Estonia*		
	Overall innovation activities p-value = 0.0002 Success rate: 67.2%	*Product innovation activities p-value = 0.0000 Success rate: 72.3%*	*Process innovation activities p-value = 0.0000 Success rate: 74.8%*	*Overall innovation activities p-value = 0.0607 Success rate: 80%*	*Product innovation activities p-value = 0.0000 Success rate: 71.5%*	*Process innovation activities p-value = 0.0000 Success rate: 69.6%*
	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i
Intercept	0.0268** (1.2063)	0.8509 (-0.0546)	0.0619* (0.6565)	0.2470 (0.7605)	0.0125** (-1.2367)	0.9594 (-0.0236)
GP	0.7584 (0.0973)	0.4388 (-0.1159)	0.9411 (-0.0136)	0.0948* (0.5707)	0.3005 (0.2533)	0.8442 (0.0451)
MARLOC	0.6477 (0.1935)	0.6584 (-0.0941)	0.5382 (-0.1720)	0.8707 (0.0581)	0.1010 (0.4119)	0.6436 (0.1079)
MARNAT	0.5236 (0.2207)	0.4545 (-0.1314)	0.8717 (-0.0376)	0.0297** (0.8203)	0.1722 (0.3980)	0.8222 (0.0644)
MAREUR	0.4359 (0.2823)	0.8603 (0.0317)	0.7656 (0.0694)	0.5463 (-0.2919)	0.8379 (0.0687)	0.2944 (-0.3468)
MAROTH	0.5155 (0.2200)	0.2166 (0.1974)	0.5913 (-0.1083)	0.9930 (0.0031)	0.0129** (0.5930)	0.2063 (-0.2846)
RRDIN	0.8158 (-0.0763)	0.0003*** (0.6314)	0.7561 (-0.0620)	0.8229 (0.0803)	0.0313** (0.5458)	0.1494 (-0.3560)

Determinant	*Lithuania*			*Estonia*		
	Overall innovation activities p-value = 0.0002 Success rate: 67.2%	*Product innovation activities p-value = 0.0000 Success rate: 72.3%*	*Process innovation activities p-value = 0.0000 Success rate: 74.8%*	*Overall innovation activities p-value = 0.0607 Success rate: 80%*	*Product innovation activities p-value = 0.0000 Success rate: 71.5%*	*Process innovation activities p-value = 0.0000 Success rate: 69.6%*
	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i	p-value β_i
RRDEX	0.9290 (-0.0376)	0.3501 (-0.2142)	0.2192 (0.3261)	0.6056 (-0.1853)	0.7861 (-0.0671)	0.5968 (-0.1230)
RMAC	0.0000*** (1.3094)	0.3219 (-0.1675)	0.0000*** (1.3872)	0.5113 (0.2314)	0.0055*** (-0.7224)	0.0000*** (1.0803)
ROEK	0.5057 (-0.2624)	0.3700 (0.1872)	0.2440 (-0.2739)	0.3160 (0.4002)	0.1333 (-0.3935)	0.3937 (0.2056)
RTR	0.4726 (0.2330)	0.5451 (-0.0957)	0.0134** (0.4932)	0.2895 (0.4103)	0.2606 (0.2861)	0.1606 (0.3339)
RMAR	0.0497** (0.9780)	0.0000*** (1.2699)	0.4675 (0.1798)	0.2067 (0.5317)	0.0000*** (1.4767)	0.2879 (-0.2762)
RDSG	0.6333 (-0.1953)	0.0000*** (0.9705)	0.0034*** (-0.6774)	0.6217 (0.1999)	0.0005*** (0.9386)	0.2942 (-0.2676)
FUNLOC	0.9351 (0.0693)	0.1306 (-0.5910)	0.2984 (0.6941)	0.0673* (1.7745)	0.9667 (-0.0285)	0.1644 (0.9115)
FUNGMT	0.0909* (0.9842)	0.6563 (-0.0906)	0.1414 (0.4193)	0.0487** (-0.9666)	0.5538 (-0.2093)	0.3289 (-0.3140)
FUNEU	0.0575* (-0.6077)	0.1739 (0.2304)	0.1034 (-0.3258)	0.0685* (1.0688)	0.1206 (0.5116)	0.5337 (0.1824)

Legend: the table shows the results of p-values and β_i coefficients (in round brackets) for the models of logistic regression in the Lithuania and Estonia; * significant at significance level P <0.1; ** significant at significance level P <0.05; *** significant at significance level P <0.01.

Table 5 shows the influence of innovation determinants on the firm's innovation activities in randomly selected 400 firms within CEE countries. Significant positive determinants of overall innovation activities are participation in the firm group, acquisition of machinery, equipment, software and buildings, and market introduction of innovations. In the analysis of product innovation activities, a total of 5 determinants were identified as positive significant: sales on the national market, sales to other countries, internal R&D, market introduction of innovations, and design.

In the case of process innovation activities, we found out that participation in the firm group, acquisition of machinery, equipment, software and buildings, and public financial support from the EU have a significant positive impact. Surprisingly, determinants like internal R&D and design have a negative impact on innovation process activities.

Table 5 – Influence of Determinants on Innovation Activities in Random Companies in All 4 Countries

Determinant	*Overall innovation activities p-value = 0.0003 Success rate: 74.6%*	*Product innovation activities p-value = 0.0000 Success rate: 70.3%*	*Process innovation activities p-value = 0.0000 Success rate: 70.4%*
	p-value β_i	p-value β_i	p-value β_i
Intercept	0.0026*** (1.0160)	0.2207 (-0.2720)	0.9130 (-0.0238)
GP	0.0081*** (0.5662)	0.7326 (0.0433)	0.0076*** (0.3300)
MARLOC	0.0748* (0.3824)	0.3672 (0.1242)	0.2542 (0.1525)
MARNAT	0.1069 (0.3810)	0.0035*** (0.4434)	0.9497 (-0.0101)
MAREUR	0.7209 (-0.0882)	0.3589 (-0.1427)	0.0704* (-0.2859)
MAROTH	0.0861* (0.3825)	0.0014*** (0.4238)	0.1631 (0.1782)
RRDIN	0.7425 (0.0720)	0.0025*** (0.4006)	0.0122** (-0.3256)
RRDEX	0.4211 (-0.2034)	0.5783 (-0.0875)	0.4188 (-0.1187)
RMAC	0.0059*** (0.5821)	0.2274 (-0.1675)	0.0000*** (0.9306)
ROEK	0.8700 (0.0437)	0.1535 (-0.2216)	0.3837 (-0.1283)
RTR	0.9620 (-0.0105)	0.9046 (0.0158)	0.1909 (0.1692)
RMAR	0.0141** (0.7240)	0.0000*** (1.2016)	0.9671 (-0.0062)
RDSG	0.5194 (0.1797)	0.0000*** (0.7985)	0.0143** (-0.3641)
FUNLOC	0.4214 (0.4519)	0.3266 (-0.2958)	0.2936 (0.3571)
FUNGMT	0.6890 (0.1195)	0.9273 (0.0163)	0.3470 (0.1621)
FUNEU	0.9815 (-0.0063)	0.2569 (0.1875)	0.0251** (0.3672)

Legend: the table shows the results of p-values and β_i coefficients (in parentheses) for the given models of logistic regression in random countries; * significant at significance level P <0.1; ** significant at significance level P <0.05; *** significant at significance level P <0.01.

5 DISCUSSION AND IMPLICATIONS

For product innovation activities, internal R&D was found to be a significant positive factor, both in individual countries and in the random selection of CEE countries. These results are consistent with the results of previous studies, see Kotkova Stříteská and Prokop (2020) and Odei, Stejskal and Prokop (2020). Surprisingly, in the case of internal R&D, we found a significant negative effect of internal R&D on firms' process innovation for the random selection of CEE countries. Moreover, externally provided R&D was identified as significant only in the case of the Czech Republic. In the case of process innovation activities, the most significant positive determinant is the acquisition of modern machinery, equipment, software, and buildings, which was identified significant within individual countries and consequently within the random selection of CEE countries. Lewandowska, Szymura-Tyc and Gołębiowski (2016) proved this significance in a sample of Polish companies from the traditional industry - tended to appear in high/medium-tech companies. The Czech Republic and the Slovak Republic, similarly to the random selection of companies from the CEE countries, positively benefit from participation in the firm group. For the Czech Republic and the selection of companies from the CEE countries, public financial support from the EU is important.

Firms' overall innovation activities were significantly influenced by the following determinants - marketing activities related to the introduction of new products and services on the market; acquisition of modern machines, equipment, buildings, and software, as well as determinants expressing the market, served in terms of geography. These results are in accordance with D'Attoma and Ieva (2020) who found out, in the case of German firms, that marketing activities at the aggregate level were not a significant determinant to innovation success. For the Baltic States (Lithuania and Estonia), public financial support is important. Lithuania tends to benefit from public financial support from the government nevertheless public financial support from the EU has a negative impact on overall innovation activities. Surprisingly, in Estonia, public financial support from the government has a significant negative impact on overall innovation activities. Similarly to Prokop, Stejskal and Hajek (2018), public funding from the government play a key role in the process of firms' innovation activities, while misdirected financial support can lead to rather negative effects.

Based on the result of these analyses, we propose some practical implications. Czech innovating firms should invest in employees' R&D trainings that could boost their innovation activities and absorptive capacity. It is specifically crucial because of the importance of internal R&D in the Czech Republic. Moreover, Czech firms should pay attention to the market research and launch advertising, including markets outside the EU. In addition, firms should also focus on design activities. Slovak innovating firms should participate in firm groups that can make it easier for individual companies to access additional knowledge resources, share costs together and benefit from the goodwill of other companies.

Moreover, Slovak firms should primarily focus on internal R&D, also supported by acquisition of external intangible as well as tangible assets.

In the case of Lithuania, market research and launch advertising, acquisition of advanced machinery, equipment, software and buildings are highly recommended. Similarly to other countries, support of internal R&D and design are crucial for firms' innovation activities. These activities could be supported by trainings of employees. On the other hand, Estonian firms should focus primarily on the national markets. Moreover, public policy makers need to make provision of public funds more efficient because financial support from the government had a negative significant impact on firms' innovation activities. We propose following steps - matching the interests of individual (cooperating) actors, reducing the bureaucratic burden on companies, and greater control over the funds provided.

In general, from the results that we reached from the random selected datasets, we propose following implications. Firms should focus on activities for the market introduction of new or significantly improved goods or services, including market research and launch advertising. Moreover, we propose networking of firms and inter-firm cooperation activities. It is due to the fact that firms' participation in the firms' groups is significant. Moreover, we propose firms' cooperation with universities, as the generators of new knowledge. This kind of cooperation is also usually supported by public funds so it could provide additional funds for firms. Moreover, firms' cooperation could speed up the creation of knowledge spillovers as well as help to support firms' absorptive capacity that is also crucial in the process of internal R&D that is one of the key activities within CEE countries. In addition, creation of networks between firms could help to build external social capital that could subsequently help firms to avoid above-mentioned not-invented-here syndrome.

6 CONCLUSION

Finding proper determinants of firms' innovation activities was proved as a crucial task for firms, scholars and policy makers. However, as we have shown in this study, even after finding suitable determinants (for example, based on an extensive research on this topic), firms are not able to achieve innovative outputs, specifically within CEE countries. This is due, among other things, to several factors such as different conditions in individual countries, different innovation policies at the national as well as company level, managerial approach (aversion) to risk, mistrust between the various actors, and many others. A typical example is the impact of internal R&D on firm innovations. While in the case of product innovations we found a significant positive impact, in the case of process innovations the impact was negative. On the other hand, it creates number of challenges for the future research. It is necessary to focus on and deeply analyze the role of firm internal R&D, absorptive capacity of firms within CEE countries and building of firm social capital. This study contains also some limitations.

Primarily, analyzes were performed on outdated data. On the other hand, this fact provides us with basic results, which we can use in the following analyzes. Furthermore, we see as a possible limitation of this research in the fact that we did not make a comparison with countries from Western Europe. That is why we are also planning larger studies across European countries.

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Business Process Risk Modelling in Theory and Practice

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ABSTRACT

Purpose: The purpose of the paper is to introduce SW based decision-making tool that helps managers cope with risks and uncertainties of selected industrial processes. The solution is substantiated by the theoretical background.

Methodology/Approach: The research is based on combination of contextual interviews with process management experts and Business Process Modelling Notion (BPMN). The former is aimed at the identification of industrial processes with highest risk exposure the latter is conducive to the design of processes to be subjected to stochastic simulation.

Findings: The findings show that the risks and uncertainties in the management of industrial processes can be kept under control when using advanced tools of risk analysis as simulation approaches. The solution proposed comes in handy to risk analysts or process managers.

Research Limitation/Implication: The library of process models which were included into stochastic simulation includes selected processes as investments, service providing or economic value-added engineering. Additional processes are being included on ongoing basis.

Originality/Value of paper: The paper offers the solution to industrial process risk management which goes far beyond academic sphere and provides industrial practitioners SW tool that facilitates process risk management.

Category: Technical paper

Keywords: process modelling; probabilistic approach; stochastic simulation

1 INTRODUCTION

Industry 4.0 can be interpreted as a digitalization of a material production that is propelled by cybernetic systems in the environment of Internet of Things (IoT). In the Industry 4.0 era, intelligent analytics and cyber-physical systems are teaming together to realize a new thinking of production management and factory transformation. IoT is composed of two main parts which are Internet of services and Internet of media. This facilitates the transformation of processes from their generic versions to customizable ones as well as the transformation from partial participation to full participation in the production (Zhang, Liu and Tang, 2014). The core of Industry 4.0 will become a Factory 4.0 which is expected to produce and deliver products that are not encumbered by increasing costs. In this way, series production will be combined with line-level personalization (Kagermann, Wahlster and Helbig, 2013). Within Industry 4.0 intelligent products are permanently identifiable and localizable. Terms like „intelligent production", "intelligent factory" or "smart factory" are now commonly used in Europe (Smit et al., 2016). The President's Council of Advisors on Science and Technology in the United States advised the Government to implement an advanced manufacturing strategy, which was accompanied by a national strategy plan one year later (Prause and Weigand, 2016). Chinese version of Industry 4.0 is termed "Made in China 2025" (China Academy, 2016; Hao et al., 2017). Similarly, Russian government has been prioritizing advanced production since 2013 (Dezhina, Ponomarev and Frolov, 2015). Basically, the concept of Industry 4.0 deals with the creation of a novel manufacturing paradigm and environment comprising intelligent and self-controlling objects. Smart products are constantly identifiable, steadily locatable, as well as aware of their latest condition and alternative paths to their destination (Ramsauer, 2013). In the vision of an extensive penetration with this manufacturing approach, orders guide themselves through entire value chains autonomously and machines set-up automatically as well as reschedule the production on their own, if an error is predicted (Kaufmann, 2015). Smart factories handle complexity and they are less vulnerable to losses of production. In addition, resource efficiency in terms of material usage, energy consumption, and human work is significantly enhanced (Wildemann, 2014). Nowadays, smart factories focus mostly on control-centric optimization and intelligence. Moreover, greater intelligence can be achieved by interacting with different surrounding systems that have a direct impact on machine performance. Achieving such seamless interaction with surrounding systems turns regular machines into self-aware and self-learning machines, and consequently improves overall performance and maintenance management. Transformation from today´s status into more intelligent machines requires further advancement in the science by tackling several fundamental innovations (Lee, Kao and Yang, 2014). Current business operations within a framework of Industry 4.0 are confronted by high risks and uncertainties.

Despite these problems it is imperative for the company management to create the value for both customers and shareholders. Capability to manage companies in periods of breakthrough business discontinuities remains highly valuated managerial competence. From this point of view, it is very demanding for company managements to challenge these risks and uncertainties. Risks and uncertainties are usually bundled into the term *risk factors*. By the term risk factor management usually understands stationary or non-stationary phenomenon which may be the source of danger (Tichý, 2006). These risk factors may change both continuously and discontinuously depending on the nature of the parameter in question. Typically, some of them like price or output quantity may change continuously while others like facility size discontinuously. Individual risk factors usually operate with varying intensity and they are very often statistically dependent. Moreover, the company can be exposed to varying externalities that may exert negative effects on company performance. These externalities include ongoing pandemic threat, climate changes, migration or global financial crisis, regional or global political instability, population aging and other. Even under these worsened condition when the risk factors are not only dependent on each other but also difficult to predict the managers are compelled to make reasonable managerial decisions. At these circumstances the managers are unable to incorporate all these uncertainties into decision-making process and incline to intuitive decisions that are often imprecise or even completely faulty. The inability of the managers to make right decision at these complex situations is considered the main problem that triggered this type of research. The practice shows that there are no trivial means that would significantly improve the quality of managerial decision-making. Possible way out of this problem is using advanced tool of risk management like probabilistic approaches that may take into account both continuous character of risk factors and their stochastic dependence. The paper submitted offers a rational approach to the management of business processes where purposefully designed software solution facilitates decision-making processes upon the inclusion of concomitant risk and uncertainties. The main goal of the research was to design industrially applicable software tool that would be able to analyse key business risks, determine the severity of the impact of risk factors on main performance characteristics and contribute to search for optimum decisions which are conducive to entrepreneurship sustainability. Supporting goal is the identification of a generic set of business processes the variability of which can undesirably decrease overall company performance. One of the tools that has been already implemented in decision-making practice in both financial and industrial sector is Monte Carlo simulation which has been attracting certain popularity since the War II. (Silva, de Abreu and de Amorim, 2019). This paper aims at the development of software based decision-making tool that would simplify and facilitate key managerial decisions. The concept comes out of Business Model Canvas (BMC) that comprises nine underlying factors that are decisive for running operable business model. These factors include key partners, key activities, key resources, cost structure, value proposition customer relationships,

customer segments, channels and revenue streams (Osterwalder and Pigneur, 2010). Based on the literature search and preliminary contextual interviews with risk management experts following research question was raised: (RQ) In what extent can company risk management processes be computerized to effectively contribute to company financial performance?

2 METHODOLOGY

As an approach of choice triangular approach was selected. This methodological approach is based on the combination of several data sources, research methods, investigators, and theoretical schemes (Wang and Duffy, 2009). At first the methodology was based on extensive content analysis that enabled to identify practices that routinely apply probabilistic approaches to risk analysis, processes modelling or business model development. Following terms were subjected to literature quest: business model simulation, business process modelling and business process management. Furthermore, six contextual interviews with risk managers or specialists were conducted. Contextual interview was preferred to other research methods (including quantitative questionnaire survey) due to its flexibility to go deeper into details if some interesting information occurred during the interview. Direct contact with respondents enabled to repeatedly ask "why" if currently discussed problem required further explanation. Interviewed persons were purposefully selected to represent service and production sector in the equal proportion. Each interview lasted from 40 to 50 minutes Research team gave priority to semi-structured interviews which proved to be comfortable for interviewed persons. Contextual interviews were recorded manually. The interviews focused on following points: (i) processes that are essential for company business, (ii) the approaches to the assessment of process risks (iii) risk measurement and (iv) risk mitigation provisions that company actually applies. Finally, the interviewees were allowed to make a final review of recorded interviews to prove that the notes were made correctly. Interviews coding was carried out as per Campbell et al. (2013). The execution of contextual interviews with company practitioners led to the identification of company processes that are exposed to the highest risk. It dealt with investment process, new product development, launch of a new product, ways of product delivery, increase in production capacity etc. Contextual interviews furthermore enabled the research team to develop generic BMC that specified key processes for selected categories of BMC. Furthermore, these processes were decomposed to sub-processes and activities. It helped the team exactly describe the activities which were further subjected to modelling. The most appropriate approach to activities description proved to be graphic presentation of activities. This way of presentation is quite illustrative and understandable. Research team chose BPMN because of several reasons: the first reason rests in fact that this approach is proven, quite flexible, illustrative and easily adaptable to almost any type of organization. The second reason is the flexibility of the language that comprises broad scale of elements that are able to precisely capture the nature of workflow. It encompasses initial

events that are the trigger points of the process in question. Activities and intermediate events represent the events themselves and activities of the process. By means of end events it is possible to express the outcome of the process. Processes management is executed through decision-making gates. Generally defined standard of elements encompasses the set of parameters that ensure one of the most relevant capability that is starting the process. Aforementioned capability can be used with advantage for simulation modelling. By this way it is possible to incorporate the specifics of individual organizations into simulation modelling. BPMN thus enabled to design usual (generic) company processes in their mutual interconnection including subprocesses and activities. In addition, stochastic simulation appeared to be the method of choice because of its easiness and smooth adaptability to actual managerial practices that undergo almost permanent change. Stochastic simulation is based on exactly identified risk factors that represent the input variables. Risk factors were identified either by sensitive analysis or expert opinion. The former was conducted by stepwise testing the change of a chosen output variable (Net profit, value added, Net Present Value) in dependence to the incremental change of input variable (sales volumes, unit price, material, energy or personnel costs, investment expenditures, production capacity etc.). The latter refers to expert opinion which may also include creative methods application. For this reason, established creative methods like brainstorming, brainwriting, Crawford Slip or Delphi were used (Al Badi, 2019). Risk factor identification process was accomplished by the validation of findings by means of contextual interviews with the experts familiar with process management. The experts (company managers, investment managers) validated the findings based on critical assessment and comparison with their own management practices.

