Dependability, vol. 19 no. 4, 2019 Original article
https://doi.org/10.21683/1729-2646-2019-19-4-32-44

Mining machines accident problem solving via the Toyota A3 Report

Ljubiša Papić[1], Irina V. Gadolina[2*], Milorad Pantelić[3], Neda Papić[4]

[1]Research Center of Dependability and Quality Management (DQM), Čačak, Serbia, [2]Mechanical Engineering Research Institute of the Russian Academy of Sciences, Moscow, Russian Federation; [3]Enterprise Kolubara Metal, Lazarevac, Serbia, Faculty of Technical Sciences, University of Kragujevac, Čačak, Serbia; [4]BSc in Industrial Engineering, MSc student in Industrial Engineering, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia
**gadolina@mail.ru*

Ljubiša Papić

Irina V. Gadolina

Milorad Pantelić

Neda Papić

Abstract. *The Aim of the paper is to show the advantages associated with the application of the Toyota A3 Report as a standard method of information exchange. It must be noted that as of today this method has not found widespread application. It deserves better. Using specific examples of accidents involving mining machines, the authors show how a Report is completed hoping that this information will help in the adoption of this system in other enterprises. That may contribute to the solution of many problems of industrial management. This paper will be most useful for operators of mining machines. The* **Method** *consists in presenting material on an A3 sheet of paper, that is required in order to set forth all the information needed to solve a problem. Why the A3 format? A3 is the maximum size of a sheet of paper that can be faxed. Before the emergence of personal computers it was the most common tool of communication between Toyota Motor factories. The above example of application of the Toyota A3 Report contains such crucial sections as maintenance and reliability of mining machines, information on prior research, application of the "5 Why?" method and consideration of the human factor. In the example given in the paper, the report describes the circumstances of the accident involving the SRs 1200 24/4 (G2) excavator, that occurred on April 6, 1995 in the open-pit mine Field D, mining basin Kolubara by the Electric Power Industry of Serbia. The report also includes an estimate of the consequences and analysis of the causes of the accident. The* **Findings** *include the methodological approach to the solution of problems, brief format of information presentation, documentation and registration, so that other people involved in the process can review it; assuring the persons involved can form an idea of the operating procedures and outcome of problem resolution. A common language is provided for communication within the company along with a culture of Lean production. The A3 Report is a training process and foundation for future changes in the manufacturing process management.* **Conclusions.** *The Toyota A3 Report has two primary functions: submission of proposals and reporting on the approved measures per the submitted proposals. It allows strictly defining the problem and proceeding to the measures aimed at improving the situation. The practical application of the Report as part of communication within the company and with suppliers will enable quick and targeted solution of managerial problems. Initially developed in Japan within the Toyota company, the method currently finds wider application in Serbian enterprises and elsewhere.*

Keywords: *Accident, Problem solving, Mining machines, Open-pit coal mine, The Toyota A3 Report, Reliability and safety, PDCA, 5 Why?, Human factor, Swiss cheese model, Black swan event.*

For citation: *Papić L, Gadolina IV, Pantelić M, Papić N. Mining machines accident problem solving via the Toyota A3 Report. Dependability 2019; 4: 32-44.p. https://doi.org/10.21683/1729-2646-2019-19-4-32-44*

Received on 23.05.2019 / Revised on 09.11.2019 / For printing 14.12.2019

1. Introduction

The basis of contemporary industrial manufacturing is made of natural recourses. Approximately 70% of natural recourses make mineral raw materials. In the world, today over 1.000 milliard dollars are spent on raw materials (metallic ore, non-metallic ore, coal, clay, stone, sand, and gravel), which for many countries represent the main good of export and import.

As an economic branch, mining in many countries represents the basis of development and has a great impact on their total economy. The fact of how much the mining economy impacts the economy of the country is illustrated the best by the following data [1]:

• the price of iron, the price of coke (stone coal) and ore participates with 80-90 [%],

• the price of non-ferrous metals, price of ore and electric power participates with 90%,

• the price of electric power, coal participates with 60%,

• the price of coal, maintenance of mining machinery on open-pit mine participates with 35-40 [%], etc.

Solving problems in the mining industry, before all, represents the ability to think. How to document the most important information and decisions in every stage, so that would be possible to exchange data with associates, include them into the working process and import corrections considering their opinion? When it comes to documenting a complex process of solving problems, piles of papers or, considering a contemporary situation, online data basis are given. However, Toyota Motor Company gives priority to the more simplified approach which requires a pen, an eraser and a piece of paper. Often, that method of work is called The Toyota A3 Report. Why the A3 format? The very format has been used in Toyota since the beginning because the significant portion of information exchange between organizational items of Toyota in Japan and its factories abroad has been carried out by fax and A3 format (297cm x 420cm) is the largest one that can be sent by facsimile.

The Toyota A3 Report method for problem-solving has been developed in order to present improvement description in a cleanly manner. The Toyota A3 Report has two main functions: proposition making and manner of reporting on approved actions given in the proposition. The idea of A3 method is to enable the visualization of proposed ideas on one A3 format piece of paper [2]. The Toyota A3 Report is an effective method because it decreases large amounts of data into a format that is easy to read and understand. That is a useful tool for work rationalization within companies in which employees perform multiple functions, for example in Lean companies, so they have very little time for reading a large number of documents to understand a particular problem or actual situation.

Advantages of using The Toyota A3 Report for solving problems are:

• methodological approach for solving problems,

• concise format for representation or for reporting to other persons,

• documenting and leaving a trace which other persons can follow and for others to understand procedures and results of solving problems,

• the common language in communication within a company,

• creating the Lean culture within a company,

• setting a basis for future changes.

In most companies, as a rule, information is made accessible but unconnected, without a clear logic. As a result, a large portion of time is spent on conversations and attempts for understanding, bringing into order, researching and analyzing data. Thereat, there is endless usage of laptop computers, but descriptions of work methodologies and principles of Lean production [3] lie on bookshelves, without a great hope that they are going to be read. The Toyota A3 Report is shaped not only to be read by the employees but to be worked upon, for example – to solve certain problems!

2. Maintenance and reliability of mining machines

Maintenance of bucket-wheel excavators on open-pit mines is directly in function of accomplishing acquired effectiveness (reliability, availability, maintainability, and safety), both on their design level as well as during their exploitation [4]. Well-chosen maintenance conception for BWECD system (Bucket-Wheel Excavator – Conveyor – Disposer System) and for BWECL system (Bucket-Wheel Excavator – Conveyor – Loader System), with well-trained personnel and maintenance management quality, impacts improvement of financial results on open-pit mines.

Bucket-wheel excavator carries a great potential risk from possible failures and accidents occurrence that is dangerous for the operative and wider environment. Reliability of bucket-wheel excavators, designed for successfully performing the objective function, determines the duration of the time interval in which they will operate without failure. Investigations [5] referred on increasing of reliability level and reliability management during a life cycle of bucket-wheel excavators have a goal to define safety precautions system of economic exploitation and achievement of complex regulations in connection with environmental protection and safety, both of operational as well as of more extensive environment.

Open-pit coal exploitation practice has proven that systems of continuous operating mode, such as BWECD and BWECL, provide maximal technological and economical results. Bucket-wheel excavators are required to have a high level of the task performing reliability. That indicates the necessity to determine the reliability quantity characteristics, among other issues, in order to adopt an adequate bucket-wheel excavator maintenance concept [6].

3. Previous reliability and safety investigations of mining machines

During the last few decades, there have been plenty of investigations with the purpose to determine productivity, reliability, and effectiveness in the stage of mining machines exploitation within the BWECD and BWECL systems and auxiliary mining machinery on open-pit mines in Serbia [1,4]. A large number of data, which substantiated for concluding about mining machines behavior during the exploitation in open-pit mines, has been collected, processed, and published and analyzed in the papers [7,8,9]. Results of investigations that are systematized within the monograph [5] refer to entire BWECD (BWECL) system. These results give the amount of breaks that was caused by the bucket-wheel excavator, self-propelled transporter (bandwagon), belt conveyor with rubber band and disposer, within open-pit mines Mining Basin Kolubara, Lazarevac, Serbia, as shown in Figure 1.

