Human error management approach in practice: the use of HERCA tool for a systematic analysis of human errors*

*Silvia Tomić, Milovan Lazarević, Leposava Grubić-Nešić, Danijela Ćirić Lalić, Jelena Kanjuh***

Abstract

In recent years, human errors have been perceived as circumstances contributing to the organizational learning process. On the other hand, as inevitable products of human performance, human errors have been cited as a factor with a high impact on various types of losses for organizations. To reduce the negative consequences of human errors and increase the potential *of their positive impact, it is of tremendous importance for organizations to manage them. This study applied the Human Error Root Cause Analysis (HERCA) tool to analyze human errors and their real causes. Based on the literature review, additional parameters were identified and included in data collection to increase the quality of the data collection phase as a crucial step for understanding the circumstances that led to an error. Research for this study was conducted on a sample of 176 human errors in a floor-producing company.*

Keywords: human error management, HERCA, root cause analysis, organizational learning
JEL Codes: J24, D22, D24

1. Introduction

Due to a turbulent and fast-changing environment, increased productivity and overall efficiency have become the most critical objectives of organizations. To achieve these objectives, all losses, including those caused by humans, should be minimized. Humans are prone to errors due to various causes, mostly related to their knowledge, attention, and person-related factors (Jo/Park 2003). It is known that human errors have a significant impact on productivity and efficiency due to minor faults during operative work (Di Pasquale/Iannone/Miranda/Riemma 2013). Depending on the industry, it has been observed

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** *Tomić Silvia,* (Corresponding author), PhD student at Faculty of Technical Sciences, University of Novi Sad, Serbia. E-mail: silvia.tomic85@gmail.com. Main research interests: human resource management, error culture and management, continuous improvement.
Lazarević Milovan, Full Professor at Faculty of Technical Sciences, University of Novi Sad, Serbia. E-mail: milaza@gmail.com. Main research interests: production processes and systems, lean management, continuous improvement.
Grubić-Nešić Leposava, Full Professor at Faculty of Technical Sciences, University of Novi Sad, Serbia. E-mail: nesle@uns.ac.rs. Main research interests: human resource management, leadership, organizational change.
Ćirić Lalić Danijela, Assistant Professor at Faculty of Technical Sciences, University of Novi Sad, Serbia. E-mail: danijela.ciric.86@gmail.com. Main research interests: project management, agile organizations, change management.
Kanjuh Jelena, Communications expert, Elixir Group, Serbia. E-mail: jelena.vujanac@gmail.com. Main research interests: internal and external communication, project management, data science.

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that human errors are responsible for more than 60 % of accidents, with the highest impact up to 90 % in chemical and nuclear industries (Madonna/Martella/Monica/Maini/Tomassini 2009; Griffith/Mahadevan 2011; De Felice/Petrillo/Carlomusto/Romano 2012; Di Pasquale/Miranda/Iannone/Riemma 2015).

Consequently, the practice has developed many methods and tools to reduce the likelihood of human errors (e.g., training, work improvements, employee selection, problem-solving process, procedure of conduct in situations particularly exposed to the risk of error) (Obora 2018). In the literature, numerous studies present and apply various Human Reliability Analysis (HRA) methods (Kim/Seong/Hollnagel 2006; Kim/Park 2012; Di Pasquale et al. 2013) that have a preventive nature in dealing with human errors. HRA methods focus on analyzing and predicting latent human errors by understanding the characteristics of tasks and operators' actions (Dalijono/Castro/Löwe/Löher 2006). HRA methods should gain even more attention in the context of Industry 4.0 since humans represent the most flexible part of the system (Dukic Mijatovic/Uzelac/Stoiljkovic 2020). Therefore, researchers have been reoriented towards simulation to evaluate human behavior and calculate human reliability to upgrade HRA methods. Trucco and Leva (2007) developed a new probabilistic cognitive simulator (PROCOS) to approach human errors in complex operational frameworks that allow analyzing error prevention and recovery. As a further improvement, they underlined the time-dependent simulation process. A Simulator for Human Error Probability Analysis (SHERPA) was designed to remedy this deficiency. SHERPA aims to predict the likelihood of an operator's error for the performed activity and as a function of working time (Di Pasquale et al. 2015). However, to apply any indicated methods, an in-depth analysis of errors is necessary to identify their causes and assess risk (Obora 2018; Djakovic/Lalic/Delic/Tasic/Ciric 2020). Respecting the importance of a preventive approach and the tendency to develop a high-reliability environment, one thing is sure, as long as humans are involved in any process, errors will occur to a greater or lesser extent, with all their consequences to the business (Kirwan 1994; Hockey 1996; Sexton 2000; Schultz 2010; Tulbure 2012; Skalle/Aamodt/Laumann 2014; Di Pasquale et al. 2015; Dekker 2017). One way to react positively to human errors and reduce adverse consequences is by applying the error management approach (Van Dyck/Frese/Baer/Sonnentag 2005). This approach assumes that human error cannot be prevented entirely and that it is necessary to ask what to do after an error occurs (Frese 1995; 2008). Thus, the error management approach distinguishes between an error and its consequences. While the error prevention approach aims to prevent negative consequences, error management focuses on reducing negative consequences and increasing positive impact. In addition, error management ensures that errors are reported and detected quickly and that negative consequences of errors are managed and minimized (Van Dyck et al., 2005). The benefit of this approach is organizational learning.

To date, very few studies have explored reactive methods and tools to handle active errors that led to significant losses, incidents, and/or accidents. Thus, a question about the value and effectiveness of different human error management methods and tools in different contextual conditions could be raised (Ciric/Delic/Lalic/Gracacin/Lolic 2021). In the first phase of our research, we reviewed and analyzed the existing error management approaches. We identified different methods and tools to analyze human errors, presented in the *Theoretical Background* section. According to our analysis, Human Error Root Cause Analysis (HERCA) method for managing human errors has shown to bring main advantages like universality and simplicity in its application, based on the problem-solving 7-Step Model (Obora 2018). Although this method is comprehensive and intuitive, it has not been the subject of many scientific publications. There is a lack of research in this field, signaling a clear gap in the literature.