3 LITERATURE REVIEW

3.1 Risks and Their Identification, Analysis and Mitigation

To treat risk factors properly it is inevitable to identify, analyse, measure, and finally mitigate the risks. For the risk identification various creative methods are recommendable (influence diagrams, brainstorming, checklist, Delphi method (Špaček and Červený, 2020; Silverstein, Samuel and Decarlo, 2012). Faulty or incomplete risk factors identification can substantially undermine effective risk management (Crouhy, Galai and Mark, 2014). Practical management offers various tools that may be conducive both to effective risk analysis (sensitivity analysis, risk matrix) and risk measurement (variance, standard deviation, value at risk). Managerial characteristics of risk are also very popular among company managers (e.g., probability of overcoming certain value or probability of not reaching certain value). Company management often faces problem to make key decisions when the decision is affected by high number of risk factors, their continuous character and eventually by their mutual stochastic dependence. New

investments, new product development, replacement of obsolete facilities, increase in production capacity, penetration new market, extension of product line or divestment of the part of business can be ranked among decisions of this type.

3.2 Business Models and Their Role in Supporting Company Performance

Business model (BM) can be viewed from several standpoints. There are a lot of definitions in scientific literature. The most common is that posted by Osterwalder and Pigneur (2010, p.14): "*A business model describes the rationale of how an organization creates, delivers and captures valu*e." Similarly, Davila, Epstein and Shelton (2012) presents definition of a business model as a description how the company creates, sells, and delivers value to its customers. Magretta (2002, p.87) perceives BM in a more sensitive way. According to her "*business models are at heart, stories — stories that explain how enterprises work*". There is an effluent scientific literature aimed at BM development. Gassmann, Frankenberger and Csik (2014) surprisingly came with an idea that many of existing BM are the plain replication of existing ones. According to them there are only 55 BMs which can be considered original. The rest of them are their adaptations and modifications. Structure of BM which is now accepted by the communities of business professional is quite close to BMC introduced by Osterwalder and Pigneur (2010). Organizations aim to improve their processes through frequent adaptation of new business models that can serve and cope with emerging needs (Tbaishat, 2017).

3.3 Business Process and Its Modelling

Damij et al. (2016) came out with the definition of a business process: "*A Business Process (BP) is defined as a collection of related and structured activities with the aim to create outputs that are produced to serve customers.*" It is apparent that BP is perceived as a key value driver that must be distinguished from other organizational arrangements. BPs represent an essential part of every organization regardless of size and industry. The clarity of their definition and their regular optimization is essential for overall success of the company. The optimization of BPs is critical for the company and requires proper application of modelling techniques and suitable simulation tools. Business Process Modelling (BPM) is the set of technologies and standards for the design, execution, administration, and monitoring of business processes (Harvey, 2005). BPM also improves quality of information system development. It enables to increase the integrity between business operations and information systems through visualization of business requirements (Kumagai, Araki and Ono, 2014). BPM allows organization to gain insight, reduce risk, and potentially optimize process. It provides a framework from which key risk and performance indicators can be identified and utilized to indicate quality process performance supposing that process metrics fall within pre-specified tolerance limits. It also provides the

framework into which process control for monitoring, adjusting, and controlling the output of a process can be added (Cernauskas and Tarantino, 2009). In addition, BPM helps understand the organization's work, comprehend the process in detail and then use technological support for improvements to human activities (Tbaishat, 2017). In general, BPM is understood to be a corner stone to help managers improve operational performance but on the other hand it appeared to be insufficient to help organizations face the awesome challenge of competitiveness in a constantly changing environment (Nurcan et al., 2005). The purpose of BPM is to develop a model that reflects the organization functionality of existing or newly established business processes and can be considered a predecessor to business process simulation that is carried out by using simulation tools or software. The goals of BPM were specified by Curtis, Kellner and Over (1992) as facilitation of human understanding and communication, support process improvement, support process management, automation of a guidance in performing process, and automation of execution support. Similarly, Havey (2005) specified the motivation for the execution of BPM in the way of formalizing existing process and spot needed improvements, facilitating automated, efficient process flow, increasing productivity, and decreasing head count, allowing people to solve the hard problems, and simplifying regulations and compliance issues. Apart from historical techniques like flowcharting or Integrated Definition for Function (IDEF) there are several standards to model company processes like UML (Caetano et al., 2005), XPDL, RAD (Rapid Application development) or ARIS (Architecture of Information Systems) developed by Prof. A.W. Scheer. RAD reacts to the rigidity of a classic waterfall model and accentuates the need for the adjustment of requirements as a reaction to new reality that usually come to light during the project. ARIS applies HOBE (House of Business Engineer) to address BPM in a holistic way that integrates organizational perspective with IT perspective. When collating RAD with ARIS it can be concluded that the former provides better visualisation, removes unnecessary tasks while the latter is considered rather general framework that can be used for creating models of business processes in a wider area of business analysis. ARIS provides model for creating, analysing, and evaluating the business processes (Tbaishat, 2018). The main advantage of ARIS rests in its ability to cast several views of the architecture provided, which reduces the complexity and ambiguity that is typical for other models. ARIS is able to reduce complexity by the introduction of different descriptive levels which lead the analyst from the business problem down towards technical implementation (Rippl, 2005). Visualisation of ARIS model is presented in Figure 1.

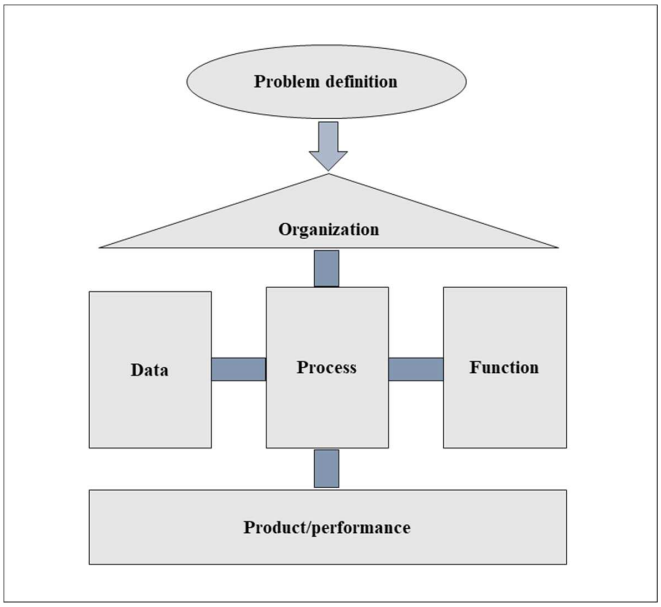

Figure 1 – The General Scheme of ARIS Architecture (ARIS HOBE) (Tbaishat, 2017)

The point of departure for the presentation of key activities by a graphic way is Standard Process Model and Notation (BPMN). This concept was brought to light in 2001 as a visual design layer for a transactional workflow system. It represents the set of principles and rules which are dedicated to graphic illustration of company processes. BPMN is a business process management standard for graphical notation that depicts the steps in a business process, providing comprehensive business process modelling capabilities to users within single environment. Graphical elements of BPMN can be split into five basic categories (Silver, 2009): flow objects, connecting objects, pools and swim lanes, data objects, artefacts ((i.e., a product created or modified by the enactment of a process element). Other components that are closely related to BPMN are processes, collaborations and choreographies. This standard is supported by well-established companies like IDS Sheer, Oracle, Intel, SAP, Adobe Systems etc. It simultaneously provides Exchange format that may be used for the Exchange of BPMN processes definition among different tools. Furthermore, BPMN enables smooth transfer of developed models into BPEL (Business Process Execution Language) which is receptive to other application. Both language standards come out of XML (eXtensible Markup Language). In addition, other authors prefer using strategy-driven BPM approach that better accentuate goal-perspective or the map-driven processes modelling approach (Nurcan et al., 2005). This approach interconnects goal-driven approach with proper specification of trajectories how to meet the goals (map-driven approach). Certain improvements were brought into problematics of process modelling by the introduction of hierarchical business variation analysis. This approach improves productivity of

the model development. It enables to extract the variations of business functions and consolidate similar business functions (Kumagai, Araki and Ono, 2014). Alongside with the development of new methods of BPM there is an attempt to implement environment that would enable seamless collaboration between business and its users to develop executable business process models. One of the examples is TIBCO Business Studio TM-BPM edition 4.3.0. TIBCO Business Studio™ is a standard-based business process modelling environment that enables business experts and process authors to collaborate to create process models, organization models, data models, forms, and page flow models. The user-specific functionality of TIBCO Business Studio enables effective collaboration between business and IT users to ensure that both parties contribute successfully to the process model in order to improve BPM implementation (TIBCO, 2020). Oracle BPM studio operates in a similar way.

3.4 Selection of a Method

In spite of the fact that variety of methods for BPM were mentioned in literature little attention was devoted to the assessment of their suitability. Selection of the suitable method for BPM is sometimes very tricky and existing literature does not offer precise approach for the method selection. Curtis, Kellner and Over (1992) suggested that four perspectives should be considered in BPM:

- *Functional perspective* – where the process elements to be performed are identified;
- *Behavioural perspective* – which represents a model that specifies when process elements are allocated and how related actions are performed;
- *Organizational perspective* – which determines who performs process elements and where;
- *Informational perspective* – which presents what informational entities are produced by a process (data, documents etc.).

Luo and Tung (1999) tried to set up a framework for selecting BPM method that is based on modelling objectives. This framework commences with setting the objectives that are considered underlying factors for further modelling. Modelling procedure then continues with the determination of perspectives which the processes can be viewed from. To make the modelling procedure more simplistic the authors categorize both objectives and perspectives into categories. Objectives are ranked among following categories: (a) communication, (b) analysis and (c) control. Perspectives are then ranked among categories as: (a) object, (b) activity and (c) role.

3.5 Simulation and Scenario Approaches to BPM

Business processes are always tied with risks that can shake their performance. Business Process Simulation (BPS) can meet several company demands in

parallel. It is applicable for BP analysis that is usually performed by the simulation of BP behaviour under various conditions and potential "what-if" scenarios or sensitivity analysis prior to its implementation (Patig and Stolz, 2013). In addition, BPS is used to assist decision-making by providing a tool that allows the current behaviour of a system to be analysed and understood. It is also able to help predict the performance of that system under a number of scenarios determined by the decision maker. An important aspect of BPS is its ability to capture dynamic behaviour of the process. There are two aspects of dynamic systems that must be taken into consideration (Greasley, 2003):

- *Variability* – which can be manifested in both key quantitative parameters of the system (e.g., output quantity, various types of costs, unit prices etc.) and duration of the processes (e.g., time-to-launch, payback period, lead time etc.);
- *Interdependence* – which means mutual stochastic dependence of input variables. It is quite commonplace that many input variables are stochastically dependent (there are some correlations among input variables). Typical example is stochastic dependence between unit price and sales volume (There is empirical evidence that this correlation is negative).

Managers and risk specialists strive to use various analytical approaches to get risks under control. IBM research team developed a scenario-based method called Operational process specification methodology (OpS). This in-house elaborated approach proved to be viable at discovering opportunities for process improvement. OpS is a technique for capturing a complete operational description of a business. OpS is based on factorization of operational business knowledge into information, function, and flow components. This model was tested under various scenarios which were characterized by different process parameters like cycle time, resources, and alternate process configuration. The main outcome of model testing was finding that substantial improvement (typically overall process cycle time) can be accomplished by process changes and proper allocation of resources (Young et al., 2020). Simulation approaches are usually used in processes that are encumbered by high risks and uncertainties. Typical parameter which is essential for company financial performance is cash flow (CF). This parameter is affected by various risk factors (sales, unit prices, investment and operating costs, costs etc.). To avoid falling in insolvency proceedings companies should be able to assess and forecast company CF. Kazakova, Zayarky and Medvedev (2019) developed a system-dynamic model for predicting the financial flows of an enterprise considering the risk and uncertainty of interaction. The model foresees the regulation block of random factors affecting the interactions processes in the financial management system. Unfortunately, the model was subjected to testing on experimental level only. Simulation of investment CF carried out by Monte Carlo method has already proved its worth within risk analysis methods. This method was tested not only in the assessment of investment process economic effectiveness but also in

decision making analysis concerning selection of production technology (Špaček, 2015; Vacík et al., 2018). Other simulation approaches were tested upon the analysis of risks and uncertainties in energy business (Praca et al., 2019). Business Process Reengineering (BPR) is considered very demanding task which require precise BPM. To get risks tied with BPR under control business process simulation was proposed as a suitable approach (Tigkiropoulos, Kyratsis and Dinopolulou, 2009). Moreover, BPS can provide support for a change process by measurement and analysis of process performance (Greasley, 2003). Heinrich et al. (2017) used simulation approach to assess mutual performance impact between BPS and information system. As for simulation software there is variety of software tools which are purposefully used for BPS. Business Model Simulation Software (BPSs) usually encompasses modelling tools (a graphical modelling environment, built-in simulation objects with defined properties and behaviour, sampling routines, property sheet and visual controls), tool to execute simulation (a simulation executive to run a model, animated graphic, virtual reality representation and user interaction with the simulation as it runs), tool to support experimentation, optimization, result interpretation and presentation, or links to other software (links to spreadsheets, databases, ERP systems etc.) (Pidd and Carvalho, 2006).

4 DESIGN OF INNOVATIVE BPS SOFTWARE

Simulation approaches represent advanced management tool which enhances the quality of managerial decision-making in situations when other managerial approaches fail, or their implementation is difficult from technical point of view. Basically, it deals with the situation when high number of risk factors were identified, and these risk factors are of continuous character. Simulation approach is a method of choice in case that any other analytical approaches are of no use. When solving the problem for instance by scenario approach it would necessitate the elaboration of excessive number of scenarios implementation of which would be impossible. The solution submitted is based on stochastic dependence between input variables represented by risk factors (like any input variable like costs, unit prices sales volumes, markets share, rate of production capacity utilization etc.) and output variables (like net or operational profit, cash flow, net present value etc.). In the background of the methods stands mathematical model. Mathematical description comes from stochastic dependence that is described by an equation 1.

$$Y = f(X_1, X_2, ...X_n) \tag{1}$$

where parameter Y is output (dependent) variable and parameters X_1, X_2, … X_n are input (independent) variables. Any input variable is assigned probability distribution that is based either on historical development of the variable (e.g., unit price) or expert opinion. To make the model understandable from managerial

point of view the authors prefer using triangular probabilistic distribution that is characterized by the lowest, the highest and the most probable value. Usually, this simplistic approach to probabilistic distribution assignment appropriately balances demandingness to operate the system in practice and reliability of the results. To make the model more reliable software developers incorporated correlation matrix into calculation. This matrix quantifies mutual dependence among input variables. Correlations among input variables (risk factors) are set on expert basis before the start of the simulation. The logic of the correlation between pairs of risk factors may be positive or negative. Moreover, the strength of correlation was quantified by means of ranking them into three levels: strong, weak and none. Needless to stress that the calculation is more sensitive to setting proper correlation than to selecting probability distribution of input variable. The nature of the simulation is the calculation of great many (round tens of thousands or even hundreds of thousands) scenarios each of them representing one discreet arrangement of the future. The simulation model repeats the calculation many times in dependence on the pre-defined number of runs. The output (dependent) variable is obtained in a form of probabilistic distribution from which it is deducible to indicate the probability of reaching desired results or the probability of overcoming desired value. BPSs incorporates pseudorandom figures generator that enables to pick up random input data for the calculation. Risk factors are determined either by sensitive analysis or expert opinion.

The BPS software development applied BPMN approach. This approach suited the purpose. Design pattern of the software solution to business model simulation is shown in Figure 2.

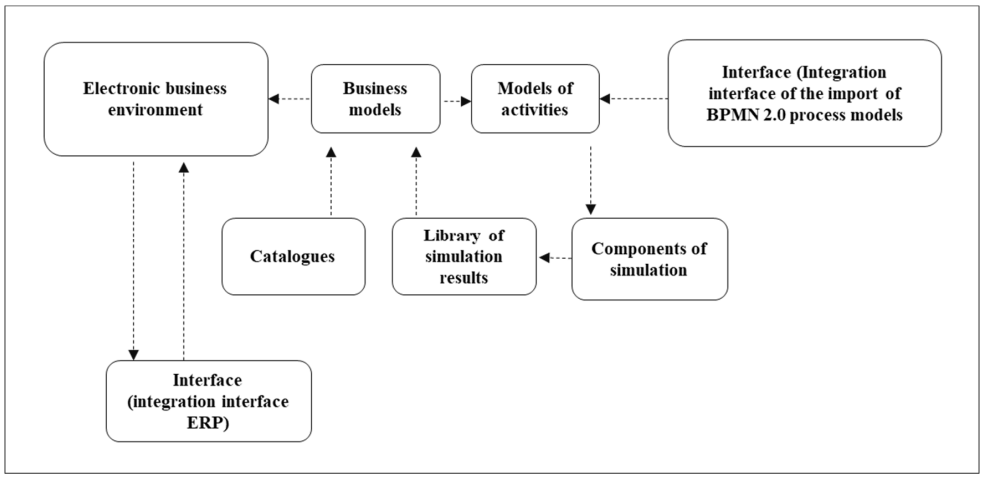

Figure 2 – Design Pattern of the Software Solution to Business Process Simulation (Own Elaboration)

Design pattern, which is presented in its simplistic form, illustrates the relationships among all components of the model. It is apparent that the core of

the model is business model that is composed of nine subcategories as pointed out by Osterwalder and Pigneur (2010). Each subcategory comprises several activities that refer to the specific type of business. Providing that these activities are describable by a mathematical model they can be subjected to simulation.

5 RESULTS AND DISCUSSION

The paper offers advanced approach to the management of risks and uncertainties of business process. The approach is based on purposefully elaborated software tool that enables simulation of variety of risk factors which influence the probability distribution of dependent variable. In addition, the model takes into consideration mutual stochastic dependence of risk factors that significantly improves reliability of the model. In principle, the model enables mangers to simulate any scenario which may come into existence during the company life-time cycle. There are also limitations to the use of this tool since the model works under proviso that the process is describable by a mathematical model. The model can be quite simple (e.g. plain calculation of profit or cash flow). On the other hand, there is a possibility to extend the model by other functionality. The model can be easily interconnected with financial analysis parameters to analyse company rentability, liquidity solvency, value creation, limits of indebtedness etc. The model is proposed to be mastered by almost any employee with adequate technical skills but the users should undergo short training in the basic statistics. Another problem may be tied with the interpretation of the results. Managers unfortunately got accustomed to understanding business process performance parameters in terms of deterministic values. When obtaining results (profit, cash flow, Net Present Value, Return on capital etc) expressed in terms of probability distribution it may cause problems with interpretation. Empirical findings derived from the software development were conducive to formulating response to RQ: Company business processes that can be easily and flexibly supported by a mathematical model are the candidates for software-based risk analysis. Typically, following processes can be involved into this group: new product development, investment processes, technology effectiveness assessment process, selection of alternative organizational concept (outsourcing, technology divestment, production termination etc.,), alternatives for assets financing (loan, leasing, equity funding etc). On the other hand, business processes the effects of which can be characterized by financial parameters with difficulties are not suitable adepts for SW risk modelling. Basically, it deals with uneasily measurable processes as development of employee soft skills, change in corporate culture, investments into environmental security or health and safety of employees, regulatory compliance etc.

6 CONCLUSIONS

Research team offers precise and reliable software tool that enables company management team to simulate various situation which might come into effect during any business activity. The software is quite flexible and enables smooth and easy adaptation to particular condition of the company. The model was validated on the example of production, service, and trading companies. These three examples personified three main types of business entities. The software makes possible to pick up key company processes from the predefined list of generic key processes (investment process, managing customer's order, managing complaints, new product development process, supply chain management process etc.). It is at company discretion to adapt pre-defined processes to particular company needs or to create own tailor-made processes that are specific to company business. The tool makes company decision-making processes more reliable since it includes all relevant risks and uncertainties into decision process and significantly improves the quality of company strategic planning because of the incorporation al possible scenarios of future development of the environment.

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CONFLICTS OF INTEREST

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Wages of Information Technology Professionals - A Czech and Slovak Republic Case

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ABSTRACT

Purpose: The objective of this article is to compare the trend in wages of ICT Professionals in the Czech and Slovak economies during the past two decades.

Methodology/Approach: The input data set for ICT Professionals was relatively large - over 2.2 million (of which ICT represented over 60 thousand) in the Czech Republic and 1.1 million (of which ICT represented over 24 thousand) in the Slovak Republic. For the purposes of presented analyses, we used basic statistical methods and characteristics.

Findings: We can make the following general conclusions based on our analyses: all analyzed wage characteristics increased over time, with the exception of the economic crisis during 2009-2014 when they stagnate.

Research Limitation/Implication: Our data include outliers, especially wages above EUR 4,000. However, these wages, which are relatively rare, significantly influence the total volume of wages.

Originality/Value of paper: Analysis of our data offers information about development of average real wages in ICT oriented jobs. There can be found analysis of wages in all sectors in literature. Analysis of ICT Professionals wages is rarely published in journals.