Generally, the largest number of DOWN TIMES occurs on the bucket-wheel excavator, although on conveyors with long belts DOWN TIME can be long-lasting. The following example is given for one BWECD system on open-pit mine Tamnava within MB Kolubara, which consists of rotary excavator SchRs 700, bandwagon, three conveyor belts with the rubber band that is 1.000 to 1.200 meters long and overburden disposer. Down-time structure shows that failures on the bucket-wheel excavator have caused 60% of down-times, failures of conveyor belts have caused 27% of down-times, bandwagon failure caused 9% and disposer failure has caused 4% of down-times. On the other hand, down-time structure of BWECD system on open-pit mine Tamnava, which consists of rotary i.e. bucket-wheel excavator SchRs 900 25/6 with five belt conveyors, shows that the percentage of excavator's failure and conveyor belt's failure is approximately the same. On the open-pit mine Field D, where BWECD system operates with rotary i.e. bucket-wheel excavator SRs 1200 24/4, with approximately 5 to 7 conveyor belts, the conveyor belts (because of their length) have almost double the share in failures then rotary excavators [1].

From given results of research we can perceive that breaks of BWECD system have mostly been caused by failure oc-

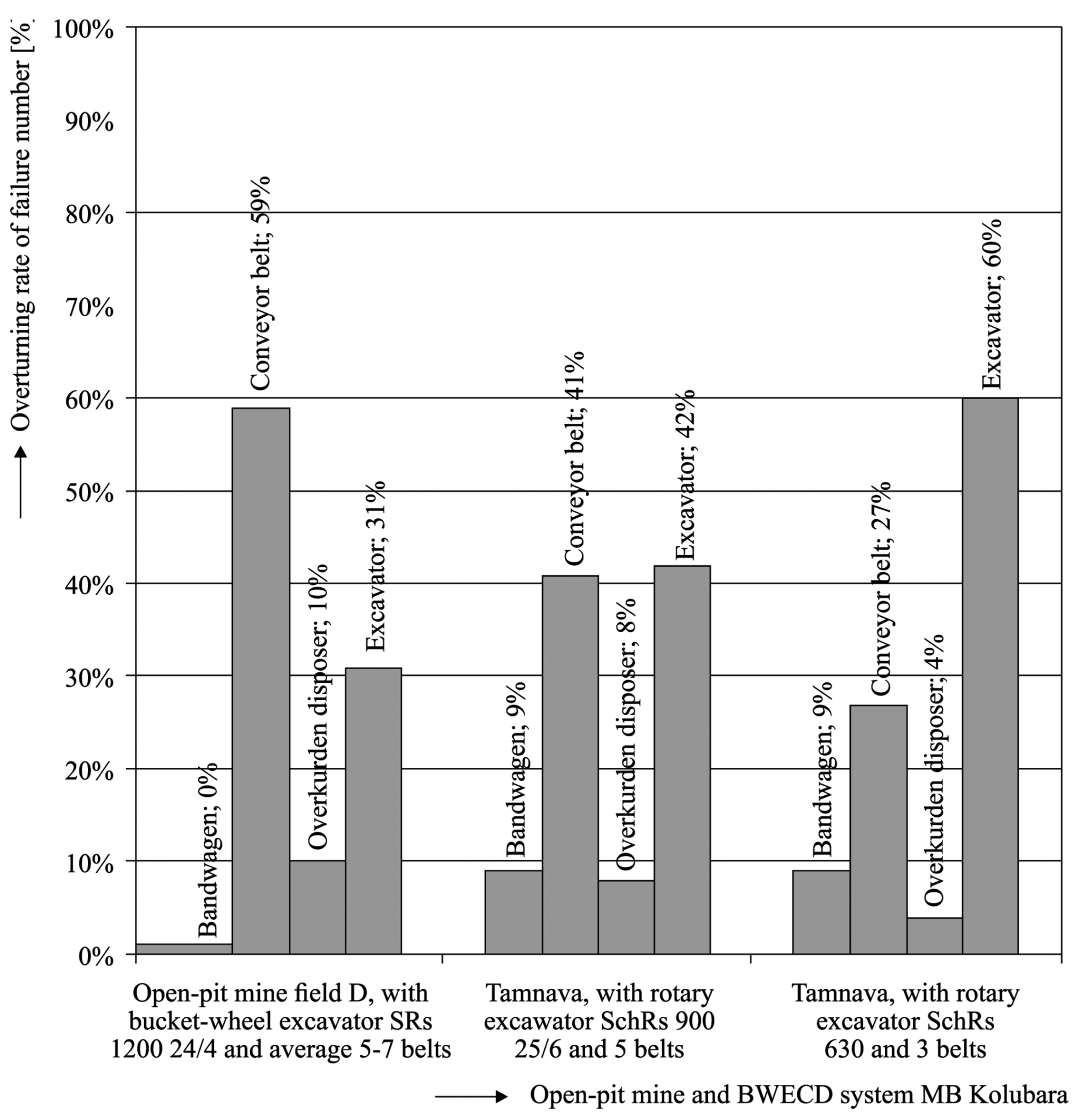


Figure 1- Overturning rate of failure number with certain BWECD systems at open-pit mines MB Kolubara, Lazarevac, Serbia [5].

currence on bucket-wheel excavators (except when there are long conveyor belt systems in question, because the length of transport cannot be influenced due to technological conditions), which leads to conclusion that with rotary excavator reliability increase to the fullest extent, the entire BWECD system reliability could be increased as well [1].

Bucket-wheel excavator (rotary excavator) is a very complex engineering system which consists of a larger number of items (subsystems, assemblies, elements). Every item represents a potential source of DOWN TIME condition, accidental by the moment of occurrence and by the time of duration. Consequences of failure occurrence on rotary excavators (bucket-wheel excavators) are productivity reduction, i.e. excavator's capacity reduction, which reflects on a reduction of open-pit mine economic effects. For those reasons, in terms of given investigations [5] the excavator's items were ranked according to priority from the aspect of reliability. Subjects of the investigation were the following items of bucket-wheel excavator (rotary excavator):

- subsystem for material excavation,
- subsystem for transportation of material on the excavator,
- subsystem for rotation of the upper construction of the excavator,
- subsystem for excavator motion.

Results of these investigations have shown that the largest number of breaks on bucket-wheel excavators occurred because of material excavating subsystem failure (up to 51%), which is shown in Figure 2. Increasing the reliability of certain items of bucket-wheel excavator is possible to increase a total excavator's reliability. Thereat, the priority should be given to those items of the excavator which reliability is the lowest.