Based on that, the main objective of this research was to test the value and effectiveness of the HERCA tool by analyzing human errors in the first instance and to test if discovering real causes and performing corrective actions contributes to the reduction in negative effects of human errors, in the second instance. According to the literature review, errors have been perceived as circumstances contributing to the organizational learning process because of their negative but informative feedback that points out what needs to be learned, improved or changed. Also, studies have shown that by following the time of error occurrence, it is possible to predict human unreliability (Folkard/Tucker 2003; Tucker/Folkard/Macdonald 2003; Di Pasquale et al. 2015). These findings led to the specific objective of this research, which was to include the time of error occurrence as an additional parameter in analyzing human errors to get more in-depth findings and advance the data collection section in the HERCA tool.

Following the aforementioned, the research was underpinned by the following research questions: Does the use of the HERCA tool contribute to organizational learning and reduce adverse effects of human errors? Do specific circumstances such as the time of performing a job affect human error occurrence?

We empirically addressed these questions on a sample of 176 human errors collected during the research period in a floor-producing company in Serbia. Research results provided more extensive evidence and findings for scholars and practitioners that could support the application of the HERCA tool, with additional circumstantial parameters in various contextual settings, to contribute to the organizational learning process and reduce the negative effects of human errors in the long term. The rest of this paper is structured as follows. The second section reviews the literature on human errors, error management methods and tools. In the third section, the theoretical background for hypotheses development is presented. The research framework with the data collection process is explained in section four. In section five, statistical data and results are presented, and section six discusses the results, followed by a conclusion with limitations and directions for future research in section seven.

2. Theoretical Background

2.1. Human error

The concept of human error is a widely researched field by various authors, so it is challenging to give only one satisfactory definition of human error. Considering the already given definitions by Reason (1990), Nielsen (1994), Norman (2013), etc., Whittingham (Whittingham 2004:6) said that "*A human error is an unintended failure of a purposeful action, either singly or as part of a planned sequence of actions, to achieve an intended outcome within set limits of tolerability pertaining to either the action or the outcome.*" With this definition, human error occurs if: there was no intention to commit an error when acting, the action was purposeful, and the intended outcome was not achieved within set limits of tolerability. He also presented the distinction between errors and violations in his work, which lies in intention and knowledge. Errors can be latent and active, meaning that significant time has elapsed between an error being made and its consequence being manifested. When an error is not latent, it is said to be an active one. An active error is an error where the effects are manifested immediately or almost immediately. The key to dealing with those types of errors lies in detection speed. The sooner a latent error is detected, the more likely a potential consequence will be prevented or managed in case of a dynamic error.

To understand the research described in this article, the terms error, failure, violation, incident and accident need to be differentiated. Failure refers to negative organizational outcomes. Not every error leads to failure. Errors can be detected and corrected immediately, or they may occur in a safe environment, thus not leading to a failure (a consequence of an error) (Frese/Keith 2015). On the other hand, violations have been defined as intentional errors (Gertman/Blackman/Haney/Seidler/Hahn 1992) where prior knowledge of the violated rule existed. To deal effectively with violations, it is necessary to investigate why a violation has occurred in the first place. Anyhow, both types require an adequate reaction through fast detection and deep analysis to avoid recurrence in the future. Incidents and accidents, together with the previously explained term failure, refer to negative error consequences. This article discusses active errors that led to failures, various losses, incidents, and/or accidents and directly affected the discrepancy between what was planned and what was achieved.

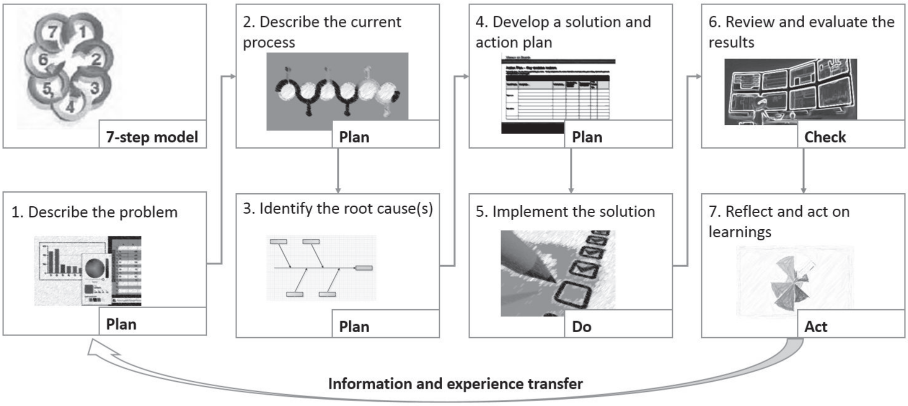
2.2. Error management

Human errors are found more frequently in the stages of decision-making and operational execution of various actions. Still, they may occur at any stage of human performance (Cheng/Hwang 2015). According to Norman (1984), there are four different stages of human performance: intention to do something, selecting an action, executing the action, and evaluating the outcome. Therefore, it is desirable to identify them at a very early stage before they cause any loss.

Despite the existence of numerous preventive methods to avoid human errors, researchers on this topic agreed on one fact – human errors are inevitable. Following Dekker's new view of human errors, they are a symptom of a deeper problem in the system; to explain errors, asking where people have made them is not needed. Instead, it is necessary to look for the deeper cause in relation to the circumstances surrounding them (Dekker 2017). In this case, human errors are the starting point for further research that proves that they are systematically linked to tools, human tasks, and the operational/organizational environment. If the analysts stop on *what* and *how* it happened, if the organization has not probed deeply enough to understand the reasons for the human error, they will not be able to prevent the event from occurring again (Rooney/Heuvel 2004). The core step in discovering why it happened is root cause analysis (RCA). "*Root cause analysis is a structured investigation that aims to identify the true cause of a problem and the actions necessary to eliminate it*" (Andersen/Fagerhaug 2006:12). Only when investigators can determine why an event occurred, they will be able to define and implement adequate corrective measures to solve the problem and prevent the possibility of re-occurrence. Berry and Krizek (2000) concluded in their work that an effective root cause analysis system involves more than just the application of the analysis techniques. It consists of defining the problem, gathering appropriate information, developing potential solutions or changes, implementing system improvements, process improvements, or both, and subsequent evaluation of these solutions. They also pointed out the importance of adequate follow-up and monitoring phases that ensure appropriate implementation and effective use of resources.