Category: Research paper

Keywords: digital economy; ICT Professionals; wages in ICT; trends in wages development

1 INTRODUCTION

The present, even according to politicians, economists and managers of multinational companies, can be characterized as a turbulent time during which digitalization has significantly strengthened. Different levels of management or sectors of the economy have different ideas about what digitalization actually is. The public administration promotes the concept of e-government, the municipalities promote the concept of smart cities, while industrial enterprises are implementing a new concept of production - the so-called Industry 4.0 (Basl and Doucek, 2019). The main objective of this trend is the digitization, robotization and automation of production (Mařík, 2016), i.e. including the deployment of information and communication technologies (ICT) in the life cycle of products, from their design, through their development, implementation and use all the way to their final disposal. This closed life cycle of products or services leads to a very topical concept of a so-called "Circular Economy". Its relations to Industry 4.0 are described in more detail e.g. in (Tseng, et al., 2018).

Integration and further expansion of ICT into the economic and everyday life of people depends, among other things, on the number and qualifications of ICT Professionals. There is no company, office, ministry or institution that can do without IT (Malá, 2015). The ICT profession is a prerequisite for the successful operation of each of the mentioned institutions. There is a constant demand for, and a great interest in, these workers on the labour market.

If we want to gradually switch to a digital economy, we will need to have enough qualified ICT Professionals (Hanclova et al., 2014). Their financial remuneration should correspond to their important role in the economy (Mysikova and Vecernik, 2018). We can expect that it is much higher than the average remuneration in the entire economy (Doucek, Nedomova and Maryska, 2015). Without higher remuneration of key ICT Professionals, it is not possible to build a digital economy. To verify this fact in the small, open economies of the Czech Republic and the Slovak Republic, we have analyzed the trend in wages of ICT Professionals in both countries over the past 19 years.

The need for qualified workers for digital transformation and the need for their adequate remuneration in the Czech Republic is addressed in particular by Mařík (2016). Other designers of digital economy and Industry 4.0 models also focus on the relationship of the digitalization of the economy, the need for qualified workers and their remuneration – i.e. their wages. It mainly concerns studies on the German Industry 4.0 model (Wang, Towara and Anderl, 2017; Suri et al., 2017) at its macroeconomic level. Although society is expected to grow after the implementation of digitalization at the macroeconomic level, it is interesting to note that job opportunities and wages in this field do not grow accordingly. Torrent-Sellens (2008) and the conclusions of his study confirm this fact especially in terms of an increase in job opportunities and wages in various ICT professions. The wages of ICT Professionals tend to be higher than average wages in economies (Torrent-Sellens, 2008; Marek and Doucek, 2016); this fact

also opens up the issue of equal pay for equal work - that is, the issue of equality in remuneration for ICT Professionals' work not only in the economy but also in heterogeneous work teams comprising of men and women (Simard et al., 2014).

The objective of this article is to compare the trend in wages of ICT Professionals in the Czech and Slovak economies during the past 19 years. We will compare the average wage of ICT Managers, ICT Specialists and ICT Technicians with the average wage of the relevant country and with the average for all aforesaid categories. We will also analyze average wages in the first and ninth deciles in 2018.

2 METHODOLOGY

2.1 Data Collection and Processing

We used to select data from the Average Earnings Information System (AEIA). Based on the source (ISPV, 2020), it is a system that regularly monitors the earnings and work hours of employees in the Czech Republic. The Average Earnings Information System contains data obtained from regular statistical surveys called the "Average Earnings Quarterly Survey", which are included in the statistical survey program announced by the Czech Statistical Office in the collection of laws for the relevant calendar year.

The Average Earnings Quarterly Survey is harmonized with the structural survey of the European Union called the Structure of Earnings Survey (see Commission Regulation (EC) No. 1916/2000 as amended). We analyzed the gross monthly wage or salary and hourly earnings as well as the individual components of the gross monthly wage (salary), i.e. bonuses, extra pays and reimbursements. The gross monthly wage in our data group was calculated as a multiple of hourly earnings in the second quarter and average monthly working hours for each year. We rounded off the average working hours to a whole number. We analyzed the number and structure of hours worked (e.g. overtime) and not worked (e.g. sickness and vacation). The AEIA includes the Labor Cost Regional Statistics providing detailed information about wage gaps in the individual regions of the Czech Republic. The administrator of the Average Earnings Quarterly Survey is the Ministry of Labor and Social Affairs. The survey and its progress are overseen by a commission composed of the representatives of the Ministry of Labor and Social Affairs, the Czech Statistical Office, the Ministry of Finance, the Czech National Bank, the Bohemian-Moravian Confederation of Trade Unions, the Confederation of Industry and Transportation of the Czech Republic, CERGE EI, the University of Economics in Prague and other institutions. The private data were provided by the Czech and Slovak company Trexima, two different firms with the same name.

The data have a relatively detailed structure; wage bands, in which absolute frequencies are analyzed, are set at 20 EUR each.

The trend in wages in the Czech Republic and the Slovak Republic is very similar. Of course, the wages of ICT Professionals increase over time. These are data for two countries with different currencies and different inflation. First, we had to adjust these data for inflation. We used inflation data shown on the websites of the national statistical offices (CZSO, 2020a; SUSR, 2020). After that, we converted the data in CZK to EUR, using the exchange rate of the Czech National Bank. We also had to recalculate Slovak wages before the year 2009 since the Slovak Republic did not switch to EUR until the year 2009. For the conversion, we used the exchange rates of the Czech National Bank (CNB, 2020) and the Slovak National Bank (NBS, 2020). The input data set for the analyses was relatively large. The number of wages analyzed in the last year 2018 was as follows: over 2.2 million (of which ICT represented over 60 thousand) in the Czech Republic and 1.1 million (of which ICT represented over 24 thousand) in the Slovak Republic.

2.2 Categories of ICT Professionals

We used the internationally recognized ISCO (CZSO, 2020b) to classify the occupation of ICT Professionals. Both countries switched to this classification in 2009 and are using it now. Based on this classification, the occupation of ICT Professionals is divided into the following three main groups (CZSO, 2020b):

- *ICT Managers* (ISCO 133) (hereinafter as the ICT 133 category);
- *ICT Specialists* (ISCO 25) (hereinafter as the ICT 25 category); and
- *ICT Technicians* (ISCO 35) (hereinafter as the ICT 35 category).

ICT Managers (ISCO 133) – plan, manage and coordinate the purchases, development, maintenance and use of computer and telecommunication systems. They work in management sections or as CEOs of an enterprise or organization that has no management hierarchy (CZSO, 2020b).

ICT Specialists (ISCO 25) research, plan, design, write, test, provide consultations and improve IT, hardware, software and related concept systems for specific applications; process related documentation, including policies, principles and procedures; design, develop, supervise, maintain and support databases and other information systems to ensure their optimal performance and data integrity and security. Most occupations in this class require university skills and knowledge (CZSO, 2020b).

ICT Technicians (ISCO 35) support the regular operation of computer and communication systems and networks and perform technical tasks related to telecommunications and to the transmission of image, sound and other types of telecommunications signals on land, on the sea or in the air. Most occupations in this class require high school skills and knowledge (CZSO, 2020b).

This article focuses only on these three categories of ICT Professionals represented in ISCO as ISCO 133, ISCO 25 and ISCO 35. The article does not

analyze the wages of ICT academicians and researchers. We only focus on the professions that have an immediate impact on the number of ICT Professionals in the Czech economy and in the Slovak economy.

2.3 Processing Methods

For the purposes of our analyses, we used only basic statistical methods and characteristics. Since the average is the most common wage characteristic, we worked mainly with the average wage. Since the average is sensitive to outliers, it was necessary to mention and compare other statistical locations, especially quantiles. Our data include outliers, especially wages above EUR 4,000. However, these wages, which are relatively rare, significantly influence the total volume of wages (Marek and Doucek, 2016). In our case, they significantly increase the average wage. Our article also includes a quantile analysis.

We used MS Excel statistical functions to process our data and provide our tables and figures.

3 RESULTS

3.1 Average Wages of ICT Professionals

First, let's examine average wages. The trend in average wages is shown in Table 1, Figure 1 and Figure 2.

For the purposes of comparison, we show average wages in each analyzed republic (CR - Czech Republic, SR - Slovak Republic) without the wages of ICT Professionals, the average wages of ICT Professionals in both republics (Average ICT CR in the Czech Republic and Average ICT SR in the Slovak Republic), the wages of ICT Managers (133 CR in the Czech Republic and 133 SR in the Slovak Republic), ICT Specialists (25 CR in the Czech Republic and 25 SR in the Slovak Republic), and ICT Technicians (35 CR in the Czech Republic and 35 SR in the Slovak Republic).

Table 1 – Average Wages

Year	*CR*	*Average ICT CR*	*133 CR*	*25 CR*	*35 CR*	*SR*	*Average ICT SR*	*133 SR*	*25 SR*	*35 SR*
2000	530	897	1,391	845	822	534	850	1,335	921	658
2001	621	1,054	1,615	986	972	517	803	1,167	850	703
2002	715	1,186	1,840	1,130	1,089	562	942	1,331	1,059	754
2003	732	1,204	1,830	1,166	1,117	575	917	1,453	1,011	750
2004	749	1,208	1,978	1,152	1,131	590	876	1,525	847	811
2005	830	1,384	2,228	1,345	1,280	623	1,090	1,774	1,145	910

Year	*CR*	*Average ICT CR*	*133 CR*	*25 CR*	*35 CR*	*SR*	*Average ICT SR*	*133 SR*	*25 SR*	*35 SR*
2006	890	1,475	2,524	1,466	1,334	685	1,216	2,075	1,336	927
2007	950	1,713	2,962	1,659	1,583	784	1,440	2,292	1,577	1,017
2008	1,095	1,971	3,371	1,941	1,793	913	1,591	2,671	1,774	1,144
2009	1,018	1,829	3,096	1,780	1,689	956	1,723	2,827	1,842	1,319
2010	1,080	1,769	3,092	1,857	1,499	976	1,775	3,037	1,897	1,360
2011	1,113	1,809	3,181	1,896	1,513	1,000	1,811	3,051	1,982	1,323
2012	1,089	1,780	3,146	1,855	1,454	1,006	1,866	3,822	1,917	1,284
2013	1,038	1,726	3,106	1,785	1,417	996	1,816	3,285	1,925	1,190
2014	976	1,644	3,039	1,705	1,342	1,025	1,878	3,535	1,964	1,214
2015	1,004	1,718	3,071	1,797	1,386	1,067	1,980	3,647	2,066	1,273
2016	1,060	1,813	3,269	1,894	1,459	1,116	2,033	3,777	2,119	1,291
2017	1,138	1,932	3,522	2,029	1,528	1,175	2,065	3,507	2,157	1,371
2018	1,249	2,079	3,690	2,184	1,630	1,243	2,151	3,624	2,246	1,421

It is clear that wages in individual categories differ. Even wages in the same category in the Czech Republic and the Slovak Republic sometimes differ. Since there are too many numbers in Table 1, the following two figures (Figure 1 and Figure 2) will provide a much better and more detailed comparison.

The average wages in the legend are arranged from highest to lowest average wages. It is quite clear that the ICT 133 category in both countries maintained the highest wages during the entire period of 19 years. On the other hand, the national average was the lowest. It is important to mention that the national average wage does not include ICT wages. We will show how ICT increases the national average.

There is a very small difference in both countries between the ICT category (Average ICT, which is the average wage for entire ICT – i.e. ICT 133, ICT 25 and ICT 35 together) and the ICT 25 category (Average ICT 25). The ICT 35 category (Average 35) is also above the national average.

The order of individual categories is the same in both countries. However, individual categories differ in both countries. The average wage of ICT 35 was significantly higher in the Czech Republic for the entire time period of 19 years. The average wage of ICT 133 and 25 was higher (with some exceptions) in the Czech Republic during 2001-2011, but then the situation turned around and the average wage was higher in the Slovak Republic. The differences in 2018 were relatively small (certainly smaller than in previous years) and wages were basically the same.

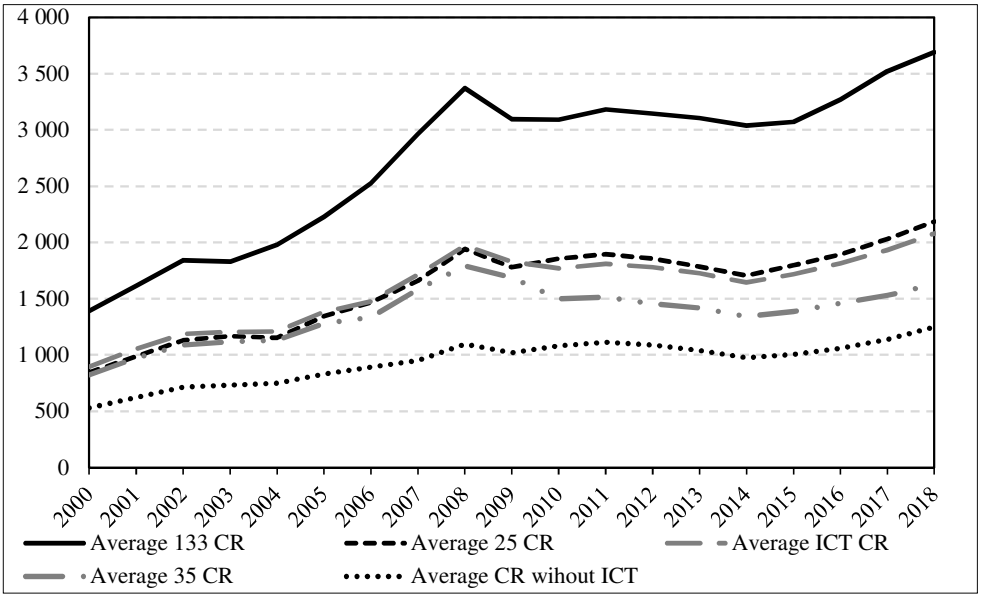

Figure 1 – Average Wages – CR

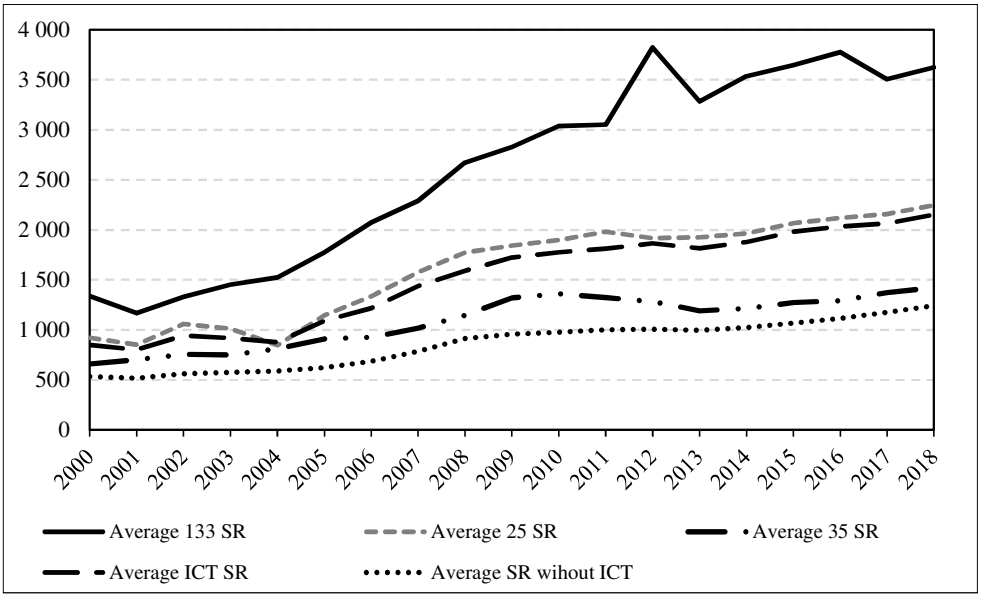

Figure 2 – Average Wages – SR

If we calculate the average of the differences in individual years, the data seem to be in favour of the Czech Republic. Average differences for the entire analyzed time period are shown in Table 2.

Table 2 – Differences between CR and SR

CR - SR	CR ICT - SR ICT	133 CR -133 SR	25 CR - 25 SR	35 CR - 35 SR
81	72	117	-9	280

The ICT 35 category shows the biggest difference. Table 2 shows that ICT Professionals were paid better in the Czech Republic during the entire analyzed time period, with the exception of ICT Specialists who were paid a little bit better in the Slovak Republic in the long term. As mentioned above, the older data in the analyzed time series speak in favour of the Czech Republic. ICT Technicians were the only category where the Czech Republic showed higher wages for the entire analyzed time period.

Let's compare the average wage of ICT Professionals with the national average wage (we would like to point out again that this wage does not include ICT). The results are shown in Table 3.

Table 3 – ICT Categories as Compared to the Average National Wage

ICT/CR	133/CR	25/CR	35/CR	ICT/SR	133/SR	25/SR	35/SR
1.687	2.866	1.689	1.464	1.739	2.939	1.851	1.280

We can say that the average wage of ICT Professionals is considerably higher than the national average wage in the Czech Republic and in the Slovak Republic. In the Czech Republic, it is higher by approximately 69% and in the Slovak Republic by as much as 74%. The ICT 133 category shows the highest average wage as compared to the national average. ICT Managers in the Czech Republic earn 2.78 times more than the average and in the Slovak Republic 2.94 times more. This means that their wages are almost three times higher than the average wage. The wages of the ICT 35 category and the ICT 25 category are also significantly higher than the average wage. Overall, we can say that ICT Professionals in both countries are paid very well as compared to other workers. The situation in Slovakia is more favourable for ICT because the three ICT categories, with the exception of the ICT 35 category, are better off in Slovakia.

Figure 1 and Figure 2 show that the average wage in different categories does not grow at the same rate. Therefore, we calculated the average growth coefficient for the entire time period of 19 years and showed the results in Table 4.

Table 4 – Average Growth Rate of Wages

CR	ICT CR	133 CR	25 CR	35 CR	SR	ICT SR	133 SR	25 SR	35 SR
1.049	1.048	1.056	1.054	1.039	1.048	1.053	1.057	1.051	1.044

3.2 Quantile Analysis

The average wage of the ICT 133 category grew the fastest - by 5.6% a year in the Czech Republic and by 5.7% a year in the Slovak Republic. The ICT 25 category is also doing well; the ICT 35 category is lagging behind the national growth rate. However, the situation in both countries is similar; there are no significant differences between individual categories.

The wages of 10% of the worst and best paid ICT Professionals (i.e. wages below the 10th percentile and above the 90th percentile) provide interesting information in Figure 3.

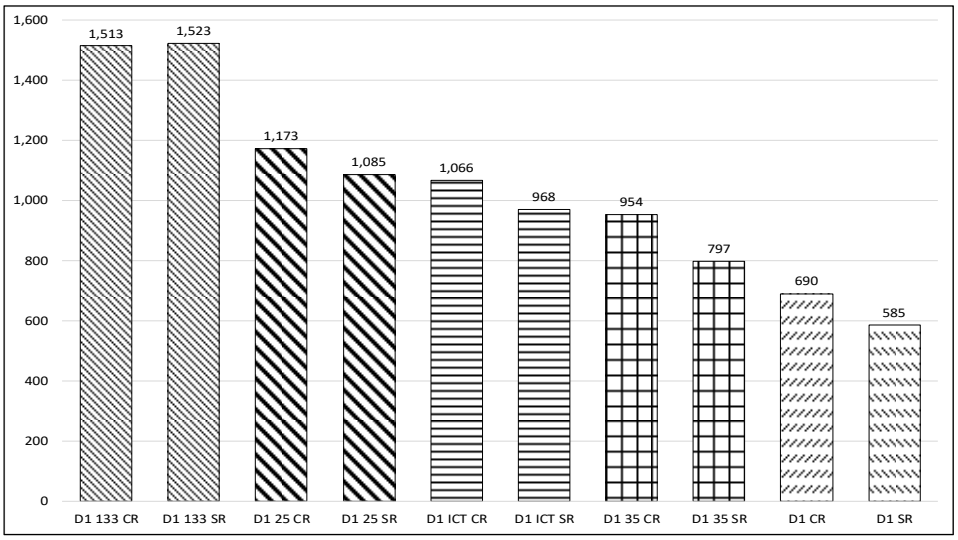

Figure 3 – 10% Wage Quantile

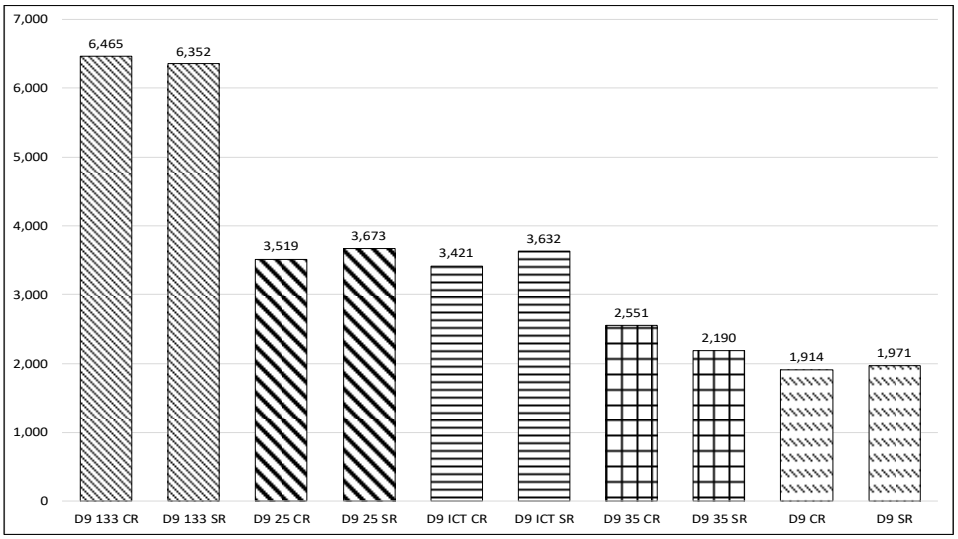

Figure 4 – 90% Wage Quantile

Figure 4 and Figure 5 compare only the values in 2018. The situation in previous years was similar in terms of comparison, but the values grew constantly over time, as was the case with the average wage. Except for the ICT 133 category, where the 10% quantile was almost the same (it differs by EUR 10 in favour of the Slovak Republic), the values in the Czech Republic were generally higher than in the Slovak Republic. There was a difference of about EUR 100 in the ICT 25 category, the ICT 35 category and at national levels. The biggest difference (approximately EUR 350) was in the ICT 35 category in favour of the Czech Republic.