Investigations [1,5] for reliability assessment of the bucket-wheel excavator SRs 1200 24/4 (G2), in the time period from 1.1.2006. to 31.12.2006. have been based on Dispatch Report of Electric Power Industry of Serbia, MB Kolubara, open-pit mines Field D, Zeoke. Investigations have given the data about kinds, consequences, and causes of failure, as well as data about UP TIME and DOWN TIME condition occurrence. These investigations have shown that the most reliable groups of bucket-wheel excavator SRs 1200 24/4 (G2) building are: Mechanism For the Hoist of the Rotor's Arrow (MFHRA) and Supporting Steel Structure (SSS), followed by Circular Motion Mechanism (CMM), Excavator

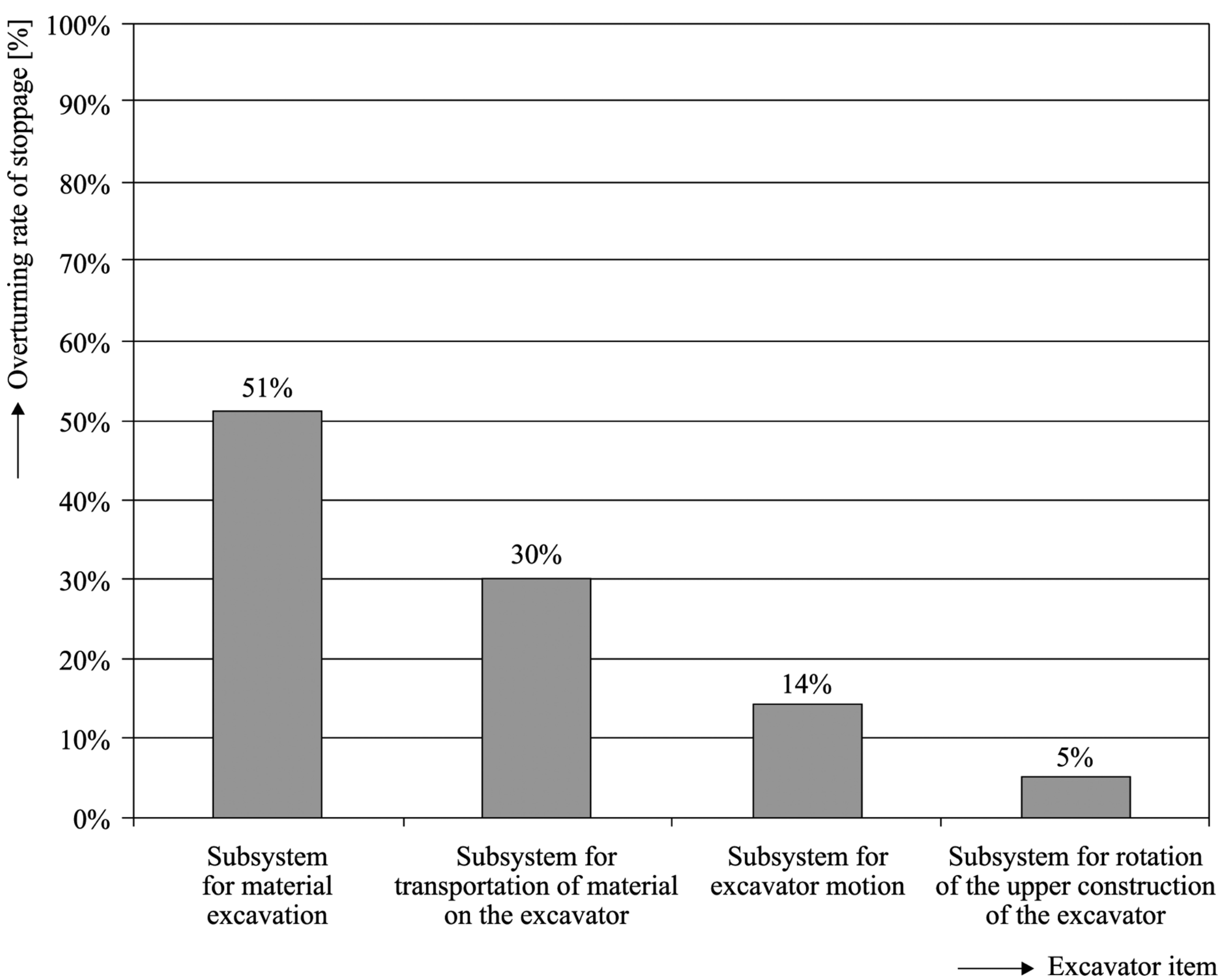


Figure 2 – Overturning rate of break with bucket-wheel excavator [5].

Transportation Mechanism (ETM), Material Transportation Mechanism (MTM), and Material Excavating Mechanism (MEM), see histogram on Figure 3.

Reliability and safety of bucket-wheel excavator items don't always have to be in positive correlation. In other words, for high reliability, there's not always a low criticality to comply with and vice versa. Criticality of bucket-wheel excavator item's failure kind is an indicator which characterizes the safety of excavator functioning. For example, some items of bucket-wheel excavator could have a high reliability but at the same time a low safety as well (i.e. high criticality), which investigations have shown [1,5]. Here, this is the case with building groups (items): Mechanism For the Hoist of the Rotor's Arrow (MFHRA) and Supporting Steel Structure (SSS). That practically means that all kinds of failures of this building group occur rarely, but when they occur it causes serious consequences for bucket-wheel excavator functioning, and that means the entire BWECD system as well. In determining reliability, along with the length of time period UP TIME, a frequency of failure occurrence plays its part as well as the level of criticality for safety determining.

Therefore, taking into consideration the consequences of potential failure kinds, as well as in due time removing their causes, enables incensement of bucket-wheel excavators safety.

The availability factor is an important complex index of reliability and maintainability of the restorable systems used in the problems of reliability and risk analysis. The method of estimating the variability of the availability factor has been developed in the paper [10] based on the statistical methods with the generation of the repeated samples (resampling). The subsystems of the bucket-wheel excavator SRs 1200 24/4 (G2) using the statistical data on the failures collected in Mining Basin Kolubara, Lazarevac, Serbia, have been used as the object of applying the method. The use of the resampling methods, i.e., the jackknife and bootstrap methods, permitted one to estimate the variability of the availability factor of the excavator subsystems.

Except for the MEM subsystem, the reliability and maintainability of the subsystems corresponds to the requirements to the reliability of the complex technical objects. The lower quartile of the scattering of the availability factor reaches 0,9977 for the most responsible subsystem MFHRA without taking into account the outliers, which corresponds to a rather high reliability event considering the range estimated using bootstrap [10]. The 90% confidence interval for the availability factor for the total system reaches [0,81; 0,94] according to the estimate based on the developed method with the median 0,90.

The digging system in some cases does not demonstrate sufficient dependability. That is caused by premature wear of the implements. In [11] the engineering formula for wear assessment was refined based on the previously known formula subject to various modes of operation. The application of this formula will help schedule preventive maintenance and inspections.

The beta factor method [12] can be used for the analysis of the failures of excavators as complex systems. It is the most simple in terms of simulation of dependent failures and further calculations. However, it has limitations of its own. For a complex system, such as an excavator, dependability must be ensured from the earliest life cycle stages through consecutive execution of specific design, process-related and manufacturing procedures [13]. The Toyota A3 Report can put some clarity into this matter.

4. Accident of bucket-wheel excavator SRs 1200 24/4 (G2) which happened on April 6th 1995 and its consequences

Bucket-wheel excavator SRs 1200 24/4 (G2) that has been assembled and put into operation in 1968 on the open-pit mine Field D, MB Kolubara, and was given internal mark G2 («Grinding Machine 2»), Figure 4.

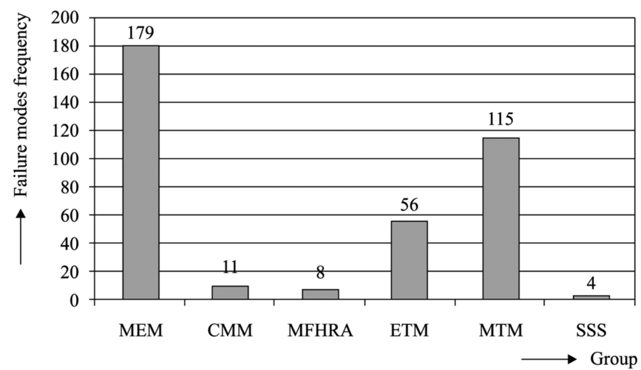


Figure 3 – Failure modes frequency of groups for bucket-wheel excavator SRs 1200 24/4 (G2) [5].

The accident of bucket-wheel excavator SRs 1200 24/4 (G2), Figure 5, has brought to great damages that had to be failure diagnosed and assessed, which was done by MB Kolubara and Kolubara Metal experts. Certain parts of the damaged machine have been transported on the assembly site in Zeoke, and some in Kolubara Metal Workshops.