A practical and systematic approach to problem-solving is to use the 7-Step Model, which provides a repeatable set of steps, actions, and tools as part of the Plan-Do-Check-Act Cycle (Picture 1) (Brassard 2000). The PDCA Cycle, the fundamental component of Dr. W. Edwards Deming, or the "Deming Cycle," consists of four stages: Plan, Do, Check, Act. A detailed review of the PDCA cycle and the 7-Step Model can be found in this book (Brassard 2000). The PDCA cycle was at first used as a tool to control the quality of products, but soon after, it was recognized as a method to develop improvements in organizational processes (Maruta 2012), with a focus on continuous improvement (Albuquerque 2015; Silva/Medeiros/Vieira 2017). According to Sokovic et al. (2010), PDCA is much more than a simple tool; it is a concept of continuous improvement philosophy embedded into the organization's culture. Literature shows that the PDCA cycle has been implemented with positive results, reducing costs and defects and improving the quality of processes and products (Realyvásquez-Vargas/Arredondo-Soto/Carrillo-Gutiérrez/Ravelo 2018). We compared the existing tools for human error management in literature with the 7-Step Model integrated into the PDCA model to find the most suitable tool to use in our research (Matrix1).

Picture 1. Snapshot of the 7-Step Model



2.3. *Error management tools*

Liginlal et al. (2009) illustrated the application of GEMS (Generic Error Modelling System) error typology and defense-in-depth solution strategy founded on error avoidance, error interception and error correction in the case of the two leading causes of privacy breach incidents. This approach combines three steps in two phases: preventive (error avoidance and interception) and reactive (error correction) phases. Another human error management tool, ARCTM (Accident Root Cause Tracing Model) (Abdelhamid/Everett 2000), is tailored to the needs of human errors that led to accidents in the construction industry. ARCTM proposes that accidents occur due to three root causes: failing to identify any unsafe condition, deciding to proceed with a work activity after an unsafe condition has been determined, and acting unsafe regardless of the initial conditions in the work environment. Accident investigation questions help identify the root causes behind accidents: How did the unsafe condition occur? Why did the worker decide to proceed with the work despite determining the existing unsafe condition? Does the worker know the correct procedure for doing the work? Has the worker always/occasionally proceeded with the work despite identifying unsafe conditions? Mirza et al. (2011) analyzed 32 hydrogen processing incidents chosen from HIRD (Hydrogen Incident Data Base) to learn about their root causes. This approach consists of four steps: data collection, defining probable causes, defining contributing factors, and lessons learned. Love et al. (2018) underlined the importance of establishing a positive error management culture and did the practical implementation of error management practices defined by Van Dyck et al. (2005). Those steps are important, representing a significant part of the error management and learning process. Two approaches were derived from disasters in medicine caused by human errors. One is an incident-monitoring technique (Bhasale 1998) with its roots in psychological studies of human behavior. Four steps were performed for the analysis: identifying what happened, describing how it happened, identifying the cause and contributing factors, and determining preventability and possible safeguards. The second one is error analysis (Troidl 1999) with another four questions: What was the clinical situation? What happened? Why did it happen? How do we avoid negative events or disasters in the future?

Another tool for human error management was derived from World Class Manufacturing (WCM) – HERCA (Human Error Root Cause Analysis) tool. Only organizations that apply this methodology use the HERCA tool to manage human errors. WCM is a compilation of a modern approach to production systems development. It is based on the concept of the Toyota Production System, Lean Manufacturing elements, and Total Quality Management (Pałucha 2012). Hayes and Wheelwright were the first authors to use the term world-class manufacturing described as a set of practices, implying that best practices would lead to superior performance (Flynn/Schroeder/Flynn 1999). A brief explanation of the tool is given in (Ławniczak/Iwanowicz/Mazurek 2014), and the form for applying the HERCA tool is attached in APPENDIX A. The following section explains each of the seven steps of the HERCA tool:

1. **Problem description** – this step aims to understand what occurred and describe the problem as a gap between what should have happened and what actually happened;
2. **Data collection** – in this step the team gathers information to discover the problem. The information required by the HERCA form is: name of the problem, interviewer name, date of the interview, sector where the error occurred, and the name of the person who committed the error;
3. **Interview on the spot** – so-called TWTTP (The Way To Teach The People) interview is performed to find out all details about the situation which led to an error. This step should be performed as soon as possible after the error occurs, with all involved people. Otherwise, essential details may be missed;
4. **Root cause and countermeasure identification –** this step aims to select the proper root cause (presented in Table 1), generate possible solutions, construct a detailed action plan and communicate it with the people involved;

Table 1. HERCA´s root cause categorization

KNOWLEDGE BASED	Lack of knowledge and/or competence to perform a certain activity
BEHAVIOUR BASED	Issues related to: ■ Coping with work instructions ■ Personal issues
METHOD BASED	Issues related to: ■ Work instructions ■ Work condition ■ Working process ■ Work place organization ■ Technical and/or equipment characteristics

5. **Implementation of defined actions** – in this step, the realization of the action plan is followed and reported timely;
6. **Effect evaluation** – this step is used to review the entire process and evaluate the change results. Follow-up can start after all countermeasures are implemented, people are trained, and no shortcomings are identified. The following can be done daily, weekly or monthly, depending on the nature of the problem. If the result of performed improvements is not positive, the entire process should be revised and, if needed, repeated until the problem is completely solved and prevented;
7. **Reflect and act on learning** – in the final step, all information about the problem is documented. This step addresses the lessons learned from the process and identifies the following improvement opportunities. Finally, lessons learned are shared and communicated through information boards, newsletters, e-mails, meetings, training, or other suitable way, depending on the type and scope of the problem.

The following matrix (Matrix 1) presents steps of reactive tools in literature and their compatibility with the 7-Step Model.

