FMEA method in operational reliability of forest harvesters

Abstract: The article deals with the research of operational reliability of forest felling machines by FMEA method (Failure Mode and Effect Analysis). It describes collection of operational data and its analysis. It explains the procedure of realization for the method FMEA in the organization. Harvesters John Deere 1070D in the Company Lesy SR B. Bystrica were chosen for this research. The research was held in real operational conditions. Application of the FMEA method allows flexibility in case of unexpected situations and optimization of human potential abilities. FMEA tool is a tool preventing outages operational reliability and preventive tool for ensuring the maintenance of facilities. The method of information analysis mentioned below is simple and precise enough for implementation in real working conditions.

Keywords: FMEA method, operational reliability, maintenance, forest machines

1 Introduction

Forestry is the source of the most used material for the people. Forest harvesting is process of achievement wood by cutting. Harvesting can be done by axe, chainsaw or by harvester [2, 8].

There are several methods of information processing regarding to reliability parameters but some of them are very difficult and in standard operational conditions are not usable. Risk management requires the development of optional risk management plans for situations that may arise and trigger the implementation of appropriate corrective actions that we plan when a risk occurs, and this is detected and diagnosed with the cause of the risk [11]. The method of information analysis mentioned below is simple but precise enough for implementation in real working conditions [12]. For all objects it is necessary to record the time to failure, cycles to failure, transport distance, mechanical stress or similar continuous or discrete parameters [20].

Failure mode and effect analysis – FMEA

Failure mode and effect analysis FMEA was developed in accordance with STN IEC 60812 - Methods of system reliability analysis, method of analysis of methods and consequences of faults (FMEA). The FMEA method has been applied to all failures (two-state failure model) that have been repeatable more than once. The FMEA method was carried out by successive systematic filling of the FMEA form for the construction of the observed machine type.

When deciding on the scope and mode of FMEA application in a particular system and on a particular element, it was necessary to consider for which specific purposes the method is to be used. The required degree of awareness of undesirable phenomena, disturbances and their consequences has also to be considered. Based on these considerations, it was possible to decide on the depth of analysis at a particular system level (system, subsystem, part and element).

The purpose of the FMEA was to analyse potential errors / failures in a particular system over the selected life span of the system so that corrective measures can be taken to reduce the risk that errors arise. The analysis begins with the selection of the lowest level for which sufficient information is available. Subsequently, different types of failures can occur in the table, which can occur for each element of the observed level. Elements are judged individually, with the consequence of failure of each of them being considered as a mode of failure being superior to a...
higher level, the malfunction of the spark plug is considered to be a failure of the engine.

The condition for applying this procedure is knowledge:

• system structures,
• operating conditions,
• environmental conditions and other specific working conditions.

The mode of disorder is thus defined as the phenomenon through which the disorder is observed.

FMECA uses the following critical error scale:

IV: a phenomenon that could cause failure of the system's major functions resulting in significant damage to the system or its surroundings, or death, serious harm to human health,

III: a phenomenon that could cause failure of the system's core functions resulting in significant damage to the system or human health,

II: the detrimental effect of the system, but without its serious damage to, or endangering, the life or health of humans,

I: the detrimental activity of the system with its negligible damage or threat to life or human health.

The result of the analysis of individual elements is summarized in the network graph of criticality [21].

FMEA method is a step-by-step approach for identifying all possible failures in the design, a manufacturing or assembly process, or a product or service [10]. FMEA may deliver information about: where errors could occur and where risks are hidden. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service [3].

Failure Mode and Effect Analysis (FMEA) is a quantitative analytical method for no-failure operation with inductive approach, its content is focused on study of potential types of failures (e.g. materials, components, devices) which can exist in every part of the system and defining evaluation of possible impacts of every type on the closest functional higher level of the system. Repetition of this procedure leads to possible failures of the system. It is usable for analysis of systems consisting of thousands parts. It is not usable for systems with backup, their combinations and dependencies and also it is not possible to use for complex strategies of maintenance [9, 19].