The assessment of consequences is in connection with the analysis of direct and indirect damages, which can occur at a certain outcome (end state). If damages have been calculated in different units of measurement, as a result of a certain outcome, they should be reduced to one coequal damage. Besides, the end states can have a current or delayed effect. For example, during bucket-wheel excavator's SRs 1200 24/4 (G2) accident on the Field D, MB Kolubara open-pit mine, the cost analysis [1] has shown the existence of two kinds of expenses, as follows:

1. Direct expenses which include:
- designing,
- a dismantling of damaged bucket-wheel excavator,
- transportation of damaged bucket-wheel excavator,
- manufacturing and recovering of bucket-wheel excavator's items (assemblies, subassemblies, elements),
- an assemblage of the bucket-wheel excavator,
- putting into operation.

Figure 4 – Look of bucket-wheel excavator SRs 1200 24/4 (G2) before the accident appearance.

Figure 5 – Look of bucket-wheel excavator SRs 1200 24/4 (G2), after the accident which occured on April the 6th 1995.

The worth of direct costs (expenses) is: 7.500.00,00 EUR.

2. Indirect expenses, because of non-engagement of capacities on the open-pit mine during the period of bucket-wheel excavator revitalization, amount to 157.000.000,00 EUR.

This data was obtained on the basis of the price of 4.500,00 EUR of excavator's items down-time within the system (BWECD or BWECL).

Time of break duration:

9 years x 12 months x 30 days x 24 hours x 0,45 = 35.000 norm-hours

The worth of indirect costs is:

35.000 norm-hours x 4.500 EUR/hour = 157.000.000,00 EUR.

5. Analysis of bucket-wheel excavator's SRs 1200 24/4 (G2) accident cause

5.1 The «5 Why?» method application for determination of basic accident causes

The basis of the approach to the determination of quality problem causes in the Toyota company consists of asking the question «Why?» for five times during discovering the problem, which is labeled as «5 Why?». If there is the answer to the question «Why?» five times, then the basic cause and the way for its solution will be clear. The analysis of the basic maintenance problem causes based on quintuple repeating the question «Why?» is implemented into the maintenance system of the Toyota company (Lean Maintenance System) [11]. The «5 Why?» method is committed to a detailed investigation of problems and culture that lead to the basic causes of these problems. The «5 Why?» method is usually used in the Toyota for searching for the source of the maintenance problem. It describes the way of thinking needed to reach the level necessary for preventing reoccurrence of maintenance problems. This doesn't have to be the basic cause, but at least on this level, the corrective measures could be appropriate to prevent the return of the problem. In case of accident of the bucket-wheel excavator SRs 1200 24/4 (G2), the application of «5 Why?» method describes the way of thinking necessary to prevent reoccurrence of the accident, in terms shown in Figure 6.

According to data published into book [4], a significant percentage portion of every kind of failures on complex mining machines was caused by human error. They happen in the stages of designing, manufacturing, control, assemblage, exploitation and system maintenance, and also in the stage of operating, to any level of education, qualification, competence, and personnel experience. Errors of maintenance personnel consist of wrongly executing engineering system's maintenance manuals and they depend on their psychophysical state (fatigue, stress etc.), wrongly organized workplace due to the absence of a 5S system for workplaces managing [12], error in ergonomic calculations, the presence of noise on the workplace, not sufficient brightness on the workplace etc.

In the past period in Serbia, many investigations have been performed on account of determinating accidents' causes of mining mechanization on the open-pit mines for coal excavation. One such report from the investigation was published in [5]. Investigations show that errors of the personnel (operators, maintainers) play an essential role in accidents occurrence, which is confirmed by data from Table 1.

Analysis of this data shows that human errors in 87% of cases represent accidents' causes on the mining machines. Based on this, from Figure 6, we can conclude that «Bad bearing quality» in carrying roller is as well a human error i.e. personnel error in the final control, in the entry control, or even in the poorly made decision about bearings supplier choice.

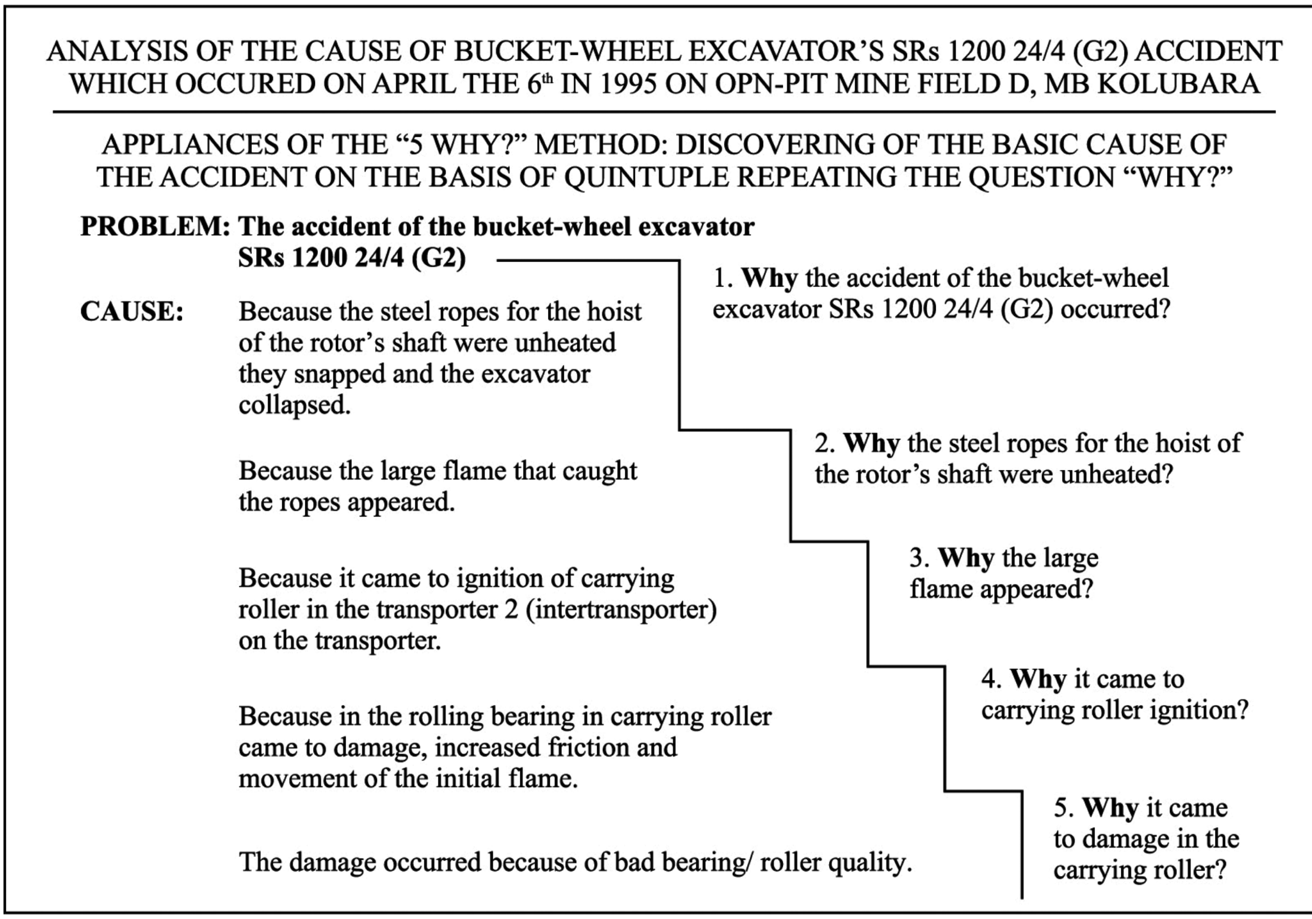


Figure 6 – Application of the «5 Why» method: Discovering of the basic cause of the accident on the basis of quintuple the question «Why».