Matrix 1. Compatibility of error management tools with 7-Step Model

	Describe the problem	Describe the current process	Identify the root cause(s)	Develop a solution and action plan	Implement the solution	Review and evaluate the results	Reflect and act on learnings
Error management program			Root cause analysis	Error correction		Periodically evaluation of measures	
ARCTM	Asking accident investigation questions						
Error management practices	Analyzing error			Handling and coordinating error			Communication about error; Knowledge sharing; Error assistance
Hydrogen Incident Reporting	Data collection		Defining probable cause and contributing factors				Lessons learned
Incident monitoring technique	Error analysis		Identifying the cause and contributing factors				Detemining preventability and possible safeguards
Error analysis in clinical practice	Retrospective interview						
HERCA	Problem description; Data collection	Interview about current way of performing acitvity	Root cause analysis	Countermeasure and action plan identification	Implementation of defined actions	Effect evaluation	Closing and knowledge sharing

3. Hypothesis development

3.1. Identification of human errors root causes using the HERCA tool

As previously mentioned, Dekker (2017) gave two views of dealing with errors: the old and the new view of human error. The new idea perceives human error as a symptom of trouble deeper inside a system. If organizations want to look deeper into the systems they operate, they will perceive human errors as a window to a problem that each of the participants in the system might have; a marker in the system's everyday behavior and an opportunity to learn more about organizational, operational and technological features that create error potential (Dekker 2017). Tulbure (2012) summarized the main factors that give rise to human errors. According to his findings, the most people-related causes of human errors are lack of knowledge, lack of skills, divided attention or cognitive resources, reliance on false information, emotional imbalance (Piattelli-Palmarini 1994) and possibly people's explicit and implicit attitudes toward errors. Besides these endogenous causes of error, the context in which human activity is carried out might predispose or protect people from system-induced errors (Whittingham, 2004). For example, the general work environment, human/machine interface, and even non-physical elements like the company organizational structure and working culture contribute to human error (Tulbure 2012). In a related study of 32 H2-based incidents (Mirza/Degenkolbe/Witt 2011), which took place in industrial hydrogen processing plants, the analyzed causes of human errors were categorized under five significant classes: management, design, technical, maintenance and operator error, where "operator error" primarily refers to operators' lack of response, failure to follow instructions, and similar performance issues. The analysis showed that most of the root causes for the incidents were evaluated as "technical", with a contribution of 33.3 %, while 23.5 % of causes were "maintenance". "Design error" and "operator error" each contributed to 15.7 % of causes while "management" was the least with the contribution of 11.8 %. Another related study (Dalijono et al. 2006) presented a new man-machine-system model, and a means for determining performance influencing factors (PIFs), which primarily influenced the operators during their task performance. Three groups of PIFs were evaluated: technical conditions, organizational conditions and operator's internal PIFs such as communication, skills and stress level. This method was validated in an industrial plant in Germany. Two cases confirmed that "organizational" and "technical conditions" had the most significant influence, with 71.9 % and 14.1 % in the first and 40.5 % and 44.5 % in the second. "Human factors" influenced with 14 % in the first case, where only 1.8 % were related to behavior, and in the second case with 15 %, where 1.6 % were related to behavior. Skalle et al. (2014) modeled Technical Human & Organizational Error as an ontological hierarchy. The causes behind error were determined, with the most significant influence of "procedures" – around 30 %, "organizational culture" – about 20 %, "safety communication" – approximately 18 %, "training and competence" – around 15 %, "organizational change" – around 10 % and "fatigue and workload" and "design factor" with less than 10 %. The above-mentioned findings led to our first hypothesis. In HERCA root cause categorization (Table 1), knowledge-based and behavior-based errors relate to the person, and method-based errors relate to organizational/systemic issues.

Hypothesis 1: More than 50 % of analyzed errors indicate "method" as the root cause.

3.2. Interconnection between human errors occurrence and time of performing the job

Based on the literature review, it can be concluded that data collection is crucial for a proper understanding of circumstances that led to an error and performing further steps in the error management cycle. The use of data for analysis and decision-making has been emphasized for decades in quality management (Okes 2009). The quality and comprehensiveness of data can improve the probability of making a good decision. In most organizations, many records are maintained manually and computerized to provide evidence of what occurred, which can be of tremendous value in root cause analysis (Okes 2009). Time of error is recognized as critical data for analyzing a whole shift and identifying the moments of highest operator unreliability (Folkard et al. 2003; Tucker et al. 2003; Di Pasquale et al. 2015). As previously mentioned, discovering the period of highest error probability makes it possible to define preventive actions to maintain operators' attention and organize their work more effectively. Tucker et al. (2003) examined the effect of rest breaks on temporal trends in industrial accident risk by assessing accident records from a large engineering company obtained over three years. They concluded significantly more accidents during the day shift (n=296) than during the night shift (n=230; p=0·004). On the contrary, Folkard et al. (2003) concluded, from the studies reviewed in their paper, that the risk of lower productivity or safety issues was found to increase in an approximately linear fashion across the three shifts, showing an increased risk of 18.3 % during the afternoon shift and by 30.4 % during the night shift, relative to that during the morning shift. They presented through a few studies the importance of breaks by examining industrial injuries in an engineering plant. A 15-minute break was given after each period of 2 hours of continuous work. The results showed that risk rose substantially, and approximately linearly, between successive breaks such that risk had doubled by the last 30 minutes before the next break. Following the exact time of error could be helpful for further investigation: why it happens in a certain period, whether that period is connected with the global circadian rhythm, or it varies depending on the shift leader, etc. The original HERCA form does not include this parameter, so we added it for this study. Therefore, our second hypothesis is focused on following the exact time of error occurrence and is defined as follows:

Hypothesis 2: *There is a connection between error frequency and time, date, and month of job performance.*

4. Research framework

To analyze human errors and discover the real causes behind them, the research was conducted by applying the HERCA tool. Considering errors as an indicator of systemic issues, the categories "knowledge-based" and "behavior-based" were treated as one broader category of the error root cause, and "method-based" as a category in itself.