Types of FMEA analysis are:

• System – focused on global system functions,
• Design – focused on components and subsystems,
• Process – focused on production and assembly processes,
• Service – focused on maintenance functions (service),
• Software – focused on software functions [20].

3 Other methods

A few more risk and hazard analysis methods exist in addition to FMEA. For example, there exist a number of low-level risk analysis methods that analyze systems and subsystems at lower level considering only systems and their components. Some of the most well-known methods are fault tree analysis (FTA) [1] and hazard and operability study (HAZOP) [13].

FTA is a top-down hazard analysis approach. It is a deductive approach and carried out by repeatedly asking: how can this (a specific undesirable event) happen, and what are the causes of this event? It involves a logical diagram that shows the relation between the system components and their failures. [18] presented a review of the research performed on FTA with its advantages and shortcomings. Because FMEA is restricted to analyze only a single cause of an effect, FTA augments the feasibility of FMEA. An analysis using FTA in combination with FMEA may support an assessment considering, for instance, all security risks [14].

4 Materials and Method

FMEA method has a strictly given structure in several steps, similar to the literature [4–6].

The first step of FMEA application is fulfilling the FMEA table heading with machine identification data. The fulfilled data are:

• MODEL – TYPE: model and type of the observed/tested machine,
• No. of the document (object/machine): No. of the document regarding to evaluation of the group/component in the machine,
• Name of the component (object/machine): name of the component, component group which are the scope of analysis,
• Technical changes: No. or a code of realized technical changes,
• Author: name and surname of the person who realized the analysis,
• Date of processing the analysis,
• Date of revision,
• Contractor (subcontractor) of the analysed object or service, etc.

The second step of FMEA application is evaluation of the current condition. The fulfilled data are:
• System (mark): description of the place where the failure occurs.
• Failure expression: there are mentioned all possible kinds of failures which can occur.
• Possible impacts of the failure: regarding to operation.
• Possible reasons of the failure: all possible reasons of the failure regarding to the design and construction of the component or the group of components.
• Method of detection: given checking activities which are recommended to mitigate the failure or to eliminate the failure.
• Occurrence: there is realized estimation of probability or No. of failure occurrence treated in classes from 1 to 10 according to classification Table 1. Failure occurrence means the probability or frequency how often the failure can occur due to taken actions (measures).
• Meaning: there is created estimation of significance for every failure regarding to classification in classes 1-10 according to the classification Table 2. The machine or device can be reclassified only according to the meaning of the failure based on the construction solution. It is not possible to influence due to standard checks. The failure classification is based on the failure impact.
• Detectability: there is realized estimation of probability of detections, reasons of failure occurrence earlier than the product is taken by the user and it is defined in classes from 1 to 10 (see Table 3).
• Level of risk/priority (LR/P): calculation of LR/P is given as multiplication of estimate classes of occurrence, importance and detectability. It was defined individually for every identified and possible failure. It is used for definition of all preferred identified pos-

Table 1: Failure occurrence

<table>
<thead>
<tr>
<th>Classification criteria for failure occurrence</th>
<th>Frequency estimation</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is not probable that the failure can occur.</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Very low: the failure can occur very rarely.</td>
<td>1/5 000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1/2 000</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1/1 000</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1/500</td>
<td>5</td>
</tr>
<tr>
<td>Medium: the failures can occur randomly and rarely.</td>
<td>1/200</td>
<td>6</td>
</tr>
<tr>
<td>High: the failures can occur very often.</td>
<td>1/100</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1/50</td>
<td>8</td>
</tr>
<tr>
<td>Very high: the probability of failure occurrence is very high and almost certain.</td>
<td>1/20</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1/10</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2: Failure meaning