5.2 Investigation of human errors causes at the bad bearings quality occurrence on the bucket-wheel excavator

Investigation of human errors at the bad bearings quality occurrence on the bucket-wheel excavator SRs 1200 24/4 (G2) was performed through the teamwork in Brainstorming method mode in the Kolubara Metal company. Thereat, the team acted according to all the recommendations for the Brainstorming organization [13]. The main of the recommendations were related to: team composition, the way of operating within the team, the team leader role. The team generated ideas about causes of maintenance problems which demands a solution.

Table 1. Accident share of excavators accidents causes

Cause of accident	Accident share [%]
Inadequate prepared pathway for the excavator (human error)	27
Error in parts manufacturing and excavator assembly at open-pit coal mine (human error)	22
Operator's error	18
Maintainer's error	13
Fatigue of materials, wear of equipment and corrosion processes	8
Inadequate design (human error)	7
Other miscellaneous factors	5

In these investigations, a certain rule that is suitable for composing of the initial (general) causal diagram was applied, and that rule is applicable for most of the real situations. The rule consists of that that there is almost always a certain number of categories of possible causes for some consequences (unwanted results) of the process. Solving a particular problem of bucket-wheel excavator's accident, investigations discovered from which factors (causes) and to what extent unwanted result or consequence depends on:

«Human error which provoke poorly quality of bearing carrying roller at bucket-wheel excavator SRs 1200 24/4 (G2)».

Investigations have at first determined and abstracted five samples in terms as shown in Figure 7:

- lack of training,
- inadequate information,
- lack of experience,
- carelessness,
- negligence of the danger.

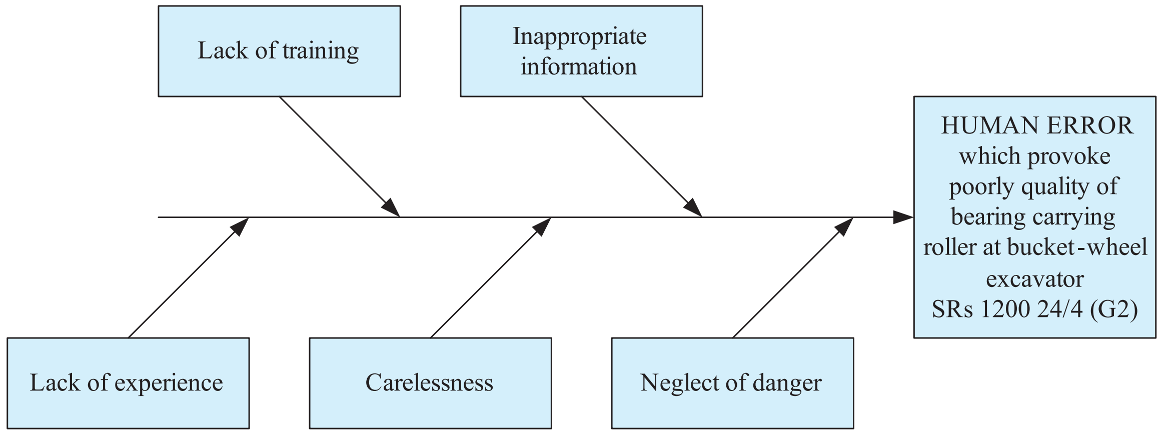


Figure 7 – Causes of the human error [6].

This problem could be further solved in a qualitative way by determining the cause of the second and higher degree of human errors.

6. Human factor in modeling of accident occurrence

6.1 The «Swiss cheese» model of human errors' causes

More often the responsibility for accidents and technical disasters are attributed to individual (personal) human errors. But in his book «Managing the Risk of Organizational Accidents» [14] psychology professor James Reason from the University of Manchester, in detail studies a problem whether one human error can cause the accident if we don't take into account cases of obvious sabotage or terrorist activities. It is proven that the entire array of hidden and undiscovered on time errors leads to an accident. Safety culture and problems which cause this array of errors, as usual, are called «human factor» [15]. After all, exactly the human factor forces the operator or maintainer of the engineering system to make wrong decisions.

Why there are accidents happening, which conditions are causing them, which factors contribute to their occurrence? Accidents, as a rule, occur not as a result of some individual error but they are a consequence of hidden, undiscovered on time damages and failure kinds that are cumulating on each other and could bring to an unwanted array of events. Hence, the largest number of accidents and unfortunate incidents are a consequence of an array of events.

That kind of accident attribute is described the best by the «Swiss cheese» model, which was developed by James Reason [16] and which illustrates various kinds of human «contribution» to engineering systems' accidents. Reason's «Swiss cheese» model explains what way people contribute to working ability disturbance of complex and mutually connected engineering systems, which leads to accidents.

If the state of a certain engineering system is shown in the shape of a slice of cheese with holes, in that case, and depending on the time of manifesting the kinds could be classified into two:

- hidden failure kinds (hidden defects),
- active failure kinds (active defects).

Hidden defects (hidden kinds of failures, hidden conditions, terms, regimes) represent the result of a decision or procedures of work which has been performed long before the accident (occurrence). These defects and their consequences can stay undetected for a long period of time (for many years). Such errors (failure kinds) usually occur on the decision making level and determining rules and regulations or on the level of operating management i.e. persons further from an occurred accident, as in time as well in space. For example, a decision about merging maintenance personnel from two different open-pit mines (two enterprises) without training that personnel for standardized procedures for maintaining the mining machines represents a clear example of hidden defect (hidden kind of failure).

Active defects (active kinds of failure, active errors) represent mistakes or disturbances which immediately (without delay) have an unfavorable effect. Such errors are usually made by operators or maintainers of mining machines. Actions of operators or maintainers which moves the lever for lifting the upper excavator's construction instead of moving the lever for excavator's rotation sets an explicit example for this kind of error (failure).

7. «The Black Swan» event risk theory

7.1 «The Black Swan, The Impact of the Highly Improbable» [16]

Mathematician and economist Nassim Nicholas Taleb, in his book «The Black Swan, The Impact of the Highly Improbable» [17] from 2007, has proposed a concept of «Black Swans» – unexpected (unpredictable) and significant (comprehensive) phenomenon that essentially change the course of history. That concept includes wars, economic crisis, internet appearance etc.