We included additional parameters to understand the error nature better and discover whether those parameters are indicators of organizational areas for improvement, i.e., influential factors that led to human errors (Table 2). Following the exact time of the error, the occurrence is already explained in the hypothesis development section. In the literature, there are numerous studies about the importance of diversity and variation at work (Jahncke/Hygge/Mathiassen/Hallman/Mixter/Lyskov 2017) and the connection between job type (jobs characterized as “static” – computerized office work or “repetitive” – dynamic tasks like short-cycle assembling work in industry (Mathiassen 2006)) and human attention; workload and fatigue (Grech/Neal/Yeo/Humphreys/Smith 2009); worker productivity during repetitive tasks (Das/Shikdar 1990; Das/Shikdar 1999; Davis/ Jorgensen 2005). To test the connection between job type and error frequency, we treated jobs at the visual control position as "static" and jobs at the working machine as "dynamic."Besides following the time of error occurrence and the type of jobs that participated in error committing, we observed if the same error recurred during the monitoring period of two years. The main goal was to check whether managing human errors by applying the HERCA tool eliminates the real cause of errors.

Table 2. Data collection section, expanded for our study

DATA REQUIRED BY THE FORM	EXPANDED DATA FOR THIS STUDY
▪ Name of the problem ▪ Interviewer name ▪ Interview date ▪ Sector where the error occurred ▪ Name of person who committed the error	▪ **Date and time of the error** ▪ **Type of job – static** (visual quality control) or **dynamic** (working at the machine) ▪ **Error repeating –** Did the same error happen again during monitoring period?

4.1. Data Collection

The research was performed in an international floor-producing company headquartered in Western Europe, with more than 30 industrial sites worldwide. This company has been deploying World Class Manufacturing (WCM) methodology since 2009. Our research monitored operators' errors managed by the HERCA tool for two years. The research was conducted in Serbia, one of the production sites of a global company in the Eastern Europe area. The total number of employees is around 950 (depending on the exact month), where 674 (487 men and 187 women) work directly on production lines. This company registers and manages all operators' errors that have an impact on incidents and losses in production. Thus,176 human errors were collected, analyzed, and processed with the HERCA tool during the research period. The structure of the impact of error is as follows: quality of the product (46 %), production process (31.8 %), stoppages (15.9 %), safety (4 %), autonomous maintenance (1.7 %) and environmental accidents (0.6 %). This research did not include errors committed by employees at higher organizational levels (managers, experts). The results were analyzed with SPSS (Statistical Package for the Social Sciences). We used the binomial test, Spearman´s correlation and Pearson´s $\chi 2$.

5. Results

5.1. Results by error category

An exact binominal test showed that 46 % of the observed errors, where the root cause was method, was not significantly less than 50 %; p = .871 (one-way) (Table 3).

Table 3. Overview of frequency, percentages and proportions with the level of significance of the binomial test

Error category	Frequency	Percentage	Proportion	Exact significance
Knowledge/Competence	24	54 %	0.540	0.871
Behaviour	71			
Method	81	46 %	0.46	

To fully understand the nature of non-methodical errors, Spearman's correlation analysis was performed (Table 4) by comparing the following factors:

- Knowledge about performed activity, Lack of attention, Lack of instruction following, and Personal issues, with
- Number of errors performed, Type of job – static (visual quality control) or dynamic (working at the machine) and Error repeating

The analysis showed that the conclusion "Employee has knowledge about performed activity" was present to a greater extent in cases where persons are employed at static jobs ($\rho S= .39$, $p <0.01$), as well as for errors that were more frequently repeated ($\rho S= .36$, $p <0.01$). The correlation between employees who have the knowledge and the number of errors performed was not found. The conclusion "Employee does not have knowledge about performed activity" was present to a greater extent where employees committed a higher number of errors ($\rho S= .25$, $p<0.05$). Additionally, a correlation between non-compliance with instructions and the number of errors was not found.

Table 4. The relationship between variables determined by Spearman's correlation

			Number of errors	Type of job	Error repeating
Spearman's rho	Employee has knowledge about performed activity	Correlation Coefficient	0.138	.394**	-.362**
		Sig. (2-tailed)	0.221	0	0.001
		N	80	80	80
	Employee does not have knowledge about performed activity	Correlation Coefficient	.253*	-0.152	0.103
		Sig. (2-tailed)	0.572	0.177	0.364
		N	80	80	80
	Employee made an error due the lack of attention	Correlation Coefficient	.417**	.559**	-.546**
		Sig. (2-tailed)	0	0	0
		N	80	80	80
	Employee made an error because he did not follow the instructions	Correlation Coefficient	0.196	-0.132	0.133
		Sig. (2-tailed)	0.082	0.242	0.241
		N	80	80	80
	Employee made an error due to bad personal condition (stress, tiredness, health issues, etc.)	Correlation Coefficient	.221*	0.123	0.045
		Sig. (2-tailed)	0.049	0.276	0.693
		N	80	80	80

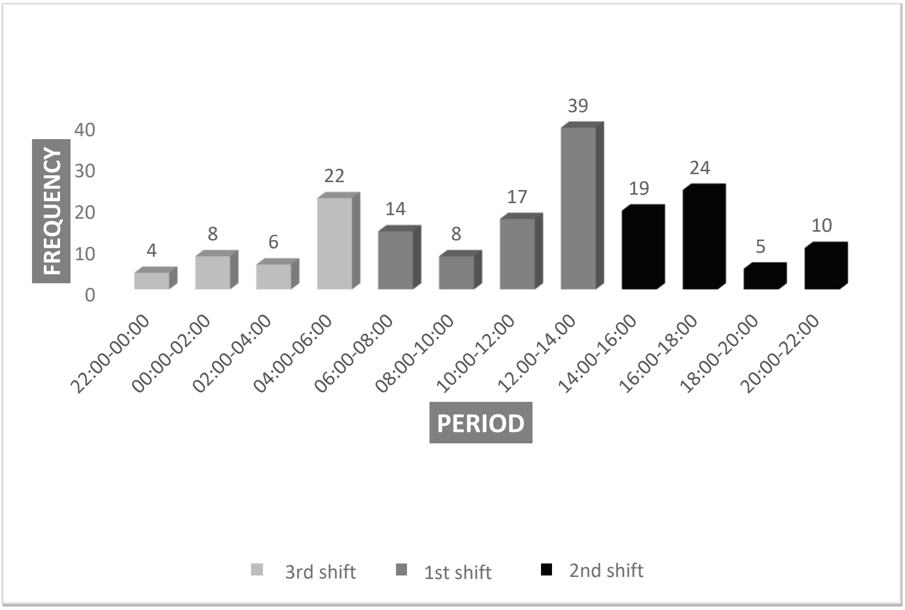
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The cause of errors where employees committed a higher number of errors was more often classified as "Employee made an error due to lack of attention" (ρS= .42, $p<0.01$). The cause of errors committed by persons employed at static jobs was more often classified as "Employee made an error due to lack of attention" (ρS= .56, $p<0.01$). Finally, the cause of errors committed by employees with more frequent error repetition was more often classified as "Employee made an error due to lack of attention" (ρS= .55, $p<0.01$).