Interestingly, even 10% of the worst-paid workers in the ICT 133 category seem to gain a wage (EUR 1,513 is a 10% quantile in the Czech Republic and EUR 1,523 in the Slovak Republic) that is higher than the national average wage (EUR 1,272 in the Czech Republic and EUR 1,421 in the Slovak Republic - this time, the average wage includes ICT).

Figure 4 shows 90% quantiles in all categories. This means that 10% of ICT Professionals gain wages higher than those displayed. The wage in the ICT 133 category is already very high in both countries and completely different from all other values. Wages in the ICT 25 category and at national levels are comparable. The situation in both countries is similar. The biggest difference between the two countries is again in the ICT 35 category.

Let's compare average and median wages. It is generally claimed that about 2/3 of employees earn less than the average wage. Our data should confirm this claim, i.e. the average should be roughly a 67% quantile and therefore should be significantly higher. We calculated the difference between the average wage and the median wage. Again, this is a comparison for the year 2018 only, although we calculated the data for the entire analyzed period. The results are shown in Figure 5.

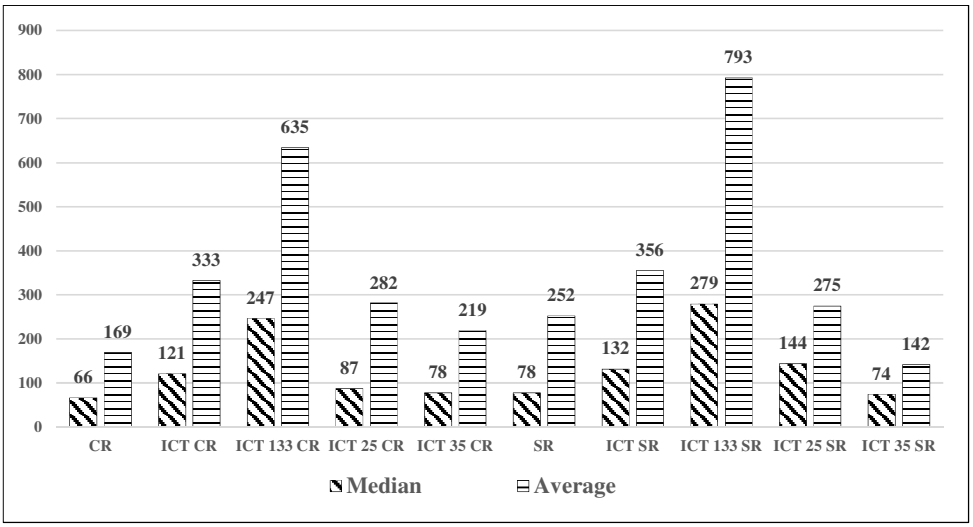

Figure 5 – The Difference between the Average and the Median

The Figure 5 shows the differences between the average and the median. To make a time comparison, we chose the difference in the first analyzed year (2000) and the last analyzed year (2018). The differences for each category in the year 2000 are shown first, the differences in the year 2018 are shown second. The figure clearly shows that the gap between the median and the average is widening over time. The difference is quite striking in all categories in both countries. The difference between the median and the average increases absolutely the most in the ICT 133 category, and this difference is greater in the Slovak Republic.

4 CONCLUSIONS

The objective of the analysis was to compare the real wages of ICT Professionals in the Czech Republic and the Slovak Republic. We analyzed the three most important categories - ICT Managers, ICT Specialists and ICT Technicians. We used data sets containing the interval distribution of wage frequencies for the Czech Republic and the Slovak Republic. The average wage of all three categories of ICT Professionals was compared with the average wage in the Czech Republic and the Slovak Republic. We compared two main areas - average real wages and wage quantiles. Based on our analyses, we can make the following general conclusions:

- All analyzed wage characteristics increased over time, with the exception of the economic crisis during 2009-2014 when they stagnate;
- There are large differences between individual categories of ICT Professionals, but the same categories in the Czech Republic and the Slovak Republic are very similar;
- All categories of ICT Professionals show significantly higher wages than national average wages;
- What was said about the average wage also applies to quantiles; the comparison between the Czech Republic and the Slovak Republic shows almost the same values in the same categories;
- The category of ICT Managers is particularly different since it shows an abnormal number of wages above EUR 4,000.

Another anomaly that needs to be explained are the significant deviations in the average wages of ICT Managers in the Czech Republic in 2008 and in the Slovak Republic in 2012. Both deviations have something in common and something different.

There was a significant shortage of qualified workers, including ICT Professionals, on the Czech labour market in 2008. For this reason, average wages in the entire Czech Republic grew faster this year than expected based on trend curves. The overall trend of the years before the year 2008 is shown in Figure 1. The

subsequent economic crisis then lowered average wages in all analyzed categories as compared to the year 2008.

On the Slovak market, the financial period of projects supported from European funds ended in 2012 and the Slovak Republic had a lot of unfinished ICT projects that lacked ICT managers or lacked good ICT managers. For this reason, EU funds were used to pay significantly higher wages to managers of state ICT projects. When the year 2012 ended and all EU funds were used up, the wages returned to their original level expected for the year 2009 based on the trend curve. Interestingly, the average wages of ICT Specialists and ICT Technicians dropped in 2008, while the average wage for all these categories went slightly up thanks to a high increase in the wages of ICT Managers.

In conclusion, we can say that there is no big difference in average wages between the Czech Republic and the Slovak Republic. All analyzed characteristics are very similar in both countries. The same situation is at the national level as well. Given the big difference between the average wage in all ICT areas in the Czech Republic and the Slovak Republic and the average wage in the entire economy of both countries, we can only say that working in ICT is very good from financially. This also creates an incentive especially for young people to work in ICT. Work in ICT is rewarded above average in both analyzed countries, which makes these professions interesting for people. It is a good thing that they are both for professionals mostly with a secondary education (ICT Technicians – ISCO 35) and for university-educated people (ICT Specialists – ISCO 25). ICT Managers (ISCO 133) are recruited from among either competent people with an appropriate education and experience or university-educated experts – typically project managers, software engineers, etc.

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AUTHOR CONTRIBUTIONS

Conceptualization, P.D. and L.M.; Methodology, L.M.; software, L.M.; Validation, L.M. and P.D.; Formal analysis, L.N.; Investigation, L.M.; Resources, L.N.; Data curation, L.M.; Original draft preparation, P.D., L.M and L.N.; Review and editing, L.N.; Visualization, L.N.; Supervision, P.D.; Project administration, L.N.; Funding acquisition, P.D.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

The Analysis of Total Quality Management Critical Success Factors

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ABSTRACT

Purpose: The primary purpose of this paper is to identify the most important factors related to the successful implementation of TQM in the literature and to compare the identified factors with the existing research.

Methodology/Approach: By conducting a systematic literature review in three main stages, this research analyzes 13 empirical papers published between 1995 and 2017. Three main stages included: formulation of the problem to be solved by the systematic literature review; definition of inclusion criteria and exclusion of articles; and article search and selection.

Findings: Analysing previous research and conducting a literature review, we identify six main critical success factors (CSF): top management leadership and commitment, customer focus, training (employees), procurement management (suppliers), information and analysis, and process management.

Research Limitation/Implication: In this paper, we focused solely on the influence of TQM practices on the financial performance of a company. As such, the non-financial performance indicators were not considered.

Originality/Value of paper: This paper adds value to the existing literature as it focuses on critical factors of TQM implementation examined in relation to the financial performance of the company and provides a good basis for understanding and developing more complex models.

Category: Literature review

Keywords: TQM; quality; critical success factors; implementation; literature review; performance

1 INTRODUCTION

The success of any quality management concept depends on its successful implementation within a company. In practice, however, the implementation of TQM is a complex and difficult process, and the benefits are typically not easy to achieve (Mohammad Mosadegh Rad, 2006). Therefore, exploring the key factors that determine the success of TQM implementation is an important issue.

Quality management (QM) is a concept with a long and complex history. The interpretation of the quality movement has varied across different periods, from quality control to total quality management and beyond. Thus, different definitions of QM have emerged (Bergquist et al., 2012). One of the most comprehensive definitions of TQM used in the literature considers TQM as "holistic management philosophy that strives for continuous improvement in all functions of an organisation, and it can be achieved only if the total quality concept is utilised from the acquisition of resources to customer service after the sale" (Kaynak, 2003, p.406).

Prior research suggests several possible key factors for the successful implementation of TQM. However, finding and selecting the right factors is a major challenge for businesses because there is no consensus on specific factors or a holistic framework (Ismail Salaheldin, 2009). The field of research into key factors and related measurement instruments is very broad and undefined. As such, various opinions and experiences related to factors exist in the literature (Nenadál, Vykydal and Waloszek, 2018). Therefore, research that provides an overview and structures previous research is a necessary step to establishing a common base in practice and academia.

In general, aspects of successful implementation of TQM can be drawn from four different theoretical areas: the work of quality authors (gurus), formal reward models, descriptive approaches, and empirical research (Claver, Tarí and Molina, 2003; Tarí, 2005). The research in the application of quality management comes from the contributions of quality gurus in the 1980s, when national governments have launched various models of quality awards. By the late 1990s, the vast majority of quality management literature consisted of case studies, descriptive and conceptual papers with rare exceptions of empirical studies (Hietschold, Reinhardt and Gurtner, 2014).

The main purpose of this research is to identify the most important factors related to the successful implementation of TQM in the literature and to compare the factors with the existing body of knowledge. In the first section (literature review), we explore key factors of successful implementation of TQM in the literature. However, different aspects of companies' performance have been included in these papers, which may or may not be related to financial performance. As financial performance is considered to be one of the most important measures of survival of a company, this paper provides a systematic literature review of the studies that confirmed the positive relationship between TQM practices and financial performance (subjective or objective). The reason to

focus on the papers with the positive relationship between these constructs is to identify the factors that contribute to the improvement of the financial performance, rather than to start another discussion whether TQM contributes to the performances.

2 LITERATURE REVIEW

Sila and Ebrahimpour (2003) and Karuppusami and Gandhinathan (2006) conducted some of the first literature review studies and identified key factors of a successful implementation of TQM. Starting with these papers, authors' focus on empirical research and identification of new key factors have constantly increased. Today, researchers most often focus on empirical studies that incorporate the principles of national quality models (Hietschold, Reinhardt and Gurtner, 2014).

Covering the period from 1989 to 2000, Sila and Ebrahimpour (2003) analysed and compared 76 empirical studies in 23 different countries. Through their research, the authors identify five key factors for successful implementation of TQM: top management commitment and leadership, customer focus, information and analysis, training, and supplier management.

Carrying out a Pareto analysis for papers published between 1989 and 2003, Karuppusami and Gandhinathan (2006) identified 37 empirical studies by conducting reliability and validation tests in order to group key factors. The five most important factors identified by the authors are the role of management leadership and quality policy, supplier quality management, process management, customer focus, and training.

The analysis of 145 articles using a structured overview of empirical studies Hietschold, Reinhardt and Gurtner (2014) identified 11 key factors, where the five most important factors are: HRM/recognition/teamwork, top management commitment and leadership, process management, customer focus and satisfaction, and supplier partnership.

Similar research on identifying key factors for successful implementation of TQM was carried on by Aquilani et al. (2017) for the period from 1993 to 2016. In this paper, the five factors mentioned above are confirmed in their work: leadership/top management commitment/top management role, customer focus/satisfaction, training and education, measurement or metric systems/data information and analysis/quality data and reporting, supplier collaboration/management/supplier quality (management).

3 METHODOLOGY

For the identification, selection, and analysis of the relevant articles, we followed the stages used by Suárez et al. (2017). According to authors, a systematic

literature review has three main stages: (1) formulation of the problem to be solved with the systematic literature review; (2) definition of inclusion criteria and exclusion of articles; and (3) article search and selection.

In the first stage, we defined the problem to be solved. The main research question was: "What are the main TQM critical success factors of the positive influence of TQM on the financial performance of a company?"

In the second stage, we defined inclusion and exclusion criteria. We covered the period from 1995 to 2017 and only scientific articles were selected which were published in journals that had a JCR (Journal Citation Reports of Thomson Reuters) or SJR (SCImago Journal and Country Rank by Scopus) impact factor. The following keywords were used: TQM, implementation, and financial performance. Papers relevant to the successful implementation were selected based on the following criteria: quantitative research; articles in English; and papers that examine the relationship between TQM and financial performance.

The third stage implied article search and selection. The first step included a total of 116 articles. After a detailed analysis of the abstracts, 94 articles were eliminated since the dependent variable had not been related to the financial performance of a company. The next phase included a complete analysis of the papers that meet the criteria. The total number of papers further analyzed is 13 (Powell, 1995; Samson and Terziovski, 1999; Douglas and Judge, 2001; Kaynak, 2003; Kaynak and Hartley, 2005; Demirbag et al., 2006a; 2006b; Sadikoglu and Olcay, 2014; Dubey and Gunasekaran, 2015; Jiménez-Jiménez et al., 2015; Valmohammadi and Roshanzamir, 2015; O'Neill, Sohal and Teng, 2016; Sweis et al., 2016). Table 1 presents the analysis of the articles identifying CSFs and used measures of financial performance. The analysis was conducted by identifying the key factors in the papers and then grouping them into broader categories.

Table 1 – Critical Success Factor Related to the Positive Influence of TQM Practices on Financial Performance

Authors	*Critical Success Factors*	*Performance*
Powell (1995)	committed leadership, adoption and communication of TQM, closer customer relationships, closer supplier relationships, benchmarking, increased training, open organization, employee empowerment, zero-defects mentality, flexible manufacturing, process improvement, measurement	financial performance/total performance, TQM programme performance
Samson and Terziovski (1999)	leadership, people management, customer focus, strategic planning, information and analysis, process management	quality performance, operational performance, business performance

Authors	*Critical Success Factors*	*Performance*
Douglas and Judge (2001)	top management team involvement, quality philosophy, emphasis on TQM-oriented training, customer driven, continuous improvement, management by fact, total quality methods	perceived financial performance
Kaynak (2003)	management leadership, training, employee relations, quality data and reporting, supplier quality management, product/service design, process management	inventory management performance, quality performance, financial and market performance
Kaynak and Hartley (2005)	management leadership, training, employee relations, quality data and reporting, supplier quality management, product/service design, process management, customer relations	inventory management performance, quality performance, financial and market performance
Demirbag et al. (2006a)	quality data and reporting, role of top management, employee relations, supplier quality management, training, quality policy, process management	financial performance
Demirbag et al. (2006b)	quality data and reporting, role of top management, employee relations, supplier quality management, training, quality policy, process management	financial performance
Sadikoglu and Olcay (2014)	overall TQM practices, leadership, knowledge and process management, training, supplier quality management, customer focus, strategic quality planning	operational performance, inventory management performance, employee performance
Dubey and Gunasekaran (2015)	human resource, quality culture, motivational leadership, relationship with internal and external partners	firm performance
Jiménez-Jiménez et al. (2015)	top management support, quality information, process management, product design, workforce management, supplier involvement, customer involvement	customer results, people results, society results, business results
Valmohammadi and Roshanzamir (2015)	leadership, strategic planning, customer focus measurement, analysis and knowledge management, workforce focus, operations focus	organizational performance
O'Neill, Sohal and Teng (2016)	QM implementations	capital labour ratio, value added labour
Sweis et al. (2016)	customer focus, continuous improvement, training and education, teamwork, top management commitment	quality outcomes, customer satisfaction, financial performance, innovation

4 RESULTS

Our analysis extracted 10 factors from the literature. More specifically, our results identified six factors of the successful TQM implementation, including employees, leadership, information and analysis, processes, customers, and suppliers. Although our goal was to focus on five main CSFs, we included the suppliers as the sixth one, due to the same usage frequency as the factor customers. The most common used factor was employees and leadership (in 12 out of 13 papers, 92%), information and analysis and processes (69%), and customers and suppliers (62%) (Table 2).

Table 2 – Main Extracted Factors

Main Extracted Factor	*Critical Success Factors*
Top management leadership and commitment (92% coverage)	committed leadership (Powell, 1995), leadership (Samson and Terziovski, 1999; Sadikoglu and Olcay, 2014; Valmohammadi and Roshanzamir, 2015), top management team involvement (Douglas and Judge, 2001), management leadership (Kaynak, 2003; Kaynak and Hartley, 2005), role of top management (Demirbag et al., 2006a; 2006b), motivational leadership (Dubey and Gunasekaran, 2015), top management support (Jiménez-Jiménez et al., 2015), top management commitment (Sweis et al., 2016)
Employees (92%)	increased training, employee empowerment (Powell, 1995), people management (Samson and Terziovski, 1999), emphasis on TQM-oriented training (Douglas and Judge, 2001), training, employee relations (Kaynak, 2003; Kaynak and Hartley, 2005; Demirbag et al., 2006a; 2006b), training (Sadikoglu and Olcay, 2014), human resource (Dubey and Gunasekaran, 2015), workforce management (Jiménez-Jiménez et al., 2015), workforce focus (Valmohammadi and Roshanzamir, 2015), training and education, teamwork (Sweis et al., 2016)
Information and analysis (69%)	information and analysis (Samson and Terziovski, 1999), management by fact (Douglas and Judge, 2001), quality data and reporting (Kaynak, 2003; Kaynak and Hartley, 2005; Demirbag et al., 2006a; 2006b), quality information (Jiménez-Jiménez et al., 2015), analysis and knowledge management (Valmohammadi and Roshanzamir, 2015), measurement (Powell, 1995)
Processes (69%)	process improvement (Powell, 1995), process management (Samson and Terziovski, 1999; Kaynak, 2003; Kaynak and Hartley, 2005; Demirbag et al., 2006a; 2006b; Jiménez-Jiménez et al., 2015), operations focus (Valmohammadi and Roshanzamir, 2015), knowledge and process management (Sadikoglu and Olcay, 2014)
Customers (62%)	closer customer relationships (Powell, 1995), customer focus (Samson and Terziovski, 1999; Sadikoglu and Olcay, 2014; Sweis et al., 2016), customer driven (Douglas and Judge, 2001), customer involvement (Jiménez-Jiménez et al., 2015), customer focus measurement (Valmohammadi and Roshanzamir, 2015), customer relations (Kaynak and Hartley, 2005)
Suppliers (62%)	closer supplier relationships (Powell, 1995), supplier quality management (Kaynak, 2003; Kaynak and Hartley, 2005; Demirbag et al., 2006a; 2006b; Sadikoglu and Olcay, 2014), supplier involvement (Jiménez-Jiménez et al., 2015), relationship with internal and external partners (Dubey and Gunasekaran, 2015)

Main Extracted Factor	*Critical Success Factors*
Cross-cutting themes of quality (53%)	adoption and communication of TQM (Powell, 1995), quality philosophy, total quality methods (Douglas and Judge, 2001), quality policy (Demirbag et al., 2006a; 2006b), overall TQM practices (Sadikoglu and Olcay, 2014), quality culture (Dubey and Gunasekaran, 2015), QM implementations (O'Neill, Sohal and Teng, 2016)
Strategic planning (23%)	strategic planning (Samson and Terziovski, 1999; Valmohammadi and Roshanzamir, 2015), strategic quality planning (Sadikoglu and Olcay, 2014)
Product/service design (23%)	product/service design (Kaynak, 2003; Kaynak and Hartley, 2005), product design (Jiménez-Jiménez et al., 2015)
Continuous improvement (15%)	continuous improvement (Douglas and Judge, 2001; Sweis et al., 2016)

As shown in Table 3, the factors of successful implementation of TQM that we identified closely correspond to the existing factors highlighted in the existing literature. Top management leadership and commitment, customer focus, training (employees), and suppliers are found in all five studies, procurement management (suppliers), and process management in four studies, while information and analysis in three studies.