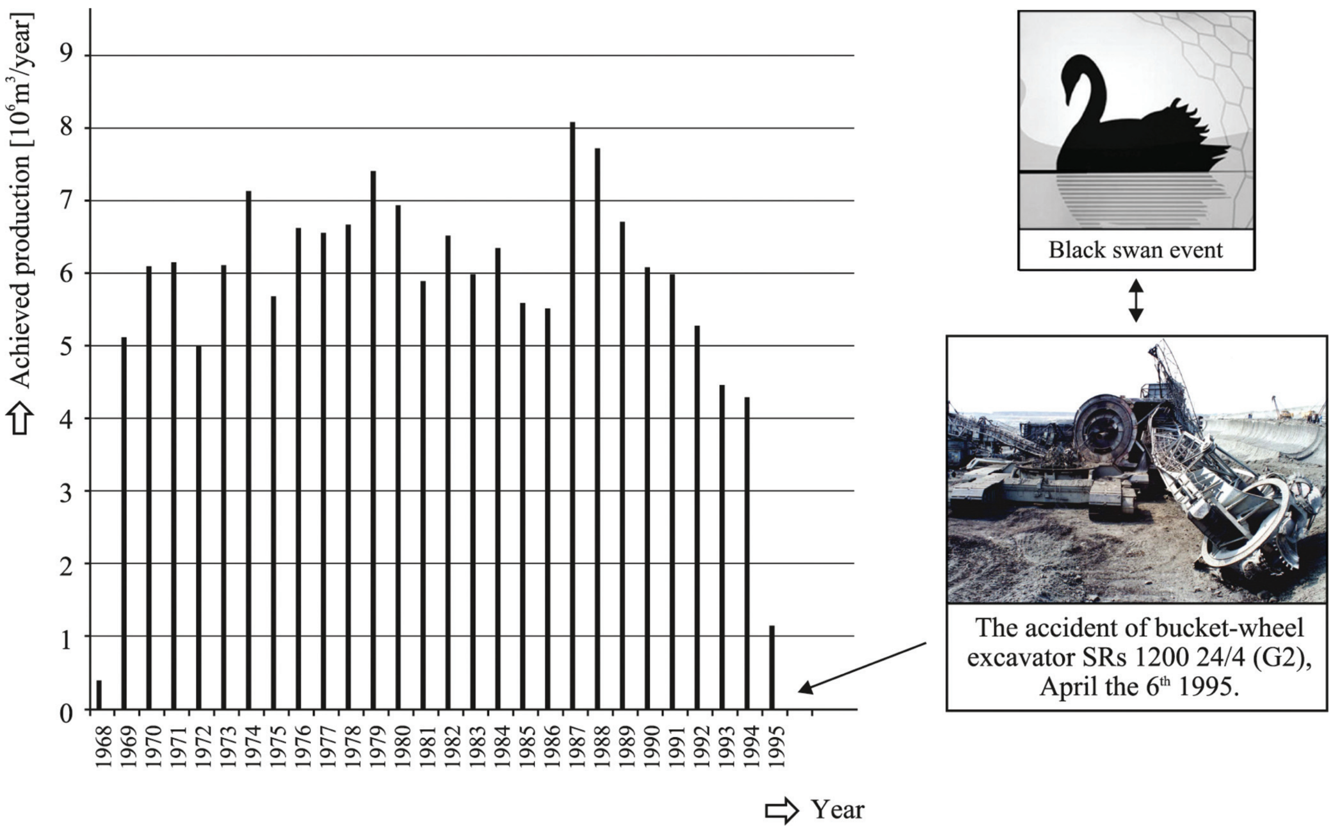


Figure 8 – The accident of bucket-wheel excavator SRs 1200 24/4 (G2) – typically «Black Swan» event.

It is impossible to predict them but we should know how to live with them.

By its character «Black Swans» couldn't be predicted because of similar events haven't ever happened before. However, it is possible to study how companies and people who have survived some disasters coped with their consequences. Such an analysis could help the company to be prepared for strategy making that help them stand on their feet after extraordinary disasters (technical disasters such as mining machines accidents) as soon as possible and with minimal damage.

Nassim Taleb has suggested the risk theory «Black Swan» which considers events that are hard to predict and rare events which have significant consequences. «Black Swan» is a metaphor which describes surprising events with great consequences.

«If you have seen only the white swans your entire life, that doesn't mean that black swans do not exist».

- writes Nassim Taleb in his book «The Black Swan, The Impact of the Highly Improbable» [17].

7.2 Criteria for «Black Swan» events and bucket-wheel excavator accidents

The accident of bucket-wheel excavator SRs 1200 24/4 (G2) which happened on April the 6th in 1995. has all the characteristics i.e. satisfies the criteria of «Black Swan» events. That what Nassim Taleb calls «Black Swan» – that is an event which has a following three characteristics:

- the event is unexpected,
- the event causes great consequences,
- after the occurrence, retroactively, the event has a reasonable explanation as if the event has been expected.

Until the accident that happened on April 6th in 1995, this bucket-wheel excavator has excavated over 160 million m^3 of overburden. How large emptiness was made due to the failure of this excavator could be seen by the production in years that moved from 5 to 7 million m^3 of overburden (Figure 8).

Since those accidents could not be predicted, the task of the owner of dangerous objects is to assure decrease of its negative impact on the personnel, population and environment. In that regard, the task of this country is to compel the owners of such objects to strictly carry out directions, regulations and directives of normative documents in safety department [18].

As far as engineering systems reliability and their complexity increases, the «human factor» part increaes as well. Therefore, safety culture education, making of non-punishment manufacturing environment stays the most important task of theory and practice for engineering systems safety.

8. Toyota A3 Report as a problem-solving tool

Making The Toyota A3 Report is teaching every employee in Toyota, first of all, their direct supervisors. There is a universal review of states and recommendations which

TOYOTA A3 REPORT

SOLVING THE PROBLEM

THE ACCIDENT OF BUCKET-WHEEL EXCAVATOR SRs 1200 24/4 (G2), WHICH OCCURRED ON APRIL THE 6th 1995 ON OPEN-PIT MINE FIELD D, MB KOLUBARA, ELECTRIC POWER INDUSTRY OF SERBIA

Plan

INITIAL INFORMATION

APPEARANCE OF THE BUCKET-WHEEL EXCAVATOR SRs1200 24/4 (G2) DURING OVERBURDEN EXPLOITATION, BEFORE THE ACCIDENT

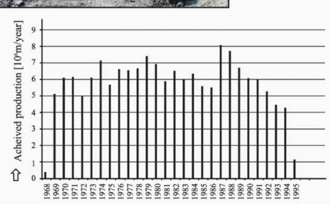
THE MAIN CHARACTERISTICS OF THE BUCKET-WHEEL EXCAVATOR SRs 1200 24/4 (G2) BEFORE THE ACCIDENT OCCURRENCE

Characteristic of the excavator	Values
Theoretical capacity	3.456 m³/h
Rotor drive power	400 kW

SITUATION CONDITION

APPEARANCE OF THE BUCKET-WHEEL EXCAVATOR SRs 1200 24/4 (G2), AFTER THE ACCIDENT WHICH OCCURED ON APRIL THE 6th 1995

ACHIEVED PRODUCTION (AMOUNTS OF EXCAVATED OVERBURDEN). BY YEARS, SINCE PUTTING INTO OPERATION IN 1968 UP TO ACCIDENT OCCURRENCE IN 1995



GOAL

GOALS OF THE BUCKET-WHEEL EXCAVATOR SRs 1200 24/4 (G2) REVITALIZATION PROJECT

Goals of the Revitalization program for the bucket-wheel excavator SRs 1200 24/4 (G2) damaged in the accident that occured on april the 6th 1995: revitalization of the bucket-wheel excavator, modernization of the bucket-wheel excavator, increasin the capacity of the bucket-wheel excavator, enabling to use the excavator for overburden as well as for coal.

CAUSE-EFFECT ANALYSIS

DAMAGE BECAUSE OF THE OCCURED ACCIDENT OF THE BUCKET-WHEEL EXCAVATOR

Direct costs of the accident	Indirect costs of the accident
Designing, dismantling, transportation of the excavator, manufacturing, and regeneration of items, assemblage, putting into operation: 7.500.000,00 euros	Because of capacity non-engagement on open-pit mine during the revitalization of the bucket-wheel excavator of 9 years: 157.000.000,00 euros

ANALYSIS OF THE CAUSE OF BUCKET-WHEEL EXCAVATOR'S SRs 1200 24/4 (G2) ACCIDENT WHICH OCCURED ON APRIL THE 6th IN 1995 ON OPN-PIT MINE FIELD D, MB KOLUBARA

APPLIANCES OF THE "5 WHY?" METHOD: DISCOVERING OF THE BASIC CAUSE OF THE ACCIDENT ON THE BASIS OF QUINTUPLE REPEATING THE QUESTION "WHY?"

PROBLEM: The accident of the bucket-wheel excavator SRs 1200 24/4 (G2)

CAUSE:

1. **Why** the accident of the bucket-wheel excavator SRs 1200 24/4 (G2) occurred? — Because the steel ropes for the hoist of the rotor's shaft were unheated they snapped and the excavator collapsed.
2. **Why** the steel ropes for the hoist of the rotor's shaft were unheated? — Because the large flame that caught the ropes appeared.
3. **Why** the large flame appeared? — Because it came to ignition of carrying roller in the transporter 2 (intertransporter) on the transporter.
4. **Why** it came to carrying roller ignition? — Because in the rolling bearing in carrying roller came to damage, increased friction and movement of the initial flame.
5. **Why** it came to damage in the carrying roller? — The damage occurred because of bad bearing/ roller quality.