A statistically significant correlation was established between the number of errors, and the cause of errors classified as "Employee made an error due to bad personal condition" (ρS= .22, $p<0.01$).

5.2. Results obtained with the expanded form – exact time and date of error occurrence

Graphic 1. Frequency of error occurrence during the working period



Graphic 1 shows that errors occurred more frequently in the last two hours of the 1st and 3rd shift, which could be connected with lower attention before the shift ends. On the other hand, the situation is different in the 2nd shift, where errors occurred more frequently in the first half of the period.

- Working shifts

Pearson's $\chi2$ showed that the frequency of errors is correlated with shifts ($\chi2=12.318$, $df=2$, $p<0.01$). The residual analysis indicates that errors are more frequent in the 1st shift and less frequent in the 3rd shift.

Table 5. Overview of observed, expected and residual frequencies for analysing the number of errors by shifts

	Observed frequencies	Expected frequencies	Residuals
1st shift	78	58.7	19.3
2nd shift	58	58.7	-.7
3rd shift	40	58.7	-18.7
Total	176		

■ Week level

Pearson's χ2 showed no statistically significant difference in the frequency of errors by weeks ($\chi2=3.86$, df=3, $p>0.05$).

Table 6. Overview of observed, expected and residual frequencies for analysing the number of errors by weeks

	Observed frequencies	Expected frequencies	Residuals
1st week	35	44.0	-9.0
2nd week	48	44.0	4.0
3rd week	41	44.0	-3.0
4th week	52	44.0	8.0
Total	176		

■ Monthly level

Pearson's χ2 showed a significant statistical difference in the frequency of errors on a monthly level ($\chi2=40.54$, df=11, $p<0.01$). Observing the residuals by months, a significantly higher number of errors occurred in August and May and lowered in December and January.

Table 7. Overview of observed, expected and residual frequencies for analysing the number of errors by months

	Observed frequencies	Expected frequencies	Residuals
January	7	14.7	-7.7
February	18	14.7	3.3
March	21	14.7	6.3
April	16	14.7	1.3
May	25	14.7	10.3
June	8	14.7	-6.7
July	14	14.7	-.7
August	29	14.7	14.3
September	12	14.7	-2.7
October	10	14.7	-4.7
November	10	14.7	-4.7
December	6	14.7	-8.7
Total	176		

6. Discussion

This study was based on active errors that led to failures, various losses, incidents, and/or accidents in a floor-producing company. Two hypotheses were tested. For the first hypothesis, the discussion is as follows. Looking at HERCA's categorization, besides method-based causes, some knowledge and behavior-based causes imply the existence of systemic issues. Only intended errors are pure non-systemic errors. As mentioned in the *Theoretical background* section, there is a distinction between errors and violations. A violation has been defined as an intentional error and is directly connected to the person itself. Spearman's correlation analysis (Table 4) showed that there was no sign of violation, considering that employees who committed numerous errors did not have the knowledge about the performed activity. The root cause, "Employee, made an error due to lack of attention," was connected with error frequency, static jobs and error repetition frequency. Quality control operators at visual classifying positions made the most frequent errors in this category (86.2 %). This position is important because, in the observed company, it is the last check before the product is delivered to the market. In addition, quality has a significant influence on customer satisfaction, which is directly connected to the company's reputation. To define the root cause, we propose a deeper investigation into what employees' attention was focused on while errors were being committed and which actions could be taken to keep their attention at the desired level during the whole shift. It is concluded that the root cause of errors committed by employees who do not have knowledge about the performed activity actually lies deeper in internal processes, such as onboarding, training, autonomy raising and similar. Related studies of 32 H2-based incidents (Mirza et al. 2011), a new man-machine-system model and performance influencing factors (PIFs) (Dalijono et al. 2006) and modeling of Technical and Human & Organizational Error (Skalle et al. 2014) concluded that operators´ errors were root causes of around 15 % incidents. Other 85 % belong to systemic issues.

Considering the related studies and the results of this study, it can be conclud-ed that human errors indicate deeper systemic issues. The above-mentioned binominal test showed that 46 % of the observed errors, where the root cause was method, was not significantly less than 50 %; p = .871 (one-way). More profound observation of categories "knowledge" and "behavior" indicated sys-temic/organizational issues that create error potential. Thus, our first hypothesis was confirmed.

According to our results for the second hypothesis, there is a significant sta-tistical difference in the frequency of errors monthly. Errors occurred more frequently during the 1st shift and less frequently during the 3rd shift. The same conclusion was reached in Tucker et al. (2003) study. On the contrary, Folkard et al. (2003) concluded that the risk is increased during the night shift. Regardless of the different results by Folkard et al. (2003), the general conclusion is that there is a connection between error frequency and its occurrence. This difference probably depends on a number of underlying factors, including the type of industry, work order, organization, management, level of resistance to disturbing social life, shortened and disturbed sleep, and disrupted circadian rhythms (Thorndike 1921; Folkard/Monk 1979; Spencer 1987;Carrier/Monk 2000). In addition, studies have shown that the trend in performance over the day varies according to the nature of the task under consideration. Performance rate is about to increase over much of the day and, with the possible exception of a "post-lunch dip," parallels changes in body temperature (Folkard et al., 2003). Our and related studies showed that following and documenting the exact date and time of error occurrence is important for further analysis, correction, and preventive actions. Going deeper with the analysis makes it possible to find causes behind human errors and improve work organization. Therefore, our second hypothesis was confirmed.