Table 3 – Key Factors for Successful Implementation According to Different Authors

Comparison to the Previous Literature Review				
Our research	Sila and Ebrahimpour (2003)	Karuppusami and Gandhinathan (2006)	Hietschold, Reinhardt and Gurtner (2014)	Aquilani et al. (2017)
top management leadership and commitment	top management commitment and leadership	the role of management leadership and quality policy	top management commitment and leadership	leadership/top management commitment/top management role
customers	customer focus	customer focus	customer focus and satisfaction	customer focus/satisfaction
employees	training	training	HRM/recognition/teamwork	training and education
suppliers	supplier management	supplier quality management	supplier partnership	supplier collaboration/ management/supplier quality (management)
information and analysis	information and analysis	-	-	measurement or metric systems/data information and analysis/ quality data and reporting
processes	-	process management	process management	Process quality management

4.1 Top Management Leadership and Commitment

According to the existing literature, the leadership and commitment of top management are undoubtedly one of the most important factors underlying the success of TQM. TQM is a management philosophy, and therefore the initiation of quality activities comes from the level of top management. Top management leadership and commitment relate to factors that measure the involvement and support of the quality of individuals at higher levels of an organization's hierarchy (Hietschold, Reinhardt and Gurtner, 2014). Thus, Oakland (2011, p.517) stated: "TQM must start at the top, where serious obsession and commitment to quality and leadership need to be demonstrated. Middle management also has a key role to play in communicating the message". The factor of top management's leadership and commitment imply that managers should be focused on aligning quality goals with their vision, on implementing quality as a part of corporate culture, and creating a culture in which continuous improvement is supported, and reluctance to change is minimized. Establishing a culture of quality that is supported by overall business strategy is crucial to the success of an organization. Therefore, it is important that leaders have competencies related to planning, communication, management, vision development and implementation as well as ensuring employee participation (Paulová and MÍkva, 2011).

4.2 Focus on the Customer and Customer Satisfaction

Some authors consider focusing on customer satisfaction to be a key factor in success, while others acknowledge customer satisfaction as a result of the successful implementation of TQM (Porter and Parker, 1993; Yusof and Aspinwall, 2000). Furthermore, Issac, Rajendran, and Anantharaman (2004) confirmed that customer satisfaction is part of the philosophy of TQM. This factor focuses on identification and meeting current and emerging customer needs (Nair, 2006). Considered in a long-term perspective, organizations can not "survive" without their customers. Consequently, issues related to customer retention or customer loyalty are considered crucial today (Vykydal, Halfarová and Nenadál, 2013). Organizations need to establish an open relationship with customers to receive information about their preferences and to receive feedback on how to fulfil these requirements in the best possible way (Das, Paul and Swierczek, 2008; Flynn, Schroeder and Sakakibara, 1994). Consumer opinions can improve the quality of products and services and should, therefore, be included at every stage of the product development process (Singh and Smith, 2004). Since customer satisfaction affects the success or failure of a company, an organization should be able to respond quickly to changing consumer needs (Mehra, Hoffman and Sirias, 2001). It is, therefore, important that every employee of a company is involved and committed to establishing and maintaining a high level of customer satisfaction.

4.3 Employees: Training and Education

Employee related factors are most often manifested through employee training and education; that is, the focus is on employee participation. By actively participating, employees acquire new knowledge, learn how to identify problems more efficiently, and to solve problems more effectively. The resulting understanding of the importance of quality leads to an increased commitment to TQM. This change in attitude makes employees to feel as a part of the organization and enables the creation of a quality culture for the entire company. Training and education are considered to be the most important aspects of human resource management, i.e., it is considered to be "a key to a successful implementation of TQM along the dimensions of cost reduction and profit increase" (Kassicieh and Yourstone, 1998, p.36). Training needs, employee motivation, and improvement of future effective evaluation are essential for building a quality performance evaluation based on quality (Aquilani et al., 2017).

4.4 Suppliers: Supplier Management and Cooperation with Suppliers

Creating and maintaining a superior supplier relationship is another critical factor. One of the prerequisites for the success of production process management is a choice of reliable suppliers. As such, this issue deserves special attention (Pech and Vaněček, 2020). Supply quality is an important aspect of TQM, as parts provided by suppliers are often the main source of quality problems (Zhang, Waszink and Wijngaard, 2000). Poor quality leads to additional costs and can damage the image of the product or the entire company. As a result of this interconnectedness, record keeping and providing quality feedback are often considered extremely important in identifying problems and improving the supplier process (Saraph, Benson and Schroeder, 1989). Long-term relationships between the organization and selected suppliers reduce the cost of quality control and costs of poor product quality and ensure a continuous supply of the required quality components (Das, Paul and Swierczek, 2008; Zhang, Waszink and Wijngaard, 2000). Improvements in the quality of products or services require that all major suppliers comply with the organization's quality specifications (González-Benito, Martínez-Lorente and Dale, 2003).

4.5 Information and Analysis

The information system is a key part of the quality management infrastructure. To maintain and continually improve quality, organizations need a flow of reliable information (Rao, Solis and Raghunathan, 1999). Collecting relevant data is essential to monitor the current quality status. Organizations can not properly evaluate the quality of products and services unless they can measure status before and after improvement activities (Jayaram, Ahire and Dreyfus, 2010). Quality data and reporting include a high level of documentation, monitoring, and feedback. Documenting the processes, identifying the level of

waste and damage in the production process, as well as keeping information easily accessible to employees, are considered important factors underlying an organization's success (Kaynak, 2003). Measurement assists in evaluating the quality of processes and products or services, which is one of the most important methods for checking continuous improvement, monitoring processes, analyzing, and correcting deficiencies from required standards. For a process to be managed, primary data must be collected (Malik, Sinha and Blumenfeld, 2012).

4.6 Process Management

The process is a series of interdependent activities that consume resources and convert inputs into outputs. Organizations need to manage processes to function without operational errors (Zhang, Waszink and Wijngaard, 2000). The importance of process management is based on the assumption that organizations are systems of interconnected processes and that process improvement determines performance improvement (Deming, 1986; Samson and Terziovski, 1999). The importance of this in implementing TQM stems from its ability to add value to processes, increase quality levels, and raise enterprise productivity (Bigwood, 1997; Motwani, 2001). To achieve better product and service quality, organizations need to identify key processes and improve them on a continuous basis (Zhang, Waszink and Wijngaard, 2000). The application of appropriate statistical methods to ensure a high level of process control and the use of assessment results to acquire process knowledge have also been emphasized as important factors in several empirical studies (Saraph, Benson and Schroeder, 1989; Flynn, Schroeder and Sakakibara, 1994; Claver, Tari and Molina, 2003). Furthermore, process redesign and reengineering can lead to dramatic performance improvements (Samson and Terziovski, 1999).

5 CONCLUSION

The main purpose of this paper has been to identify the most commonly used critical success factors in the TQM implementation. Analysing previous research and conducting a literature review, we have identified six main critical success factors: top management leadership and commitment, customer focus, training (employees), procurement management (suppliers), information and analysis, and process management. This paper adds value to the existing literature as it focuses on critical factors of TQM implementation examined in relation to the financial performance of a company and as it provides a good basis for creating more complex models to explore the impact of TQM practices on company performance. The future research might focus on other dependent variables, such as employee satisfaction and customer satisfaction. By comparing the results with previous research, similarities, and shortcomings in identifying factors for successful implementation of TQM can be identified. The interplay between these factors and the financial performance might depend on the external factors, and future studies should elaborate the mechanism by which these factors

contribute to the financial performance of a company in specific industries. Case studies would be especially useful for managers in order to demonstrate the importance of TQM factors and to explain the mechanism of how previously identified critical success factors of TQM influence financial performance.

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Improving Quality of Long-Term Bond Price Prediction Using Artificial Neural Networks

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ABSTRACT

Purpose: The aim of this paper is to propose nonlinear autoregressive neural network which can improve quality of bond price forecasting.

Methodology/Approach: Due to the complex nature of market information that influence bonds, artificial intelligence could be accurate, robust and fast choice of bond price prediction method.

Findings: Our results have reached a coefficient of determination higher than 95% in the training, validation and testing sets. Moreover, we proposed the nonlinear autoregressive network with external inputs using 50 year interest-rate swaps denominated in EUR and volatility index VIX as two external variables.

Research Limitation/Implication: Our sample of daily prices between 4th January 2016 and 13th January 2021 (totally 1,270 trading days) suggest that both Levenberg-Marquardt and Scaled conjugate gradient learning algorithms achieved excellent results.

Originality/Value of paper: Despite the fact that both learning algorithms achieved satisfying outcomes, implementation of an independent variable into the autoregressive neural network environment had no significant impact on prediction ability of the model.

Category: Research paper

Keywords: bond prices; neural networks; prediction; swaps; VIX

1 INTRODUCTION

Bond yields and prices play crucial role in global economy. They determine the cost of corporate financing, influence balances of governments and shape market expectations. Correct forecast of bond yields and prices is therefore of great importance of almost all market participants. Extensive amount of academic research has been accordingly focused on the issue of bond return predictability. Many studies indicated that precise forecasts of bond yields and excess returns are able using forward rates (Fama and Bliss, 1997; Campbell and Shiller, 1991; Huang and Lin, 1996; Fama, 2006; Vieira, Fernandes and Chague, 2017). Although these works confirm the forecasting ability of forward rates, their out of sample predictions are usually outperformed by random walk forecasts (Diebold and Li, 2006).

Carriero, Kapetanios and Marcellino (2012) introduced a Bayesian vector autoregression with time-varying optimal shrinkage to forecast term structure of government bond yields. Their approach performed better than benchmark methods on most maturities and forecast horizons, however, predictive gains of the model with respect to the random walk has declined over time. Regarding the importance of bond markets, several studies focused on the relationship between the state of the economy and bond return volatility (Bollerslev, Cai and Song, 2000; Andersen et al., 2001; Andersen et al., 2003). Chao (2016) examined whether different economic variables significantly influence the return volatility forecasts of US Treasuries and evaluated the out of sample performance of various prediction techniques.

The forecasting capability of their model was obvious at the short end of the yield curve and the turbulent historical periods, but the evidence of out of sample forecasting ability was weaker, since only a few forecasts significantly outperformed the benchmark. The link between the standard macroeconomic variables and the shape of the sovereign bond yield curve was examined by Aguiar-Conraria, Martins and Soares (2012) who used wavelet tools to analyse the yield curve components with three time-varying latent factors corresponding to its level, slope and curvature. The expectations element of the term spread could only moderately help to forecast business cycle, since the low liquidity and the risk associated to longer-term securities are represented by the term premium element which reflects the demand for higher yields. On the other hand, Hamilton and Kim (2002) suggested that both elements are statistically significant.

While, many authors claimed that macroeconomic fundamentals such as unemployment, or ratio of debt to GDP ratio are the major determinants of government bond yields (Bernoth, Von Hagenn and Schuknecht, 2004; Georgoutsos and Migiakis, 2013), von Hagen, Schuknecht and Wolswijk (2011) and Longstaff et al. (2011) suggested that bond yields are influenced by common parameters such as risk aversion of investors. On the other hand, De Grauwe and Ji (2013) argue that spreads are significantly influenced by monetary policy. On

the sample of 10-year Greek government bond Chionis, Pragidis and Schizas (2014) found that, in general, macroeconomic indicators play a significant role as determinants of Greek bond yield, while isolating the debt crisis period, inflation and unemployment among others strengthen their affect to the Greek debt market. For the period during the crisis, the balance of current account was among the top variables determining yields

Even though there has been literature exploring the impact of economic announcements on various asset classes, global bond markets have received smaller attention than stocks, derivatives, exchange rates, or other financial instruments (Ehrmann and Fratzscher, 2002; Faust et al., 2003; Chuliá, Martens and van Dijk, 2010). Share prices heavily depend on expected profits, the risk premium, and actual discount rate, which generally move in opposite manner. The relationship between macroeconomic releases and share prices is therefore ambiguous. Looking apart from the risk premium, favorable macroeconomic news increase both expected profits and discount rate, leaving the net effect on stock prices uncertain (Andersen et al., 2007). The effect of positive news on foreign exchange markets usually constitutes that assertive development of domestic economy strengthens the domestic currency, however, the empirical evidence is mixed. Moreover, many papers indicate that prices and fundamentals are independent for the foreign exchange market. If focus on the link between macro indicators and bond prices, Paiardini (2014) followed previous analyses of Balduzzi, Elton and Green (2001), Green (2004) and Andersson, Overby and Sebestyén (2009) and investigated the implications of regularly published macro news and monetary policy statements on the returns of Italian bonds. They found that out of 68 announcements, 25 news had a considerable impact on bond prices and that almost all releases were incorporated into market prices within 20 minutes, which is in compliance with Goldberg and Leonard (2003).

Lot of academic research has been devoted to the analysis of long term bond yields considering various perspectives. Kurita (2016) applied a Markov-switching variance technique to estimate structural changes in Japan's government bonds and examined internal factors in terms of Japan's inflation rate, short-term interest rate and stock returns. External factor was represented by yields on the US Treasuries. Results of this research emphasize the nonlinear characteristics of Japanese bond yields over the past three decades. The linkages between the short and long ends of the term spread was examined by Byrne, Fazio and Fiess (2012). Particularly, authors separated the role of global output, inflation, and savings as a possible interpretations of the low long term interest rates in western countries. Their results captured a globalization regime, where the longer term spreads were found to grow by approximately one third to variances in longer term yields of Treasuries. The magnitude of reactions was in conformity with results of Diebold, Li and Yue (2008) and Lange (2014). Moreover, obtained outcomes were consistent with the cross-correlations between 10-year bond yields of small economies and Treasuries described in Kulish and Rees (2011). While most of studies investigating the predictability of

bond yields (Ilmanen and Byrne, 2003; Boyd and Mercer, 2010; Moskowitz, Ooi and Pedersen, 2012) relied on the monthly data, Bessembinder et al. (2009) examined the abnormal bond returns on the daily basis. They found that applying daily data significantly increased the power of the test, even if the available time series of daily returns was short. Their results were confirmed by Goyenko, Subrahmanyam and Ukhov (2011) and Hong, Lin and Wu (2012). For corporate debt, in short term predictability was also found to be positively connected to risk of default risk. Returns on bond portfolios with risky obligations were more predictable than returns on the high-quality portfolios with low risk.

It is crucial to understand that the major drivers of current interest rates are the actions of global central banks. Central banks decrease short-term interest rates through the policy rates (and other tools) and the expectations of the short-term rates are the crucial factor in determining the long-term rates and bond yields. Reflecting given low global interest rates, particularly private sector significantly increased bond issuance and rebalanced from bank loans towards corporate bond (Chang, Fernández and Gulan, 2016). The effects of zero-rate monetary policies on bond yields and spreads has been explored by various studies (Hamilton and Wu, 2012; Wright, 2012; Guidolin, Orlov and Pedio, 2014). They highlight a broad range of channels through which expansive monetary policy increase prices of financial assets and affects risk aversion of investors.

In addition to the above mentioned applications, artificial neural networks have been repeatedly utilized for stock and commodity markets forecasts. Kara, Boyacioglu and Baykan (2011) developed two neural network based models and compared their performances in predicting the direction of movement in the daily Istanbul Stock Exchange, Ticknor (2013) proposed Bayesian regularized artificial neural network to reduce the potential for overfitting and overtraining and performed experiments with blue chips stock. While Bildirici and Ersin (2009) upgraded ARCH/GARCH family models with artificial neural networks to evaluate the volatility of daily stock returns, Tseng et al. (2008) integrated a hybrid asymmetric volatility approach into a neural networks option-pricing model to enhance the forecasting ability of the price of derivatives. Other interesting papers devoted to the estimation of the evolution of financial asset prices were presented by Hafezi, Shahrabi and Hadavandi (2015), Rezaee, Jozmaleki and Valipour (2018) or Zhang, Li and Morimoto (2019).

Despite the growing prices of stocks and bonds in last five years, the development of accurate forecasting method plays an important role in the analysis of current debt market. As stated above, none of proposed models were able to outperform the random walk benchmark consistently and provide precise out of sample predictions. In order to focus on never seen out of sample data, this paper proposes a long-term bond price forecasting model based on a biologically inspired nonlinear technique - artificial neural networks. Long-term bonds are obligations with maturity in more than 30 or 40 years. Contrary to conventional bonds with shorter maturity (if they do not include a call option), their price does not converge to face value for several decades and therefore for the considerable

period of time the price development of long-term bond can be estimated in the same way as it is in the case of shares and other similar financial instruments. Due to the inverse relationship between bonds yields and prices, there is only a small difference between forecasting of both variables. However, most of long-term bond investors do not hold purchased bonds to maturity. Instead of buy and hold approach, active investors sell purchased bond after its price rises and realize capital gain. These investors particularly focus on bond prices. And since long-term bonds are financial instruments significantly sensitive to underlying interest rates, aim of this study is to investigate the predictability of long-term bond prices not only using their past values, but also using interest rate swaps as proxy of market interest rates.

2 METHODOLOGY

Artificial neural networks are computational technique based on the functioning of biological nervous systems, which emulate the learning process in neural cells - neurons. They operate in parallel framework, hence they are not sensitive to degradation of some nodes and are able to solve nonlinear or badly defined tasks. Neural networks were successfully applied in many financial and business tasks, such as bankruptcy analysis, credit scoring, or time series prediction (see Li, 1994; Wong, Bodnovich and Selvi, 1997; Vellido, Lisboa and Vaughan, 1999; Tkáč and Verner, 2016).

An essential part of every neural network is an artificial neuron, which is an information-processing unit that receives input signal from external sources or other neurons and constructs an output signal transmitted further.

Figure 1 presents the scheme of an artificial neuron. Every connection is characterized by its synaptic weight. Signal x_j at the input of connection linked to neuron *i* is multiplied by weight w_{ij}. Summing function of the neuron sums all the weighted inputs and activation function restricts the range of its output to limited interval, usually from one to zero or from minus one to one.

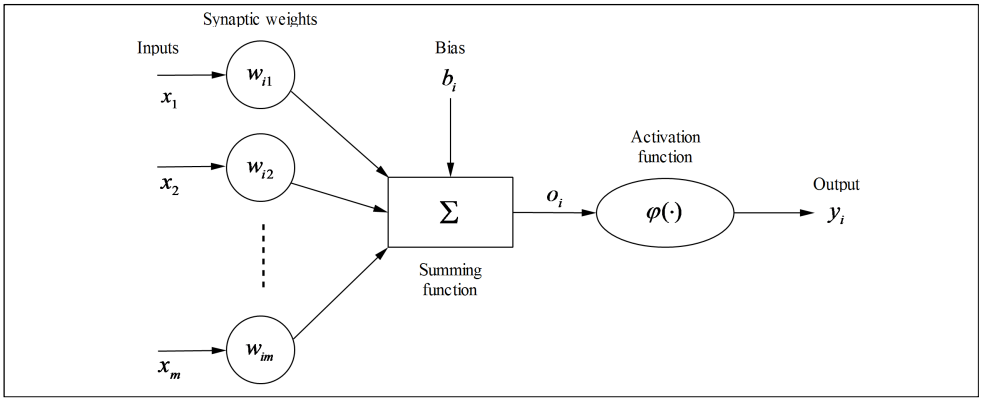

Figure 1 – An Artificial Neuron

The organization of individual neurons is called the network architecture. In case of feedforward is the signal proceeded exclusively acyclic and it is not passed back. In addition to input and output layers, multilayer feedforward networks contain at least one hidden layer with hidden neurons. Increasing number of hidden neurons give the network an ability to capture complicated patterns, which is particularly useful when solving problems with higher count of input variables. Fully connected multilayered feedforward network is depicted on Figure 2.

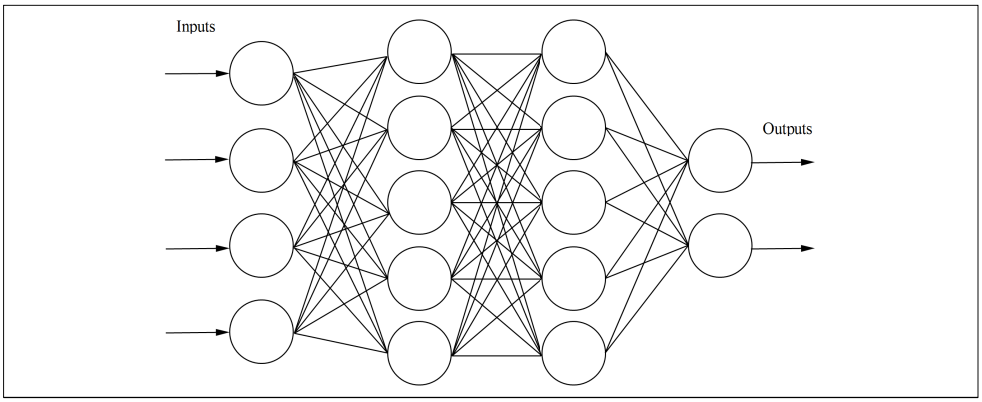

Figure 2 – Multilayer Feedforward Neural Network

The major advantage of artificial neural networks is their ability to extract the knowledge from surrounding environment by repeatedly modifying their connection weights. Every new iteration should increase its comprehension of presented data sample. The approach every network changes its free parameters based on external impulses is known as learning algorithm. Under the unsupervised learning, no target outputs are presented to the network and if the network captures valuable patterns in the data, it develops the expression of the input itself and creates its own structure. On the other hand, the most applied learning approach for multilayer feedforward networks is the learning with teacher, or supervised learning, where the network is provided with a desired outputs for given set of inputs. The synaptic weights are consequently modified according to the difference between the reached and hoped-for output of the network.