Do, Check, Act

CORRECTIVE MEASUREES

TENDER FOR THE REVITALIZATION OF THE BUCKET-WHEEL EXCAVATOR SRs 120024/4 (G2)

Since putting into operation in 1968, the excavator have excavated over 160 millions of m3 of overburden. Noticing the need for compensation of this capacity which shortage have further indangered manufacturing on the open-pit mine Field D, Electric Power Industry of Serbia have decided to open an international tender for revitalization of the bucket-wheel excavator SRs 1200 24/4 (G2), with help of favorable loan from the German government. For the realaization of this project the loan from KFW bank was provided designating value of 7.588.641,00 euros.

EXCAVATOR REVITALIZATION CONTRACTORS

As the main contractor on the tender, the job of bucket-wheel excavator SRs 1200 24/4 (G2) revitalization got the German company FAM from Magdeburg which emplyed the main subcontractors:

- for the mechanical part including intensive engineering, revitalization, manufacturing and assamblage – Kolubara Metal company from Vreoce,
- for designing, manufacturing and supervision over electrical part assemblage – ABB company from Cottbus.

THE EXCAVATOR REVITALIZATION PROCESS

The excavator revitalization process was developing in two main directions:

- revitalization of existing equipment and construction, which was evaluated as usable, inside workshops of the Kolubara Metal company,
- manufacturing of new equipment according to basic engineering of FAM and ABB for electrical equipment.

THE EXCAVATOR ASSEMBLAGE PROCESS

The excavator assemblage process had some key stages:

- processing of radial axial bearing on the moving carusel lathe,
- platform rotation,
- lifting and fitting of a pilar of mass more than 80 t and at the same time 4 hoists were used and one of them had carrying capacity of 300 t,
- lifting the counterweight shaft along with E-containers with buit-in electrical equipment of total mass over 110 t,
- lifting and contraining of rotor shaft,
- installation of 14 buckets rotor,
- installation of winches for hoisting rotor shaft and supporting ropes,
- equipping and reliance of transhipment device.

About 115 t of electrical equipment, cables and axiliary construction was embedded on the bucket-wheel excavator, during the installation.

EFFECT CONFIRMATION

REVITALIZED BUCKET-WHEEL EXCAVATOR SRs 1201 (YEAR OF 2004.)

TECHNICAL BENFIT OF EXCAVATOR`S REVITALIZATION

The maiin characteristics of revitalized bucket-wheel excavator SRs 1201 24/4 (G2)

Excavator characteristic	Values
Theoretical capacity	4100 m³/h
Drive power on the rotor	630 kW
Triple drive of rotary motion of upper construction	
Completely new steel structure of the upper construction	
First time in Serbia a container principle was applied for implementing electrical equipment	
Frequently adjusted propulsin / drive	
The latest solutions in operating section	

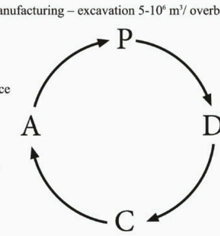
CONTROL ACTIONS

PDCA CYCLE OF CONTINUOUS IMPROVEMENT OF MANUFACTURING PROCESS

Goal: Manufacturing – excavation 5-10⁶ m³/ overburden in year

Application of maintenance concept:

- Current maintenance
- Servising maintenance
- General repair
- Predictible maintenance



Supervision, process managing and registering of realised manufacturing - excavated overburden within a year.

Comparison of realised manufacturing – excavated overburden with goal i.e. planned manufacturing and suggestion for a kind of action (corrective measures)

Figure 9 – The Toyota A3 Report view for the problem solving: «The accident of bucket-wheel excavator SRs 1200 24/4 (G2), which occured on April the 6th 1995».

are used during training for solving problems and for shaping The Toyota A3 Report. Here we give some parts of this review [19].

A. Recommendations for solving problems:

• evaluate the situation relying on facts,

• follow (monitor, observe) the problem,

• concentrate on one problem (one Toyota A3 Report – one problem),

• watch deviations where the problem appears,

• study in detail the cause and analyze all the facts and data,

• if necessary, take temporary measures to locate the problem,

• detect (determine) the main cause,

• develop corrective measures, give tasks and determine deadlines for their realization.

B. Recommendations for shaping The Toyota A3 Report:

• distribute the time so the situation can be evaluated entirely (use a wide range of information, rely on the facts and not on opinions, take into consideration longterm effect),

• orientate towards concrete listeners; Take into consideration their needs and level of understanding of the situation,

• coordinate showing material with values of the company and its philosophy,

• avoid using a lot of words, use more schemes, graphics and other ways of clear information representation,

• every word should be from the field of work; Express yourself precisely and avoid slang terms,

• evaluate the clarity of material presentation; Does shaping of report helps to the understanding of its content?

An interesting analogy could be drawn between organizing a space, based on principles of the «5S Method» [12], in the Toyota factories while making The Toyota A3 Report. In a Lean Enterprise, it is unacceptable to overload space with a surplus of supplies because they represent – loses [19]. Rational usage of space is proof of making an effective additional value. Unnecessary material decreases safety, makes mess and disturbes discovering of standard deviation. On a similar way, shaping The Toyota A3 Report it is important not to allow losses: redundant words, extensive explanations, unnecessary schemes, which disturbs an essence to be seen. In that way, maximal effectiveness of adding the value is provided. The loss in documents blurs the basic idea and often leads to people losing the key moment from their sight.

The Toyota A3 Report and the way of their preparation make communication clear and operational, besides, The Toyota A3 Reports contribute to continual development. So, if making of The Toyota A3 Report brought to standards change or to increase of knowledge circumference – the database is renewed. The Lean Thinking [20] requires learning a lesson from solving problems (not only repairing of a complicated situation) and The Toyota A3 Report helps to such training.

9. The Toyota A3 Report and PDCA cycle

Aspiration of Toyota towards experiments lies in the base of all the standardized operations and processes which represent the part of everyday work. The Toyota company converted the cycle «Plan – Do – Check – Act» (PDCA) i.e. process of continual work improvement which is widely applied in different areas of business, into unique methodology «The Toyota A3 Report». It reflects the culture of Toyota [21] where the ability to solve problems is considered to be the most important quality of an employee which is formed from the beginning of his career and is continuously improving in the training process.

Akio Matsubara, former executive director for personnel management and now the president of Toyota Gosei North America Corporation sais [22]:

«In the first ten years of a person working in the Toyota company, we repeat multiple times a three-phase cycle of training which develops the ability and skill of solving problems in a man. The entire personnel develops inside itself a skill of problem overcoming which represents the basic approach in the Toyota working. The philosophy of the Toyota company implies: overcoming the problem, the employee is giving a contribution to the realization of cooperative politics, focused on satisfying the customer demands. We advise our people that the skill of overcoming the problem is necessary for achieving success in Toyota».

The Toyota A3 Report is read from top to down, from left to right and is used for solving problems, updating states and suggestions. The Toyota A3 Report follows the methodology of the Deming cycle of continuous improvement PDCA.

10. The Toyota A3 Report about solving problems of «Bucket-wheel excavator SRs 1200 24/4 (G2) accident»

10.1 Practical solving of the problem

The process of solving problems occurred during work can be described by the logical course that follows the Deming cycle of continuous improvement PDCA, and the Toyota A3 Report contains the following seven sections (steps): initial information, current state, goal, cause-consequence analysis, corrective measures, confirmation of effect, following actions. This process is defined on the basis of observations conducted in Toyota Company and published in the book [2].