7. Conclusion

In this paper, we tested the value and effectiveness of the HERCA tool and its contribution to reducing the negative effects of human errors. After two years of conducting this research, HERCA proved to be the right error management tool. Only 19.9 % of errors were repeated, and 80.1 % never happened again during the research period. The tool is accessible, easy to use, and has structural steps based on the 7-Step Model to guide problem-solving. By revealing real causes behind human errors, as explained in the *Discussion section*, human error management contributes to insights into improvement areas of an organization. By improving internal processes or any other weak business segment, it is possible to set up a good base for preventing human errors in the future. Our expanded form proved to be more relevant for comparing various parameters and deeper analyzing the real causes behind errors. These findings give a positive answer to both research questions: Does the use of the HERCA tool contribute to organizational learning and reduce adverse effects of human errors? Do specific circumstances such as the time of performing a job impact human error occurrence?

This study contributes to the human error management literature by practically implementing the HERCA tool. Based on our results and experience in using this tool, we suggest that organizations use the 7-Step Model as a guide in coping with human errors.

7.1. Research limitations and directions for future research

Several limitations need to be recognized for this study. Firstly, there has been no extensive research on reactive human error management tools in the scientific literature which raises the question: Which tool is the most effective for eliminating losses and preventing them from occurring again? A more thorough study comparing the application and quality of various human error management tools would contribute to this topic.

After practical implementation of HERCA, we suggest improvements regarding comprehensiveness of root causes, gathering relevant information and tool universality. Those improvements could be a starting point for future work to develop the most suitable and universal model for human error management. By analyzing data gathered with the HERCA tool, the data collection field does not give enough input information for a deeper analysis of influential factors that can contribute to an error. In addition, the interview section is not standardized to gather important information about circumstances that led to an error, so important information might be missed. This section of the form mainly focuses on investigating whether the person knows how to perform a certain activity. Including more parameters to follow contributes to a more successful analysis and discovery of root causes. Data collection was already expanded for this research, with the following parameters: "time and date of error occurrence", "type of job – static or dynamic", and "has this error happened before". The interview section should be standardized to investigate knowledge levels and gather all important information about circumstances that led to an error. One of the suitable methods is 5W+2H (Börjesson/Svensson 2011; Neves/SilvaFerreira/Pereira/Gouveia/Pimentel 2018), where 5W refers to the questions What, Where, When, Who, and Which and 2H refer to questions How and How much. Another suggestion is to divide causes related directly to a person´s behavior, avoidance of following instructions and signs of violations from the systemic and organizational causes. The second limitation refers to sample size, followed by the longitudinal approach as the third limitation of this study. To understand error nature, root causes and directions for improvement of internal processes, the sample size should be larger, and a more complex statistical analysis of data should be performed.

In addition, this tool is primarily applicable in production organizations. For other branches, industries and universal usage, some parts of the tool, such as predefined root causes and countermeasures, should be adopted or changed accordingly. The importance of positive error management culture and the organization's commitment to the quality of the entire process are thoroughly explained in related works by Van Dyck et al. (2005) and Rybowiak et al. (Rybowiak/Garst/Frese/Batinic 1999), should be emphasized. Otherwise, this process could be experienced only as filling in the form and wasting time.

We encourage organizations and researchers to use this tool, to give their improvements to the tool and to share their experiences. It would be interesting to see results from different branches, industries and cultural environments.

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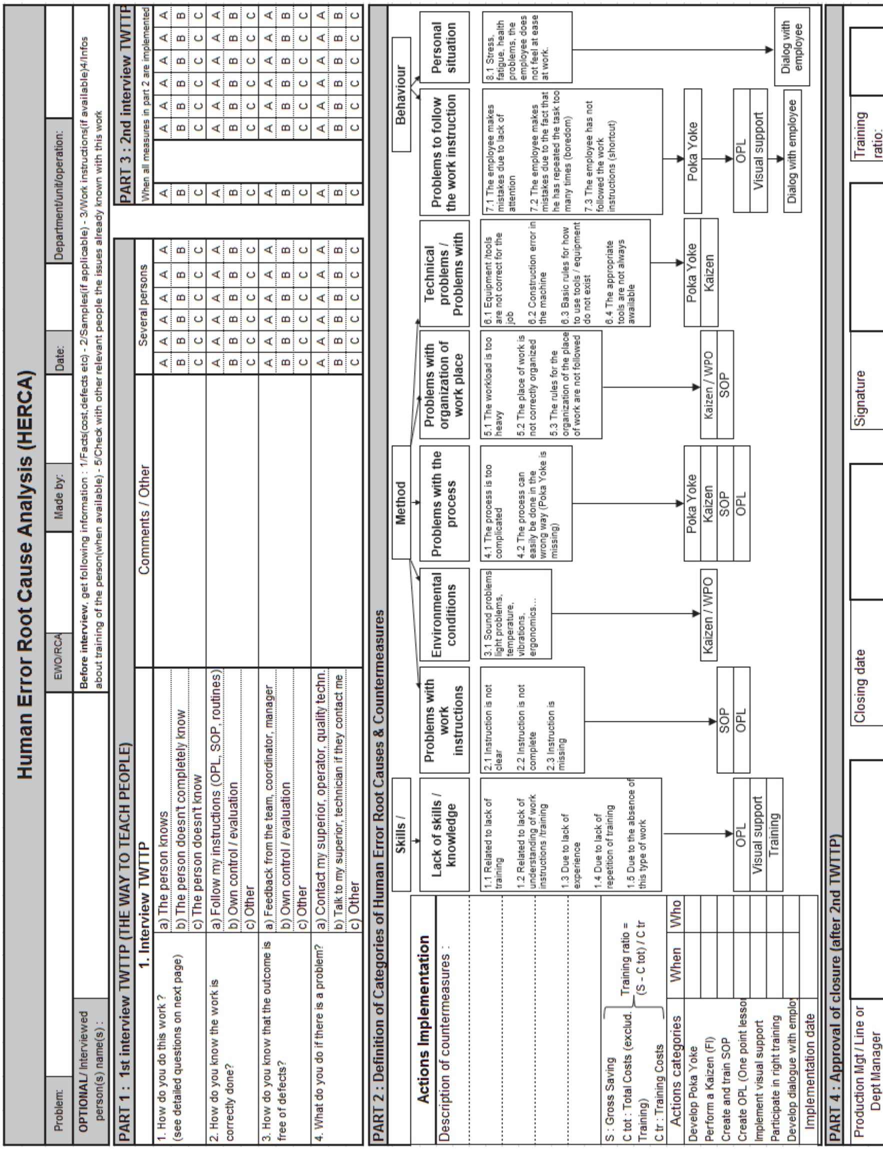
Appendix A