Error for the neuron i might be defined as $e_i(n) = t_i(n) - y_i(n)$, where y_i represents the actual output of particular neuron, $t_i(n)$ is the desired target output, and n is the number of iteration. Aim of the network learning is to minimize the cost function of the network, usually given as mean squared error of all output neurons in last layer.

The cost function is minimized by updating connection weights in following manner:

$$w_{ij}(n+1) = w_{ij}(n) + \Delta w_{ij}(n), \tag{1}$$

where $w_{ij}(n)$ is the connection weight between neuron *i* and anterior neuron *j* at iteration *n*. Various algorithms have been introduced to optimize the cost function and modify connection weights and they differ from each other primarily in the reaction to the error signal and in the adjustment of the weights. The most frequently applied learning algorithms are based on gradient descent principles, however, they utilize only first-order information about the error surface. Moreover, the learning rate and momentum in gradient descent framework are additional parameters (besides the number of hidden layers, hidden neurons or choice of activation function) that have to be determined by researcher, usually by trial and error approach.

Comparing to conventional gradient descent techniques, more sophisticated methods use second-order Taylor series approximation of the error function. According to Newton method, optimal update of synaptic weights, regarding the error function $E(\mathbf{w}(n))$ is defined as:

$$\Delta\tilde{\mathbf{w}}(n) = \mathbf{G}(n)\mathbf{H}^{-1}(n), \tag{2}$$

where $\mathbf{H}(n) = \frac{\partial^2 E}{\partial \mathbf{w}^2}|_{\mathbf{w}=\mathbf{w}(n)}$ is a local Hessian matrix and $\mathbf{G}(n) = \frac{\partial E}{\partial \mathbf{w}}|_{\mathbf{w}=\mathbf{w}(n)}$ a local gradient vector at $\mathbf{w}(n)$. Since the inversion of $\mathbf{H}(n)$ is computationally demanding, quasi-Newton methods perform update of network connection weights as follows:

$$\Delta\mathbf{w}(n) = \mathbf{G}(n)\mathbf{A}(n), \tag{3}$$

where $\mathbf{A}(n)$ represents a positive definite approximation matrix such that $\lim_{n\to\infty}\mathbf{A}(n) = \mathbf{H}^{-1}$. $\mathbf{A}(n)$ is modified at each iteration and $\mathbf{A}(n+1)$ is computed recursively utilizing the former value of $\mathbf{A}(n)$, $\Delta\mathbf{w}$ and $\Delta\mathbf{G}$ (Broyden, 1970; Fletcher, 1970; Goldfarb, 1970; Shanno, 1970, Powell, 1975). On the other hand, algorithm proposed by Levenberg (1944) and Marquardt (1963) updates network weights based on the Jacobian matrix $\mathbf{J}(n)$ of first derivatives of the network errors:

$$\Delta\mathbf{w}(n) = -[\mathbf{J}^T(n)\mathbf{J}(n) + \mu\mathbf{I}]^{-1}\mathbf{J}^T(n)\mathbf{e}(n), \tag{4}$$

If the parameter μ is zero, algorithm becomes a Newton method, while with increasing μ, it approaches to conventional gradient descent with a small learning rate. For more details see Hagan and Menhaj (1994) or Demuth et al. (2014). This algorithm has high computational speed and is suitable for mid-sized networks, therefore we apply it in our bond price prediction model as a benchmark method.

Despite the fact that in most academic researches the authors focus on the daily returns of financial assets, we focused on the estimation of daily prices. Compared to shares, bond prices have limited potential for change in the long term, as they converge to face value with maturity (in case of no credit event). Therefore, it is more important for bond investors and issuers to estimate the price of the bond or its yield to maturity rather than daily returns.

At first we identified the theoretical basis and proposed a conceptual background for the model. Subsequently, we focused on obtaining an available sample of data that would sufficiently approximate the long-term bond market. The sample consisted of long-term investment grade corporate bonds issued by global issuers and one government bond with a similar maturity and denominated in EUR. Bonds from various business sectors were included to remove potential specific impacts of the prediction tasks. After analysing the database, it was essential to create multiple neural network architectures and to optimize the number of hidden layers and neurons in each layer. It was also necessary to determine the percentage distribution of the sample for the training, test and validation sets. The bond price prediction model was based on a multilayered feedforward network containing two hidden layers with sigmoid activation function and output layer with linear activation function. Every hidden layer had 15 neurons. All parameters were chosen by trial and error approach to ensure the most satisfying prediction results. The above-mentioned Levenberg-Marquardt algorithm was applied to the learning process. It suitably combines the properties of gradient and Newton methods. In order to compare its performance with other conventional learning technique, Scaled conjugate gradient was also included in the research. After evaluating the results, an external variable was added to the model to integrate information about current market volatility.

2.1 Results

The aim of this paper is to expand the scope of previous studies on the predictability of bond yields and prices. The predictability of prices was tested on a set of long-term bonds from 5 private issuers. We employed daily price time series observed between 4th January 2016 and 13th January 2021 (totally 1,270 trading days). This data interval was kindly provided for our research by the Deutsche Boerse and represents a relatively smooth trading interval with no significant shocks or unexpected economic events with a global impact.

It is obvious that given time interval represents a relatively short period to present a complex bond market prediction framework. However, with respect to

the efficient market hypothesis, trying to create a single and universal model that is able to forecast the development of any financial asset may be rather controversial or unrealistic. From a practical point of view, it may be preferable to use a shorter period of time to set model parameters, during which no major economic changes or paradigm developments on the financial markets occur. This sector is so dynamic and influenced by many factors that long-term data predictions can lose efficiency and practical usability. For both traders and individual issuers, a period of two to three years can represent a time horizon that allows them to estimate bond market developments and plan their capital decisions. Table 1 summarizes the descriptive statistics of the sample.

Table 1 – Descriptive Statistics of the Sample

	Bayer	*Merck*	*Volvo*	*AmMovil*	*Centrica*
Mean	104.04	101.96	106.05	110.11	98.33
Median	104.09	102.48	107.77	107.75	99.77
Minimum	87.50	92.50	88.36	99.14	80.62
Maximum	110.84	106.50	115.76	121.11	104.78
St. deviation	1.84	2.89	6.19	1.66	5.30
Skewness	-0.625	-0.890	-0.876	0.326	-1.596
5% percentile	98.44975	97.282	95.6255	103.2975	88.914
95% percentile	109.3	104.99	112.551	119.835	102.875

Figure 3 depicts the development of bond prices, while Figure 4 introduces the development of returns during examined period.

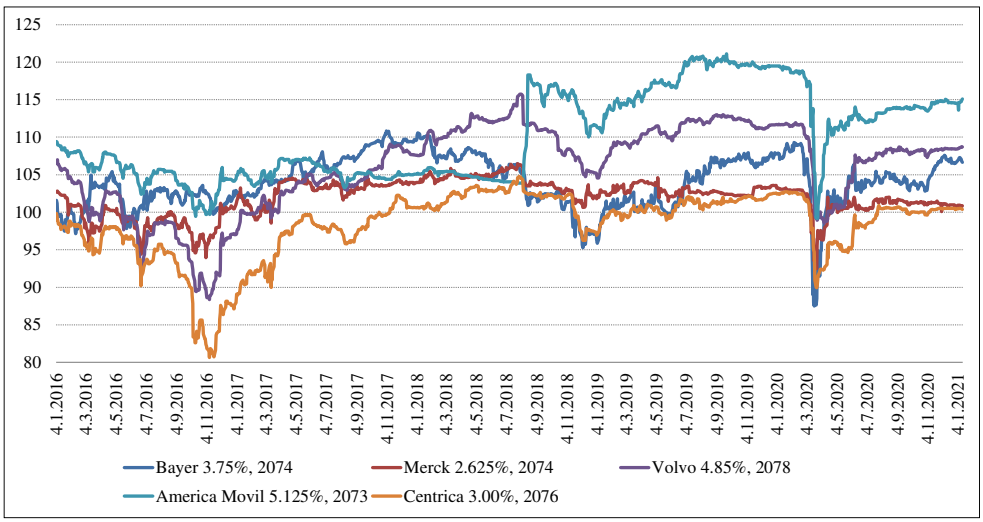

Figure 3 – Development of Examined Bond Prices

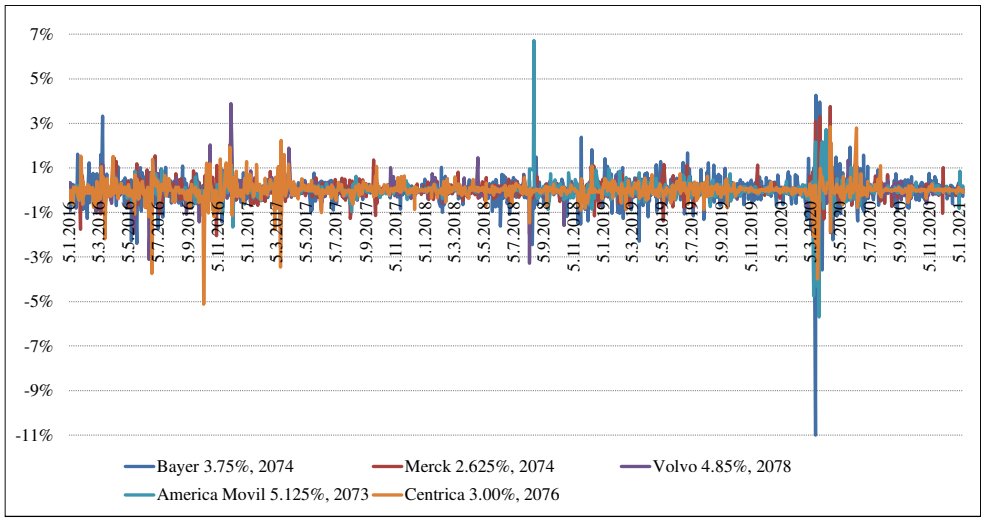

Figure 4 – Development of Examined Bond Price Returns

The first forecasting model was nonlinear autoregressive network with two delays as input variable. In our experiments, the prices of the first 890 days were for training, 190 days were for validation and those of the last 190 trading days were for out-of sample testing. To assess the predictive capabilities of nonlinear autoregressive network, we applied Levenberg-Marquardt algorithm and Scaled conjugate gradient.

Network performance was compared using mean squared error and a coefficient of determination. As seen in Table 2, both learning algorithms have achieved excellent results on the observed sample of bond prices and have reached a coefficient of determination higher than 95% in the training, validation and testing sets.

Table 2 – Results Obtained by Nonlinear Autoregressive Network

	Bayer	*Merck*	*Centrica*	*Volvo*	*AmMovil*
Training set					
LM MSE	0.15491	0.22246	0.13380	0.13789	0.05587
SCG MSE	0.20393	0.17386	0.43346	0.51877	0.12199
LM R2	95.51%	97.46%	99.58%	99.24%	98.49%
SCG R2	96.59%	99.10%	99.07%	99.40%	98.69%

	Bayer	*Merck*	*Centrica*	*Volvo*	*AmMovil*
Validation set					
LM MSE	0.24741	0.21188	0.17173	0.05943	0.08217
SCG MSE	0.28106	0.23405	0.19081	0.51529	0.12882
LM R2	96.31%	98.03%	98.13%	98.73%	98.85%
SCG R2	95.57%	99.07%	98.50%	99.33%	97.34%
Testing set					
LM MSE	0.20766	0.24384	0.51349	0.08120	0.06133
SCG MSE	0.20416	0.14995	0.79322	0.41918	0.12971
LM R2	96.59%	98.33%	99.07%	99.40%	98.69%
SCG R2	97.45%	99.27%	99.80%	99.52%	98.92%

The best result of the prediction was observed on Centrica corporate bond where the Scaled conjugate gradient algorithm reached the 99.80% coefficient of determination on the testing set. Regarding examined sample, Levenberg-Marquardt and Scaled conjugate gradient algorithms were comparable on all analysed bond prices. For illustration purposes, Figures 5 and 6 present Learning process and performance of proposed nonlinear autoregressive network using Levenberg-Marquardt learning on Merck bond sample.

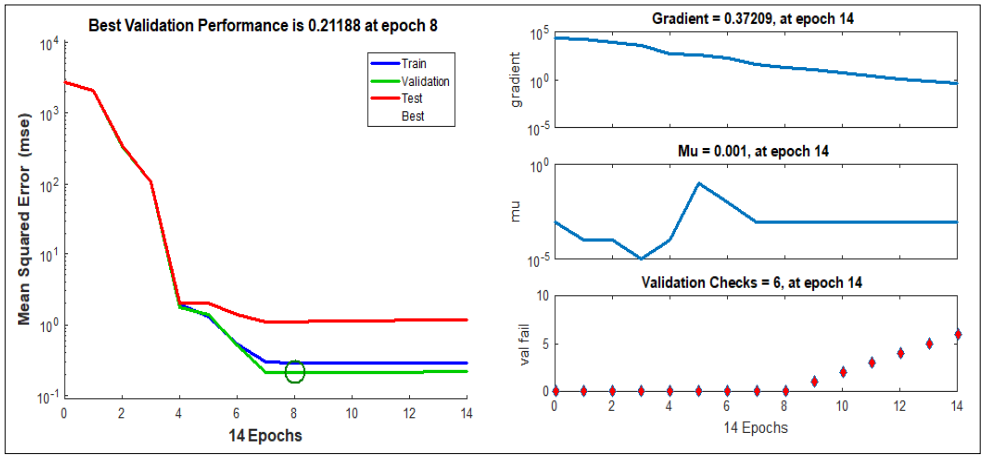

Figure 5 – Learning Process of Nonlinear Autoregressive Network Using Levenberg-Marquardt Learning on Merck Bond

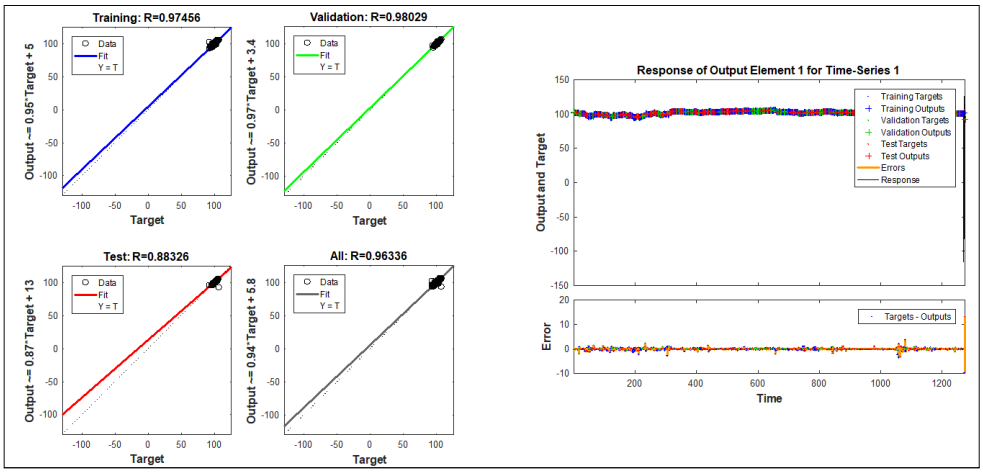

Figure 6 – Learning Process of Nonlinear Autoregressive Network Using Levenberg-Marquardt Learning on Merck Bond

As we can see, the learning process stopped after the 8th epoch, when mean squared error began to grow again. If the network continued learning, it would result into overfitting and the model would lose its generalization ability.

In order to verify the predictive power of the proposed model, we changed the nonlinear autoregressive network framework to a nonlinear autoregressive network with external inputs. As two external variables, 50 year interest-rate swaps denominated in EUR and volatility index VIX were used. Interest rate swaps are a popular choice among researchers for illustrating the risk-free market interest rate in the financial time series and are often used as a benchmark rate on which bonds are extremely sensitive. Despite the fact that the maturity of all examined bonds was longer than 50 years, this approximation can be accepted since longer-term swaps are usually not traded. Moreover, the EUR-denominated interest rate swap curve was concave over the explored period, with additional yield increments significantly declining considering longer time to maturity. Figure 7 depicts development of volatility index VIX in given period. Results of nonlinear autoregressive network with external inputs are summarized in Table 3.

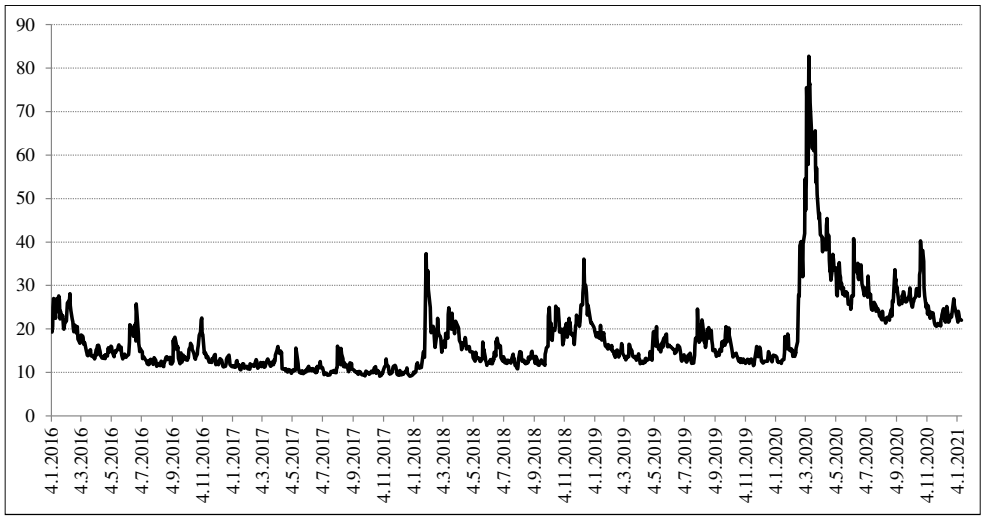

Figure 7 – Development of Volatility Index VIX

Table 3 – Results Obtained by Nonlinear Autoregressive Network with External Inputs

	Bayer	*Merck*	*Centrica*	*AmMovil*	*Centrica*
Training set					
LM MSE	0.13491	0.13246	0.11380	0.09789	-0.03413
SCG MSE	0.18393	0.08386	0.41346	0.43877	0.05199
LM R2	96.41%	98.36%	99.79%	99.44%	98.59%
SCG R2	97.09%	99.30%	99.27%	99.10%	99.59%
Validation set					
LM MSE	0.17741	0.15450	-0.03058	0.07217	0.23173
SCG MSE	0.20106	0.03405	0.50529	0.10882	0.13081
LM R2	96.49%	99.81%	99.79%	99.44%	99.79%
SCG R2	96.47%	99.37%	99.41%	97.64%	99.51%
Testing set					
LM MSE	0.15766	0.13384	-0.01880	0.02133	0.49349
SCG MSE	0.15416	0.09995	0.40918	0.03971	0.74322
LM R2	97.09%	99.80%	99.79%	98.99%	99.79%
SCG R2	97.55%	99.31%	99.41%	98.37%	99.51%

Experiments showed that both learning algorithms had again achieved satisfying outcomes on the examined sample of bond prices. The best result was obtained on Merck corporate bond where the Levenberg-Marquardt algorithm reached the 99.81% coefficient of determination on the validation data set. Based on obtained results, we can state that the implementation of independent variables into the autoregressive neural network environment had a positive impact on prediction ability of the model. If we look at individual bonds, in certain cases we can notice a marked improvement in terms of a reduction of the mean square error and the increase of the coefficient of determination.

Given values indicate that the integration of the external variable in the form of 50-year interest rate swaps denominated in EUR and volatility index VIX improved the predictive ability of standard autoregressive neural network.

3 CONCLUSION

Bond prices immediately reflect extensive market participants' interactions, the development of macroeconomic indicators as well as a set of global central bank policies. That makes prediction of future bond prices demanding and difficult. In this paper, we propose a long-term bond price forecasting system based on nonlinear autoregressive neural network. Our research demonstrated that neural networks are effective methods for prediction of time series with their ability to capture nonlinearity and hidden patterns in the data. Levenberg-Marquardt as well as Scaled conjugate gradient learning algorithm achieved excellent results on the observed sample of bond prices and reached a coefficient of determination higher than 95% in all sets of data. However, Levenberg-Marquardt algorithm overpowered Scaled conjugate gradient learning almost on all analysed bond price series. To evaluate the performance of examined model, we moreover proposed the nonlinear autoregressive network with external inputs with 50 year interest-rate swaps denominated in EUR and volatility index VIX as an external variables. Both learning algorithms had again achieved satisfying outcomes and we might argue that the implementation of independent variables into the autoregressive neural network environment had positive impact on the prediction ability of the model.

Regarding the observed outcomes of examined models in predicting bond price we might conclude that in very short time gave neural networks accurate results without overfitting the data. However, we would like to continue our research by integrating the neural network framework with various machine learning and artificial intelligence methods which may yield even better bond price predictions. Despite the selection of the long-term bonds from various sectors, the main disadvantage of the presented work is a relatively small sample of bonds. This can be mostly attributed to their low number, as the popularity of bonds with a maturity of more than 50 years has only slowly increased in recent years as a result of extremely low interest rate policies. However, as a result of the current pandemic, no significant turnaround in interest rates can be expected,

and therefore the number of these securities will certainly increase. Although it has been said that bonds with such a long maturity behave to a large extent as shares and their price may fluctuate significantly, in further research we would also like to focus on determining the point after which price fluctuations decrease and the price gradually begins to converge to nominal value. It is questionable whether this turning point depends only on microeconomic variables such as the rating or coupon of the bond, it is affected by macroeconomic variables such as volatility, or it is a fixed horizon from maturity. Combined with the application of more advanced methods of artificial intelligence, knowledge of this point could help to improve the quality of bond behaviour prediction and thus the prosperity of the global economy.