The final look of The Toyota A3 Report about solving problem of an accident on bucket-wheel excavator SRs 1200 24/4 (G2) which happened on April 6th in 1995 on open-pit mine Field D, MB Kolubara, Electric Power Industry of Serbia, which was previously partially analyzed in the paper [23], is shown in Figure 9.

11. Conclusions

The Toyota A3 Report, as a flexible mean for solving problems, occurred during work, was adjusted for terms of mining machines operation (excavators, transporters, depositors etc.) on open-pit mines. Considering the situation that there is a large number of available data and information about processes that are highly complexed, such as the process of coal and overburden exploitation on open-pit mine, there is a possible consumption of a large amount of time for their finding. Because of that, the way of documenting in the form of the Toyota A3 Report has a great significance for speeding up communication and removing a loss of time in work processes. That represents an important step at implementing Lean production and Kaizen concept on the open-pit mine in Mining Basin Kolubara, Lazarevac, Electric-power Industry of Republic of Serbia

There are potential shortcomings in the Toyota A3 Report which relate to solving a particular problem of bucket-wheel excavator SRs 1200 24/4 (G2) accident. It seems that it is overloaded with information and complicated. That is a normal reaction considering such a complex document because there is a great volume of information (data) concentrated on a small place. The immaculate Toyota A3 Reports do not exist. Every time when there is a need for making such a report – there is a way to improve its content or form.

References

[1] Papic L., Pantelic M.: Implementation Methodology for Risk Minimization into Maintenance Process of Production System at Coal Mines, Report of Contract No. 4617 (In Serbian), DQM Research Center – Kolubara Metal Company, Prijevor – Vreoci, Serbia, 2009, 468 p.

[2] Sobek II Durward K., Smalley A.: Understanding A3 Thinking. A Critical Component of “Toyota”’s PDCA Management System, CRC Press, Tailor and Francis Group, New York, 2008, 173 p.

[3] Krafcik J. F.: Triumph of the Lean Production System, Sloan Management Review, Vol. 30, No.1, 1988, pp. 41-52.

[4] Dhillon B. S.: Mining Equipment Reliability, Maintainability and Safety, Springer, London, 2008, 211 p.

[5] Pantelic M., Papic L., Aronov J.: Maintainability and Safety Engineering of Excavator Units (In Serbian), The Library DQM Monographs Quality and Reliability in Practice, Monograph No. 5, DQM Research Center, Prijevor, Serbia, 2011, 289 p.

[6] Papic L., Aronov J., Pantelic M.: Safety Based Maintenance Concept, International Journal of Reliability, Quality and Safety Engineering, Vol. 16, No. 6, 2009, pp. 1-17.

[7] Papic L., Pantelic M., Aronov J., Verma A. K.: Statistical Safety Analysis of Maintenance Management Process of Excavator Units, International Journal of Automation and Computing, 7(2), 2010, pp. 146-152.

[8] Papic L., Pantelic M.: Maintenance-Oriented Safety Control Charts, International Journal of Systems Assurance Engineering and Management, 5(2), 2014, pp. 149-154.

[9] Papic L., Pantelic M., Aronov J.: System Safety Analysis Via Accident Precursors Selection, In: Dynamics of Information Systems, Computational and Mathematical Challenges, Springer Proceedings in Mathematics and Statistics, Volume 105, Springer International Publishing Switzerland, 2014, pp. 179-204.

[10] Papich L., Gadolina I., Zainetdinov R.: Interval Estimation of the Availability Factor of the Bucket-Wheel Excavator Based on Bootstrap Modeling, Journal of Machinery Manufacture and Reliability, Vol. 45, No. 6, 2016, pp.531-537. // Папич Л., Гадолина И.В., Зайнетдинов Р.И.: Интервальная оценка коэффициента готовности роторного экскаватора на основе бутстреп-моделирования, Проблемы машиностроения и надёжности машин, № 6, 2016, с. 55-62.

[11] Gadolina IV, Pobegaylo PA, Kritsky DYu, Papic L. Refinement of the engineering practice of evaluation of the wear rate of excavator implement components. Dependability 2019;1:18-23.

[12] Antonov AV, Chepurko VA, Cherniaev AN. Research of the beta-factor model of accounting for common cause failures. Dependability 2019;2:9-17.

[13] Pokhabov YuP. Problems of dependability and possible solutions in the context of unique highly vital systems design. Dependability 2019;19(1):10-17.

[14] Weigand B., Langmaack R., Baumgarten T.: Lean Maintenance System, Zero Maintenance Time – Full Added Value, Lean Management Institute, Aachen, 2005, 165 p.

[15] Hirano H.: 5S for Operators: 5 Pilars of the Visual Workplace, Productivity Press, New York, 1996, 160 p.

[16] Dale B. G.: Managing Quality, Blackwell Publishers Ltd., Oxford, 1999, 495 p.

[17] Reason J.: Managing the Risks of Organizational Accidents, University of Manchester, 1997, 266 p.

[18] Dhillon B.S.: Safety and Human Error in Engineering Systems, CRC Press, Taylor and Francis Group, Boca Raton, 2013, 260 p.

[19] Reason J.: Human Error, Cambridge University Press, Cambridge, 1990, 302 p.

[20] Taleb N.N.: The Black Swan, The Impact of the Highly Improbable, Random House, New York, 2007, 369 p.

[21] Aronov J., Papic L.: Reliability and Safety Management of Engineering Systems Through the Prism of Black Swan Theory, In: System Reliability Management, Solutions and Technologies, CRC Press, Taylor and Francis Group, Boca Raton, 2018, pp. 103-112.

[22] Morgan J.M., Liker J.K.: The Toyota Product Development System. Integrating People, Process and Technology, Productivity Press, New York, 2006, 440 p.

[23] Womack J. P., Jones D. T.: Lean Thinking. Banish Waste and Create Wealth in your Corporation, Free Press, New York, 2003, 396p.

[24] Liker J. K., Hoseus M.: Toyota Culture. The Heart and Soul of the Toyota Way, McGraw Hill, New York, 2008, 592 p.

[25] Osono E., Shimizu N., Takeuchi H., Dorton J.K.: Extreme Toyota, Radical Contradictions That Drive Success at the World's Best Manufacturers, John Wiley and Sons Inc., New York, 2008, 288 p.

[26] Papic L., Pantelic M.: A3 Report as an Effective Tool for Excavator Accident Problem Solving (In Serbian), Proceedings of 21st DQM International Conference on Dependability and Quality Management, ICDQM-2018, Prijevor, Serbia, 2018, pp. 3-13.

About the authors

Ljubiša Papić, DR.SC in Engineering, Professor, Director, Research Center of Dependability and Quality Management (DQM), Čačak, Serbia, e-mail: dqmcenter@mts.rs

Irina V. Gadolina, Candidate of Engineering, Associate Professor, Senior Researcher, Federal State Publicly Funded Scientific Establishment Mechanical Engineering Research Institute of the Russian Academy of Sciences, Moscow, Russia, e-mail: gadolina@mail.ru

Milorad Pantelić, Doctor of Engineering, Director, Enterprise Kolubara Metal, Lazarevac, Serbia, Associate Professor, Faculty of Technical Sciences, University of Kragujevac, Čačak, Serbia

Neda Papić, BSc in Industrial Engineering, MSc student in Industrial Engineering. Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

The authors' contribution

Ljubiša Papić substantiated the expediency and requirement for the application of the Toyota A3 Report in enterprise operations management in the mining industry. Using a specific example of bucket-wheel excavator failure, the stages of analysis are shown.

Irina V. Gadolina performed a more detailed analysis of the information on the current dependability status of the excavator in terms of the variability of the availability factor, built confidence intervals of this characteristic.

Milorad Pantelić oversaw the recovery operation after the excavator accident. He collected the information on the failure of the excavator implements and its subsystems. He also ensured the delivery of the repair operations schedules.

Neda Papić ensured the presentation of information in a publishable from. She was also responsible for the design and composition of the paper.