Human Error Root Cause Analysis (HERCA)
Problem:
EWO/RCA
Made by:
Date:
Department/unit/operation:
OPTIONAL/ Interviewed person(s) name(s) :
Before interview, get following information : 1/Facts(cost,defects etc) - 2/Samples(if applicable) - 3/Work instructions(if available)4/Infos about training of the person(when available) - 5/Check with other relevant people the issues already known with this work
PART 1 : 1st interview TWTTP (THE WAY TO TEACH PEOPLE)
1. Interview TWTTP
Comments / Other
Several persons
1. How do you do this work ? (see detailed questions on next page)
a) The person knows
b) The person doesn't completely know
c) The person doesn't know
2. How do you know the work is correctly done?
a) Follow my instructions (OPL, SOP, routines)
b) Own control / evaluation
c) Other
3. How do you know that the outcome is free of defects?
a) Feedback from the team, coordinator, manager
b) Own control / evaluation
c) Other
4. What do you do if there is a problem?
a) Contact my superior, operator, quality techn.
b) Talk to my superior, technician if they contact me
c) Other
A A A A A A
B B B B B B
C C C C C C
PART 3 : 2nd interview TWTTP
When all measures in part 2 are implemented
PART 2 : Definition of Categories of Human Error Root Causes & Countermeasures
Actions Implementation
Description of countermeasures :
S : Gross Saving
C tot : Total Costs (exclud. Training)
C tr : Training Costs
Training ratio = (S - C tot) / C tr
Actions categories
When
Who
Develop Poka Yoke
Perform a Kaizen (FI)
Create and train SOP
Create OPL (One point lesso
Implement visual support
Participate in right training
Develop dialogue with emplo
Implementation date
Skills /
Method
Behaviour
Lack of skills / knowledge
Problems with work instructions
Environmental conditions
Problems with the process
Problems with organization of work place
Technical problems / Problems with
Problems to follow the work instruction
Personal situation
1.1 Related to lack of training
1.2 Related to lack of understanding of work instructions /training
1.3 Due to lack of experience
1.4 Due to lack of repetition of training
1.5 Due to the absence of this type of work
2.1 Instruction is not clear
2.2 Instruction is not complete
2.3 Instruction is missing
3.1 Sound problems light problems, temperature, vibrations, ergonomics…
4.1 The process is too complicated
4.2 The process can easily be done in the wrong way (Poka Yoke is missing)
5.1 The workload is too heavy
5.2 The place of work is not correctly organized
5.3 The rules for the organization of the place of work are not followed
6.1 Equipment /tools are not correct for the job
6.2 Construction error in the machine
6.3 Basic rules for how to use tools / equipment do not exist
6.4 The appropriate tools are not always available
7.1 The employee makes mistakes due to lack of attention
7.2 The employee makes mistakes due to the fact that he has repeated the task too many times (boredom)
7.3 The employee has not followed the work instructions (shortcut)
8.1 Stress, fatigue, health problems, the employee does not feel at ease at work.
OPL
Visual support
Training
SOP
OPL
Kaizen / WPO
Poka Yoke
Kaizen
SOP
OPL
Kaizen / WPO
SOP
Poka Yoke
Kaizen
Poka Yoke
OPL
Visual support
Dialog with employee
Dialog with employee
PART 4 : Approval of closure (after 2nd TWTTP)
Production Mgt / Line or Dept Manager
Closing date
Signature
Training ratio:

GUIDELINES TO TWTTP QUESTIONS	
1. How do you do this work ? Where are the work instructions ? Can the person show SOPs, SMPs or OPLs ? If it si not SOP, OPL, is person able to explain? Are work instructions clear ? Are they up to date ? Take work instructions and check for important details Was the person trained and who was the trainer ? Are there other root causes for this problem than skills ? Method ? Behaviour ? If there are correct work instructions, which were not correctly followed by the person then is it a problem of knowledge ? Are the job tasks too complex ? Has the person many choices to make ?	**2. How do you know the work is correctly done?** Is there any device that help person to check is his/her work correctly done? Does the person know the important Safety and Quality points ? Are the work instructions consist a formalized way of checking is the work correctly done ? How long has the person done the task ? How does the person update his knowledge ? How does the person know there is a change in a standard ?
3. How do you know that the outcome is free of defects? Can person describe verification process? Is verification proces esy to understand? Is there any test person carry out to be sure that outcome is free of defects? Are the procedures followed ? Was the person informed that he/she did something wrong ? Is the information system clear for him/her ?	**4. What do you do if there is a problem?** Does the person know what he/she should do ? Are there clear instructions on what to do in this case ? Who can help the person ? Who the person can alert? Are problem solving tools used (root cause analysis tools) ? What decisions can be made by the person ?

FOLLOW-UP/ should be done by N+1 **Starting date :**

DAILY : DATES ->																															
Team A cross																															
Team A signature																															
Team B cross																															
Team B signature																															
Team C cross																															
Team C signature																															

WEEKLY : NBERS->															
Team A cross															
Team A signature															
Team B cross															
Team B signature															
Team C cross															
Team C signature															

MONTHLY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Team A cross												
Team A signature												
Team B cross												
Team B signature												
Team C cross												
Team C signature												

If the follow-up shows a deviation

DESCRIPTION OF DEVIATION	ACTION	WHO	WHEN	DONE