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CONFLICTS OF INTEREST

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A Comparison of the Application of the SMED Methodology in Two Different Cutting Lines

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ABSTRACT

Purpose: This study was carried out in a cork company. Its purpose was to observe and analyse the practices and methods used during the tools/series change moments and to propose improvements to these same procedures so that the time needed to carry out the setup is reduced by 15% in both lines.

Methodology/Approach: The methodology included the following phases: 1st – historical data collection, 2nd – footage analysis and conduction of informal interviews with employees, 3rd – flow, Gantt, and spaghetti charts creation and making of an action plan based on the waste and improvement opportunities, 4th – validation with the line workers of the new operating mode created with the SMED tool, 5th – placement of plasticized cards on the cutting lines to ensure that new operating mode is followed in the action plan.

Findings: Throughout this project using observations, video recording and its subsequent analysis, as well as, interviews to the workers operating in the line, it was found the existence of several actions carried out by them during the setups which did not add value to the product and lack of work tools in general.

Research Limitation/Implication: The study was limited by the lines and products under study and by the duration of the curricular internship, which was about five months.

Originality/Value of paper: The article demonstrates the added value in terms of product quality and production output rate that SMED methodology can bring to companies that adopt the lean philosophy and in particular this continuous improvement tool.

Category: Research paper

Keywords: series change; time reduction; SMED; changeover; productivity

1 INTRODUCTION

In the last decades we have seen a significant change of the manufacturing sector. According Parwani and Hu (2021), companies focus on reducing non-value-add activities, eliminating wastage, and decreasing the setup time to remain competitive. Industries have to compete with manufacturing from other countries with relatively cheap labour. Thus, as technological advances happen, the end consumer is more informed and becomes more and more demanding with what he/she wants, seeking products with more quality, at more affordable prices and with very fast delivery times. As such, companies are currently under tremendous pressure to adapt and meet the quality needs of demand while reducing their response time and consuming less resources, thus ensuring their survival (Silva and Gouveia, 2020). One of the critical points of the industries is the setup changes, since they are activities that do not add value to the product, but are necessary for its production (Godina et al., 2018). As such, the challenge is to use the Single Minute Exchange of Dies (SMED) methodology to promote an improvement in product quality, productivity and reduction of setup times (Vieira et al., 2019; Rosa et al., 2017). The setup times are a typical example of waste, since they correspond to an activity that does not add value and that involves hidden expenses (Van Goubergen and Van Landeghem, 2002).

Before the Industrial Revolution, the existing productive activity was handmade and very manual, with the help of some simple machines and some helpers, the craftsman took care of almost the entire production process (Risatti, 2013; Murmura, Bravi and Santos, 2021). Henry Ford, founder of Ford Motor Company, a car manufacturing company, introduces after the end of World War I the assembly line, which will become the new industrial model (Bhagwat, 2005). Ford aimed to produce as much as possible with the minimum associated production costs (Machado et al., 2020), so that it could conquer the market with more attractive selling prices (Tomac, Radonja and Bonato, 2019). However, this model had a major disadvantage which falled in the fact that there was no variety and diversification of the product, only cars with black color were produced (Rosa, Silva and Ferreira, 2017). After the end of World War II, customers began to demand higher quality in the products and services provided, something that mass production had difficulties in providing (Jasti and Kodali, 2014; Araujo et al., 2019; Costa et al., 2019; Santos, Murmura and Bravi, 2019). In order to be able to respond to customer requirements, in the 1950s, Eiji Toyoda and Taiichi Ohno developed the Toyota Production System (TPS). This is an integrated socio-technical system, with the combination of the knowledge and skill of master craftsmen with the concepts of standardization and teamwork (Jasti and Kodali, 2014; Correia et al., 2018). Since they lacked the capacity to apply the philosophy of mass production, Toyota sought to offer what the other companies did not have: a wide variety of high quality products at low cost (Liker, 2004; Félix et al., 2019a). Thus, lean philosophy was born (Ribeiro et al., 2019; Santos et al., 2019b; Sá et al., 2020) at a time when new businesses are sought (Bravi, Murmura and Santos, 2018) and customers are increasingly demanding with

product quality and also with environmental issues (Carvalho, Santos and Gonçalves, 2019; Talapatra et al., 2019). The Lean philosophy can be synthesized as the systematic pursuit of perfect value by eliminating waste in all aspects of organizations' business processes (Dahlgaard-Park and Bendell, 2006; Neves et al., 2018). Continuous Improvement is the element guided by management that promotes cultural change in the workplace (Sundar, Balaji and Kumar, 2014; Santos, et al., 2019a). This is based on people's inherent desire for quality and value (Berger, 1997). According to Dean and Bowen (1994), improvements in quality are widely recognized as having a competitive advantage in the global economy. Lean production identifies all types of waste in the value chain and implements the necessary tools for their elimination and consequent minimization of waiting times (Abdulmalek and Rajgopal, 2007; de Oliveira, Sá and Fernandes, 2017; Barbosa, de Oliveira and Santos, 2018). Anything that interferes with the continuous flow of production is defined as waste (Rosa et al., 2018; Pereira et al., 2019). Womack and Jones (2003) identified five basic principles for a Lean philosophy, namely: value identification, value stream identification, creating a continuous production flow, implementation of a pull system and pursuit of perfection.

Karim and Arif-Uz-Zaman (2013) explain the interconnection between the five principles as follows:

The customers create value for the organization based on needs, pricing, and timing for products or services. Thus, this customer information and value transformation create the value stream for the product demanded by customer. The value added steps for product creation identify the product flow for production. Customers pull products from producers through product order. The final principle integrates and perfects the system so the first four principles can be effectively implemented. These principles guide the elimination of waste and the simplification of all manufacturing and support processes.

The following Figure 1 shows the main benefits that organizations achieve through the five principles of lean thinking. Today, customers demand high quality products at reasonable prices and with a short response time (Costa, Silva and Campilho, 2017; Félix et al., 2019b).

Companies must implement a Lean philosophy and customer-based production in order to meet their requirements. Being able to evolve in the industry at different operating levels means that workers must be able to exceed expectations for their performance each day. For this, it is necessary to have a stable and viable structure to support these performances (Boran and Ekincioğlu, 2017). The Lean production practices and tools have been commonly used to reduce wastes, to meet the client's requirements in the desired quantity and at the right delivery time, leading to gain competitive advantages over their direct competitors (Rüttimann, 2017; Rodrigues, et al, 2019; Sá et al., 2019; Bravi, Murmura and Santos, 2019; Jimenez et al., 2019).

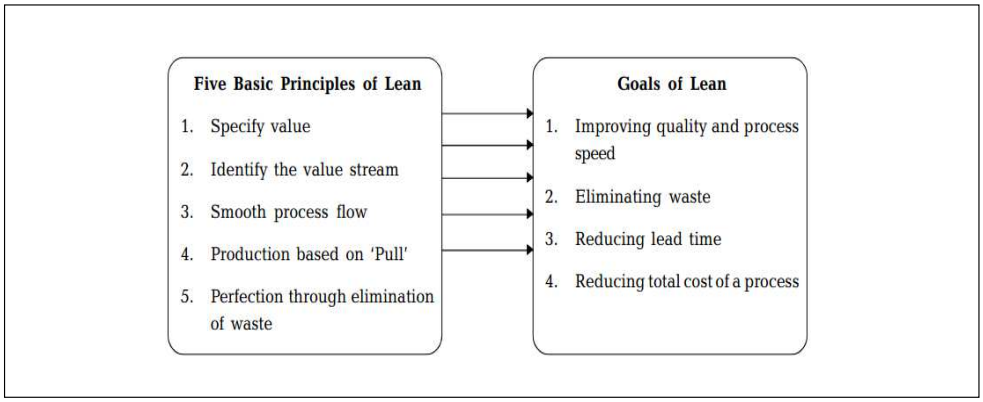


Figure 1 – The Five Principles of Lean and Their Respective Goals

The most effective way to achieve this is to increase flexibility by producing smaller lots (Costa et al., 2018; Bravi, Murmura and Santos, 2019), however this type of production tends to lead to an increase in setup frequency (Costa et al., 2013). For this reason, companies must find a way to reduce setup times, eliminate waste and limit non-value-added activities (Sousa et al., 2018; Santos et al., 2019c) where it is important a quality culture (Zgodavova, Hudec and Palfy, 2017) and control the risks (Ferreira, Santos and Silva, 2019). An efficient series change is, therefore, an important element that supports the control of the production process on the industrial shop floor, (Martins et al., 2018), proving to be even more important if the demand is complex (Allahverdi and Soroush, 2008; Bravi, Murmura and Santos, 2017).

The present work was carried out in a cork company and its goal was to observe and analyze the practices and methods used during the tools/series change moments and, with the help of Single Minute Exchange of Dies (SMED) methodology implementation in the cutting lines present in the final finishing areas of the process, propose improvements and alternatives to those same procedures, so that the time needed to perform the setup is reduced by 15% in both lines and the likelihood of errors on the part of employees and malfunctions on machines decrease.

2 THEORETICAL CONTEXTUALIZATION

The SMED methodology was developed in the 1950s by Shigeo Shingo, a Toyota industrial engineer, and its main goal was to reduce setup times (Ahmad and Soberi, 2018). SMED was the proposed solution to reduce the bottlenecks caused by Toyota's printing presses (Dillon and Shingo, 1985).

SMED is essentially a methodology for analyzing and improving time lost in manufacturing series changes due to the execution of setups (Pinto et al., 2019). In its original definition, it defends that the tool changes to be carried out in a production line must be completed in less than 10 min, thus guaranteeing its

representation by only a single digit in the minutes field. It focuses on the analysis, systematization and normalization of tasks performed by the machine operator or line team. A correct implementation of SMED will ensure greater flexibility and result in improved product flow in the manufacturing area (Dave and Sohani, 2012; Azevedo et al., 2019; Doiro et al., 2019).

Setup time is defined as the period from the time when the last good product from the previous production order leaves the machine and the first good product from the next production order is produced (Coimbra, 2009). Changeover time is defined as the time needed to set up a given production system to run a different product with all the requirements (Díaz-Reza et al., 2016).

Current theory and practice regarding SMED techniques are still centered on the original concept developed by Dillon and Shingo (1985) in the 1950s and 1960s (Moxham and Greatbanks, 2001). The implementation of the SMED methodology involves the following steps:

- Study of the current situation,
- Classification of tasks into internal and external tasks,
- Transformation of internal tasks into external tasks,
- Optimization of internal tasks,
- Optimization of external tasks.

In the first stage, study of the current situation, it was sought to make an analysis of the current operating procedures and conditions in the work area. In the second phase, one then seeks to distinguish between what can be done before and what can be done after the change of series. Having differentiated between the two types of tasks, the next step is to transform, whenever possible, internal tasks into external tasks. The next point of the methodology has the internal activities as focus. This phase aims to reduce the time of internal tasks by simplifying, optimizing and standardizing them in order to reduce or eliminate internal work that could not be transformed into external in the previous step. Finally, the last stage of the methodology only deals with external activities (Vieira et al., 2019).

3 METHODOLOGY

The company where this study was developed is specialized in the manufacture of cork-floated floating floors. The research methodology used in this work was the action research methodology.

The methodology included the following phases:

- *Diagnosis* – collection of historical data and recording of configuration video. Filming was analyzed and informal interviews were conducted with employees and spaghetti diagrams were also drawn up to identify waste;

- *Action Planning* – elaboration of the action plan based on the residues and opportunities for improvement identified in the video analysis;
- *Action Taking* – Elaboration of new standard works with the objective of reducing the time for changing the machines;
- *Evaluating* – validation with workers who operate in line with the new procedures created with the aid of the SMED methodology and communication to the Maintenance department about their role in this project;
- *Specifying Learning* – making and placing plasticized cards on the cut lines to ensure the fulfillment of the new procedure and the execution of the actions identified in the action plan.

4 CASE STUDY

4.1 Data Collection

After the meeting with the person in charge of the final finishing area, where the objectives for this project were defined, as well as the products and lines that this project encompassed, the next step consisted of collecting historical data, namely the number and the duration of stops due to damage and setups.

Through the collected data, it became possible to verify the number of important setups for this project that occurred in each month, as well as their monthly average. After processing the data and creating bar graphs it was possible to observe that the number of setups performed, and their monthly average time is not constant. In AF2 the average time is decreasing while in AF3 the opposite occurs. AF2 averages 193.84 minutes per setup while AF3 averages 41.63 minutes per setup.

With the collected data it was also possible to verify the number of unplanned stops that occurred in the two plants, the number of hours that induce production to stop and the corresponding percentage. Pareto's diagrams were made to allow easy visualization and identification of the most significant causes with the most significant stops happening in AF2 due to the occurrence of setups and machine malfunctions, totalling 62% of the downtime on the line in analysis. As in AF2, also in AF3 the stops with the most impact on the cutting line are the stops happening due to malfunctions and setups, thus making it essential to promote measures that act in these two fields to reduce the number of non-productive hours.

4.2 Introduction to the Cutting Lines

After knowing what lines this project was concentrating on and after the collection of data of said lines was done, the next step was to get to know the lines in question, observe the process that transforms material A in product B. This project focused on the final finishing areas 2 and 3, AF2 and AF3, more precisely on their respective cutting lines.

AF2's cutting line works in a regime of 3 rotating shifts, 8 hours per shift for 5 days a week. Each shift consisted of 3 workers, however, during this project it was passed to 2 workers. AF3's line works under the same regime, however, it is only operated by 1 employee.

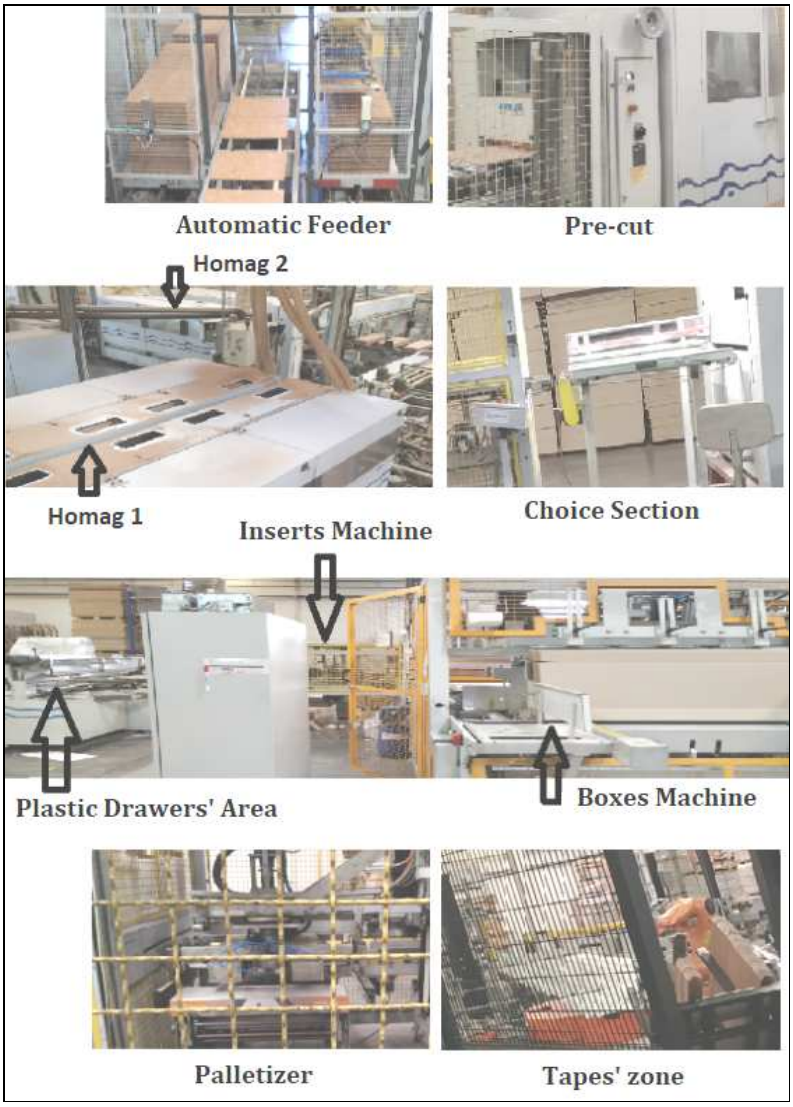


Figure 2 – AF2's Cutting Line

The entry of the boards into the cutting lines occurs with the automatic feeding of pallets, which then pass through a section called Pre-cut, where the boards are transformed into 2 or 3 tiles, then going to the Homag 1 machine that will make the longitudinal cut and then proceed to Homag 2 which will make the cross section of the tiles. In AF2 the process continues to the Choice Section, where a worker assigned to that post checks whether the tiles contain defects or are good to carry on the process. If they are without defects the tiles go to the Boxes Machine where they will be automatically deposited in a cardboard box that when it reaches its capacity frees it for the Inserts Machine where a pamphlet is placed according to the product and market in question and the box is subsequently packed in the Plastic Drawers' area.

Finally, in the palletizer's area, a robot organizes the packed boxes until they make up a pallet. When the dimensions of the pallet are reached, another robot surrounds and protects the pallet with plastic. In AF3, the cutting and packaging processes are separated. AF2's and AF3's cutting lines are shown in Figure 2 and Figure 3, respectively.

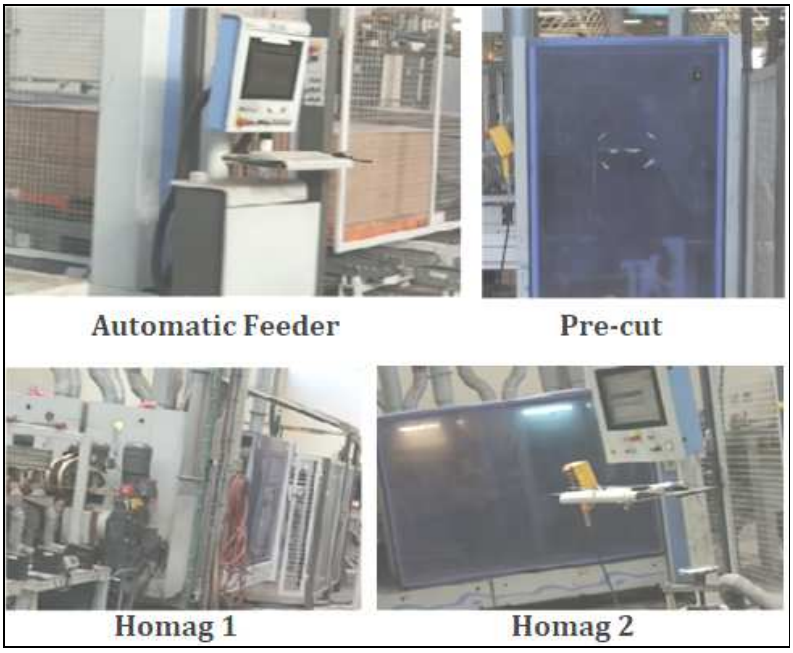


Figure 3 – AF3's Cutting Line

4.3 First Observations and Analysis of the Situation

The next step after the data collection phase and the introduction to the cutting lines was to try to involve the line workers in the project as they deal with the problems and situations of the lines on a daily basis. As such, informal interviews were conducted with them in order to understand what are their biggest difficulties during the setups.

During the data collection phase, Pareto's graphs were made to understand which events historically caused the most stops on the cutting lines. After the analysis of the graphs it was concluded that breakdowns and execution of setups were the most significant events, with the dirt and the lack of maintenance being points that contribute to that fact. After conducting the interviews and with permission of the employees, the execution of the setups under study was recorded on video for later analysis. Their analysis made it possible to identify the steps required to perform them, as well as the movements made by the workers during setups which were then passed to flowcharts and spaghetti diagrams, respectively, to facilitate their understanding and identify possible wastes.

The spaghetti diagrams created to visually represent the employees' movements during the setups in AF2 and AF3 are shown in Figure 4 and Figure 5, respectively.

As can be seen from the spaghetti diagram shown in Figure 4, all employees in AF2 show a certain level of waste during the execution of the setup, with the team leader (blue color) having the longest travel taking 258 seconds to make his journey. Product change settings actions took 59 minutes.

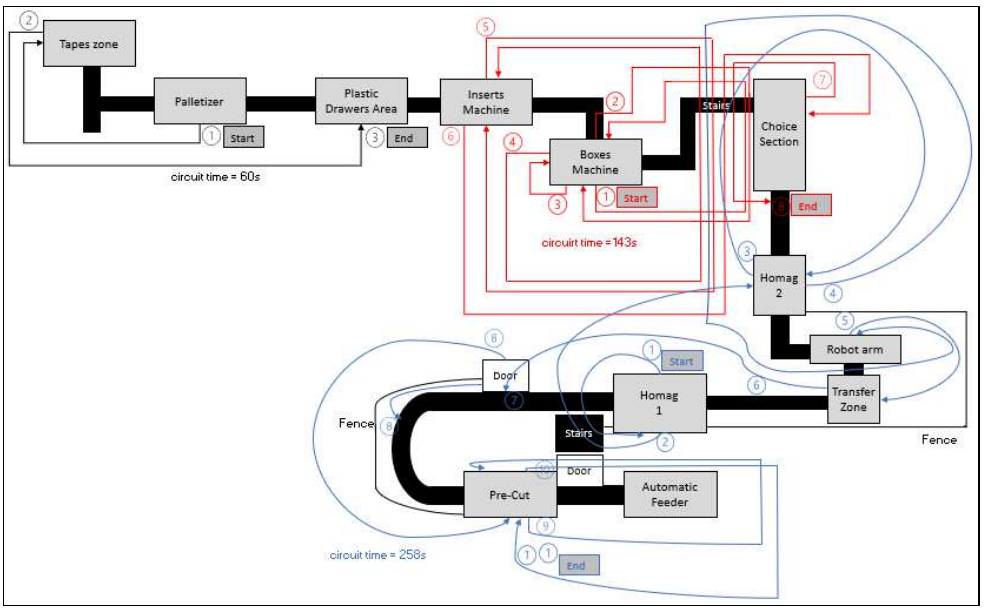


Figure 4 – Spaghetti Diagram of the Workers' Setup Movement in AF2

As can be seen in the spaghetti diagram in Figure 5, the employee responsible for the change in AF3 already uses an optimized procedure and there is no waste of movement. Product change settings actions took 26 minutes.

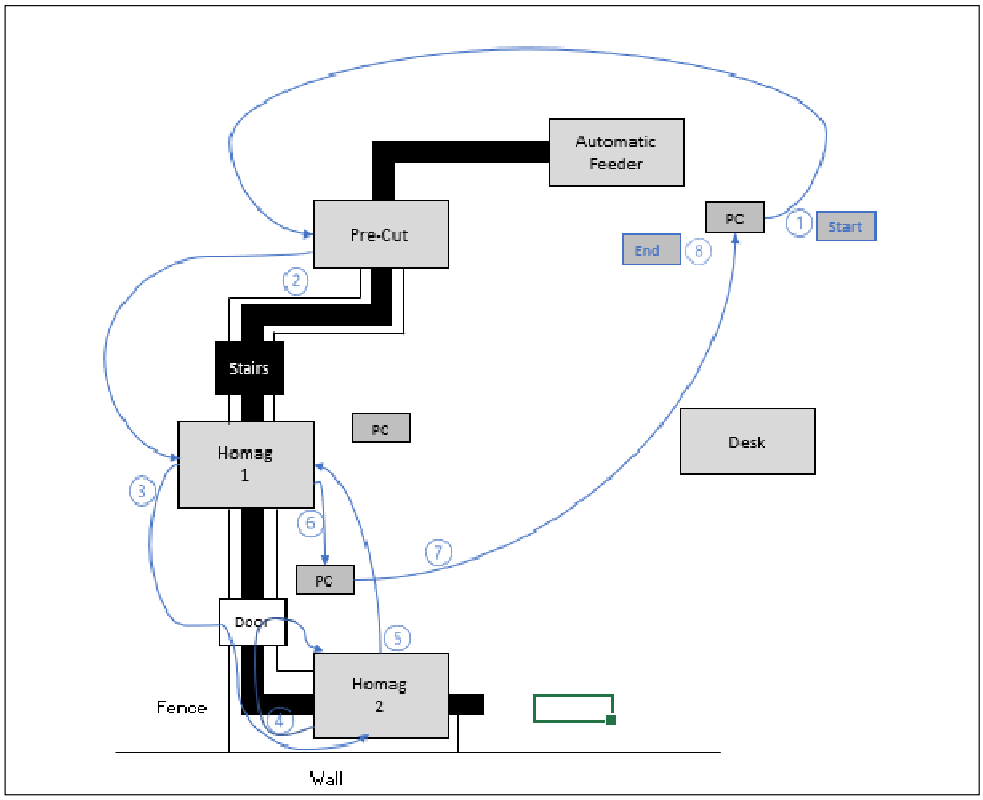


Figure 5 – Spaghetti Diagram of the Workers' Setup Movement in AF3

After the creation of the figures previously presented, two excel tables were created that synthesize the wastes which were observed during the execution of the setup tasks. Those two tables helped create an improvement action plan whose ideas would be implemented later.

Table 1 contain the wastes of time found in AF2 that is about 27 min and 52 sec. Table 2 contain the wastes do time found in AF3, that is about 6 min and 54 sec.

In Table 1, it can be seen that there is employees waste time in unnecessary situations, such as: looking for tools, disassembling and assembling suction cups, looking for a new funnel, assembling the new funnel among others. Like in AF2, the same table, that isTable 1, shows that workers also look for tools during AF3 setup, however, the largest amount of time is spent loading the material only when the setup time begins.

Table 1 – Waste Activities Found in AF2 and in AF3 When Executing Setups

To eliminate in AF2			*To eliminate in AF3*		
Activities	Time [min]	Time [sec]	Activities	Time [min]	Time [sec]
Searching for tools	00:30	30	Loading material into the feeding zone	05:13	313
Searching for and storing of tools	01:00	60	Checking the Material Information Sheet	00:20	20
			Checking the wrong saw	00:12	12
			Searching for a missing tool	00:09	9
Disassemble and assemble of suction cups	01:26	86			
Searching for new boxes	08:12	492			
Searching for tools	02:30	150			
Searching for new inserts	00:36	36			
Preparing a new film reel	07:25	445			
Preparing the Cardboard Box	01:36	196	Closing Homag 2 access door	01:00	60
Searching for the new funnel	00:22	22			
Mounting the new funnel	03:02	182			

Table 2 – Total Waste Time found in AF2 and AF3

AF2			*AF3*		
Total Time to eliminate (in seconds)	Minutes	Seconds	Total Time to eliminate (in seconds)	Minutes	Seconds
1672	27	52	414	6	54

4.4 Improvements Implemented

After analysing the videos and all the diagrams created, an action plan was carried out together with the maintenance department. The implemented measures are presented below.

4.4.1 Movement Modification and Task Reclassification

At the beginning of this project, the cutting line 4 was composed of 3 workers, however, throughout its development, the management decided that this line would be operated just by 2 workers. It was therefore necessary to balance tasks and movements for only 2 operators. The new path with the appropriate workforce reduction movements created for AF2 is shown in Figure 6.

Regarding employee movements, their starting points were changed and it was sought to ensure that employees travelled a direct path and did not travel the same path several times. With the new movement routes, it was possible to reduce the movement of the team leader from 258 to 161 seconds.

With 3 workers, the tasks during the setup took 59 minutes, plus 5 minutes of travel making a total of 64 minutes of setup. After task reorganization, the 2-worker setup takes now 62 minutes, the team leader finishes his tasks in 63 minutes resulting in a total setup time of 66 min after considering the time spent on employee travel.

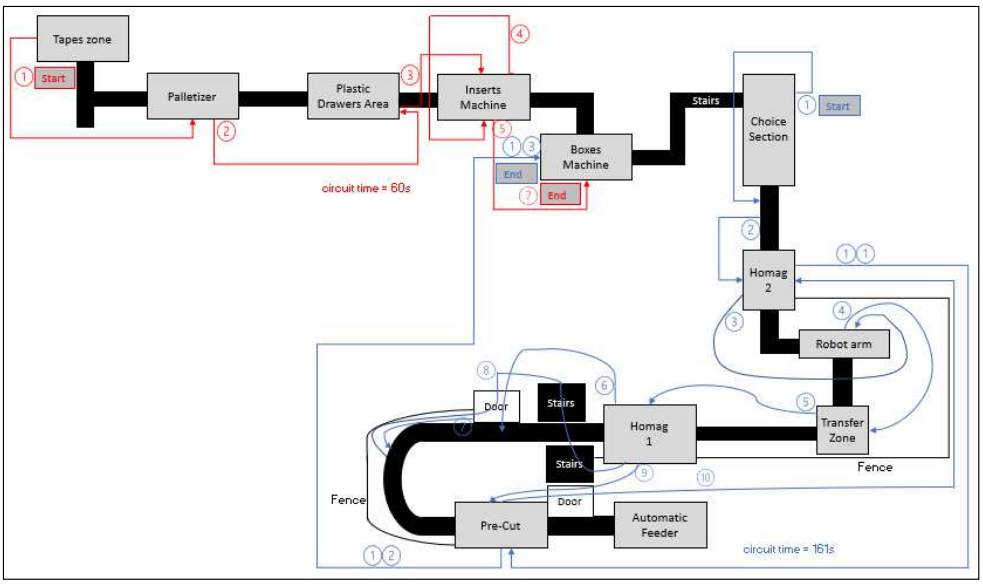


Figure 6 – Spaghetti Diagram of the Workers' New Procedure in AF2

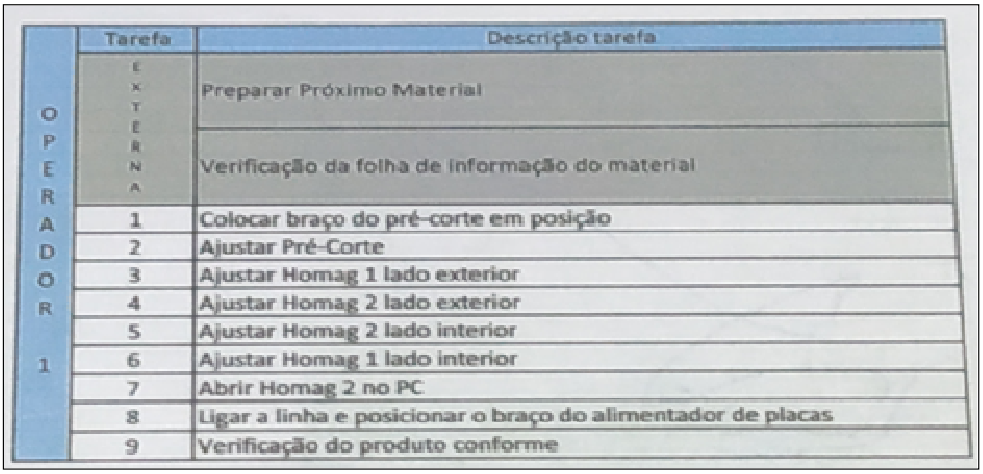
Since in AF3 the worker was already making an optimized route, only the order of tasks was changed. The preparation and checking activity of the next material to be cut is now done before the end of the last piece of the current product.

Previously, the setup took 29 minutes, 26 minutes for specific actions and 3 minutes spent traveling. Regarding the reorganization of tasks, the same setup done by the same collaborator now takes 22 minutes.

4.4.2 Creation of Operational Cards to deposit on the lines

The next step after the creation of these new procedures was the validation with the team leaders and then the creation of plastic cards to be always present in the lines for all employees to know their duties. The cards placed on the lines can be seen in the figures below.

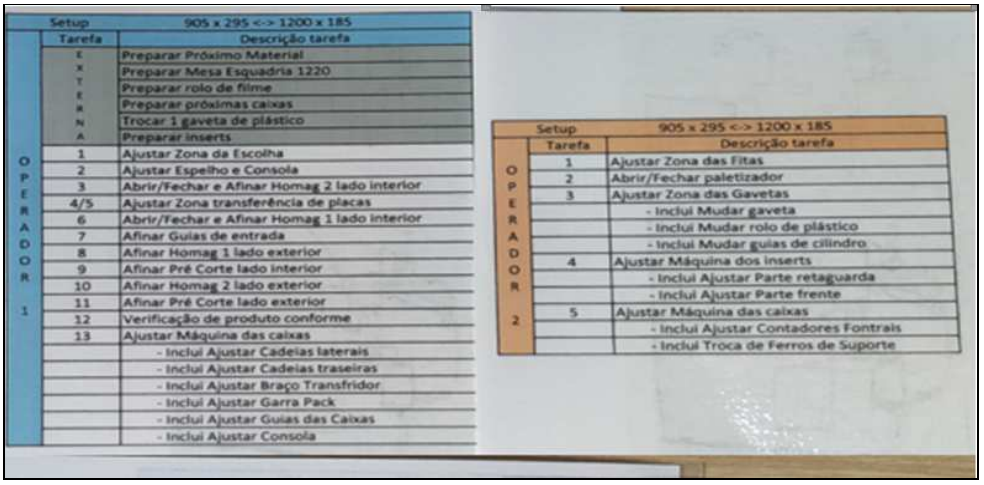
Figure 7 shows the front of the card placed in AF3, the back of the card was already show earlier in this document.



	Tarefa	Descrição tarefa
OPERADOR 1	EXTERNA	Preparar Próximo Material
		Verificação da folha de informação do material
	1	Colocar braço do pré-corte em posição
	2	Ajustar Pré-Corte
	3	Ajustar Homag 1 lado exterior
	4	Ajustar Homag 2 lado exterior
	5	Ajustar Homag 2 lado interior
	6	Ajustar Homag 1 lado interior
	7	Abrir Homag 2 no PC
	8	Ligar a linha e posicionar o braço do alimentador de placas
	9	Verificação do produto conforme

Figure 7 – Front of the card placed in AF3

Figure 8 shows the front of the card placed in AF2, this card show the new tasks and movements the workers must follow.



Setup	905 x 295 <-> 1200 x 185	
	Tarefa	Descrição tarefa
OPERADOR 1	EXTERNA	Preparar Próximo Material
		Preparar Mesa Esquadria 1220
		Preparar rolo de filme
		Preparar próximas caixas
		Trocar 1 gaveta de plástico
		Preparar inserts
	1	Ajustar Zona da Escolha
	2	Ajustar Espelho e Consola
	3	Abrir/Fechar e Afinar Homag 2 lado interior
	4/5	Ajustar Zona transferência de placas
	6	Abrir/Fechar e Afinar Homag 1 lado interior
	7	Afinar Guias de entrada
	8	Afinar Homag 1 lado exterior
	9	Afinar Pré Corte lado interior
	10	Afinar Homag 2 lado exterior
	11	Afinar Pré Corte lado exterior
	12	Verificação de produto conforme
	13	Ajustar Máquina das caixas
		- Inclui Ajustar Cadeias laterais
		- Inclui Ajustar Cadeias traseiras
		- Inclui Ajustar Braço Transfridor
		- Inclui Ajustar Garra Pack
		- Inclui Ajustar Guias das Caixas
		- Inclui Ajustar Consola

Setup	905 x 295 <-> 1200 x 185	
	Tarefa	Descrição tarefa
OPERADOR 2	1	Ajustar Zona das Fitas
	2	Abrir/Fechar paletizador
	3	Ajustar Zona das Gavetas
		- Inclui Mudar gaveta
		- Inclui Mudar rolo de plástico
		- Inclui Mudar guias de cilindro
	4	Ajustar Máquina dos inserts
		- Inclui Ajustar Parte retaguarda
		- Inclui Ajustar Parte frente
	5	Ajustar Máquina das caixas
		- Inclui Ajustar Contadores Fontrais
		- Inclui Troca de Ferros de Suporte

Figure 8 – Front of the Cards Placed in AF2

4.4.3 Tools Location Change

During the observation of the setups it was possible to verify that in both lines the employees spent too much time looking for tools, as such, one of the measures promoted was the change of location of some tools.

With this action, the workers no longer need to go to a shelf in the middle of the line and look in a metal box for the tools they need, neither need to go to the drawer storage area and collect the tools to change the plastic drawers. To avoid wasting time looking for tools, they have been placed exactly where they are needed as seen in Figure 9 and Figure 10.

Figure 9 – Before and After Changing the Location of Some Tools

Figure 10 – Before and After Changing the Location of the Drawers

4.4.4 Placement of Toolkits in Strategic Locations

Small key tool kits were also introduced where they were most used, avoiding constant travel by the employees to the tool cabinet. Figure 11 shows the toolkit placed in the two most problematic areas of the line.

Figure 11 – Toolkits Used

4.4.5 Creation of a Missing Tools List

Another key point when observing setups and through informal conversations with employees was the fact that there was a lack of tools on the cutting lines, and it was often necessary to fetch tools from other lines.

A list of the missing tools was then drawn up and later sent to the person responsible for review and ordering what the responsible thought to be a valid request.

4.4.6 Tool Modification and Duplication

As for existing tools, a Homags (cutting machine) adjusting tool was duplicated as it was not always available, and another tool was stretched to increase its range.

Stretching the tool will mean that the worker no longer must position the crank in the starting position and will allow the working range of the handle to move from 180 to 360 degrees. The operator can now perform the operation faster and with less physical effort. The duplicated tool can be seen in Figure 12 and the elongated tool in Figure 13.

Figure 12 – Duplicated Tool

Figure 13 – Elongated Tool

4.4.7 Creation of Labels for Counters and Record Sheets with past references

Another change promoted was the creation and placement of labels in various locations, as shown in Figure 14. It was noticed that during the setups the workers were always checking the value because it was easy to forget and, in some places, they wrote on the machines. This measure promotes an improvement in the appearance of the workplace as well as decreases the probability of the occurrence of human errors. The labels appear as a memory aid and prevent rapid setup execution from relying on operator retention.

Figure 14 – Labels with the Value of the Counters

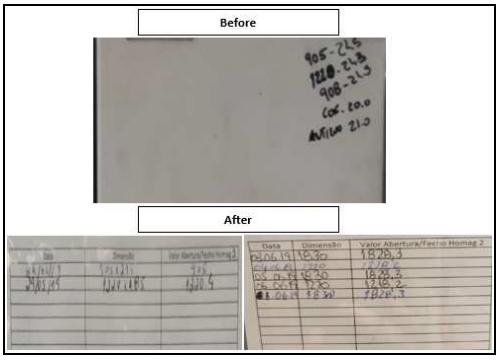


Figure 15 – Record Sheets

Record sheets were created and placed next to the cutting machines, Figure 15, to facilitate the process of opening and closing the machines by informing the last values used for certain dimensions. It is expected that with these forms and their history, product compliance will be achieved more quickly thus avoiding the need to reopen or close the machines.

Table 3 – Final Results in AF2

	min	%
Objective time (minutes)	120	100%
Historical average time (minutes)	194	162%
Expected reduction (minutes)	29	15%
Observed time (with 3 workers) (minutes)	64	100%
Time after task reorganization (with 2 workers) (minutes)	66	103%
Reduction achieved (minutes)	-2	-3%

Table 4 – Final Results in AF3

	min	%
Objective time (minutes)	120	100%
Historical average time (minutes)	194	162%
Expected reduction (minutes)	29	15%
Observed time (with 1 worker) (minutes)	64	100%
Time after task reorganization (with 1 worker) (minutes)	66	103%
Reduction achieved (minutes)	7	24%

The sheets placed on the lines prevent collaborators from writing on the equipment and allow them to see the opening and closing values used in previous setups, reducing the subsequent setting times.

Tables 3 and 4 show the above data clearly and precisely, thus allowing a quick analysis of the results obtained in this project. The objective time corresponds to the time in minutes the company set as the maximum allowed to complete the setup, the historical average setup time corresponds to the time logged on the company's production database, this average recorded time happened at a time when there were no guidelines for how the employees should act and each team had its own way of operating and includes moments where workers did not correctly registry in the system machine malfunctions, loss of power or lack of raw material. The two setup times observed included in the tables 3 and 4 for AF2 and AF3 respectively refer to the times observed before and after the proposed changes. Therefore, it can be said that the objective was met and exceeded the initial expectations of the project.

5 CONCLUSION

The steps taken to improve the setup procedure on the cutting lines were the following: make an effort to maintain an organized workplace with tools in the appropriate places, i.e. properly marked and where they were really needed, change the employees' movements and create and place on the lines cards with the new instructions. Internal tasks were transformed into external ones, record sheets were created and placed near the cutting machines with their historical opening and closing values in order to speed up the product compliance process. Another measure applied was the duplication of a tool and the modification of another, and a request was made for new tools to facilitate the work of the employees.

In AF2 the target time set in the past by the company management was 120 minutes. With the help of the company's database, it was possible to verify that the historical average since January 2018 was 194 minutes. The objective set for this project was to reduce the observed setup time by about 15%. The observed time recorded corresponded to 64 minutes of movements and actions performed by 3 workers. After the implementation of the previously mentioned measures, the setup time now takes 66 minutes, therefore there is an increase of 2 minutes in relation to the recorded time, however, it is important to highlight that this new setup time is reached with only 2 employees, one less that the situation that existed before the project started.

In AF3 the target time set in the past by the company management was 20 minutes. With the help of the company's database, it was possible to verify that the historical average since January 2018 was 42 minutes. As in AF2, the cutting line AF3 also aimed to reduce the setup time observed by 15%. The observed time recorded corresponded to 29 minutes of movements and actions performed

by 1 worker. After the implementation of the previously mentioned measures, the setup time in AF3 performed by a single operator now takes 22 minutes, which corresponds to a reduction of 24%.

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Conceptualization, A.S. and J.C.S.; Methodology, A.S.; Validation, J.C.S. and M.T.P.; Formal analysis, L.P.F.; Investigation, A.S.; Resources, M.T.P.; Data curation, J.C.S.; Original draft preparation, A.S.; Review and editing, G.S. and F.J.G.S.; Visualization, J.C.S..; Supervision, G.S. and F.J.G.S.; Project administration, J.C.S.

CONFLICTS OF INTEREST

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