<table>
<thead>
<tr>
<th>Criteria for classification failure meaning</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible: the origin of the failure does not influence the ability of the system or product i.e. the user does not record the presence of the failure.</td>
<td>1</td>
</tr>
<tr>
<td>Low: the failure makes little difficulty to the user, there are not considered any failures of the system or the product</td>
<td>2</td>
</tr>
<tr>
<td>Medium: the failure creates difficulties to the user by decreasing comfort during using, the failure makes difficulties during manipulation and controlling. The user records certain difficulties regarding to the properties of the product.</td>
<td>4</td>
</tr>
<tr>
<td>High: the failure creates certain difficulties to the user or it causes significant damage, bad properties of the product, it does not influence the safety of the product.</td>
<td>7</td>
</tr>
<tr>
<td>Very high: the failure influences the safety of the product, its ability for operation regarding to legal requirements.</td>
<td>9</td>
</tr>
</tbody>
</table>
Table 3: Classification of failure detectability

<table>
<thead>
<tr>
<th>Criteria for classification of failure detectability</th>
<th>Transmission of failure to the user [%]</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high: probability that the failure could be detected by checking or assembly</td>
<td>0 to 5</td>
<td>1</td>
</tr>
<tr>
<td>High: probability that the failure transmit to the user without detection – according to probability of failure transmission to the user</td>
<td>6 to 15</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>16 to 25</td>
<td>3</td>
</tr>
<tr>
<td>Medium: probability that the failure is transmitted to the user without detection – according to the probability of failure transmission to the user</td>
<td>26 to 35</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>36 to 45</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>46 to 55</td>
<td>6</td>
</tr>
<tr>
<td>Low: probability that the failure is transmitted to the user without detection – according to the probability of failure transmission to the user</td>
<td>56 to 65</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>66 to 75</td>
<td>8</td>
</tr>
<tr>
<td>Very low: probability that the failure is transmitted to the user without detection – according to the failure transmission to the user</td>
<td>76 to 85</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>86 to 100</td>
<td>10</td>
</tr>
</tbody>
</table>

Possible failures where it is necessary to define and realize corrective actions.

\[ LR/P = \text{occurrence} \times \text{meaning} \times \text{detectability} \]

- Recommended corrective actions: brief description of recommended corrective actions for improvement of the condition with their precise definition, it is necessary to pay attention to prevention of failure occurrence and its early definition.

- Responsibility: person or department responsible for taking corrective measures.

There is defined examination of all identified possible failures according to the size of LR/P and there are proposed corrective actions for failures with definition of the highest values of LR/P including definition of responsibilities and terms.

Criteria for decision for identified possible failures dependent on the size of LR/P are necessary to define and take corrective measures according to individual conditions.

After taking corrective measures there is held the analysis again with new values of improved conditions via LR/P:

- Taken measures: after realization of corrective measures there are defined their description, results, date of re-evaluation, etc. There is taken a new estimation of classes due to occurrence, meaning and detectability of failures in improved condition.

- Final risk number, level of risk – priority (LR/P): calculated final risk number after closing the corrective actions.

5 Results

The FMEA method is realized by gradual systematic fulfilling the FMEA form. The form is created in MS Excel for simplification of usage in a company conditions. Then there are obtained data for LR/P created for machines and their constructional groups (defined by a machine producer according to the harvester manual for operation and maintenance) in graphic form:

- bogie (Figure 1),
- gearboxes and gearing mechanism (Figure 2),
- engine (Figure 3),
- engine lubrication and cooling (Figure 4),
- electric systems of the machine – sensors (Figure 5),
- hydraulic system (Figure 6)
- hydraulic crane (Figure 7)
- cabin and controlling devices of the machine (Figure 8).

The main idea for the FMEA method implementation arises from the theory that for every symptom of the failure on the lowest level there are analyse possible local or system impacts. Application of FMEA presents: analysis of constructional kinds of machines (i.e. harvesters) and all possible failures which a team of employees can define on the basis of their work experience. At the constructional FMEA method the failures are observed on the level of components. There are not researched mutual functional interactions of individual components. The procedure is based on risk value (LR/P) as the result of multiplication between probability of the failure, significance of the failure and probability of detection.
Figure 1: FMEA results for bogie construction of harvester John Deere 1070D

Figure 2: FMEA results for gearboxes and gearing mechanism of harvester John Deere 1070D
Figure 3: FMEA results for engine construction of harvester John Deere 1070D

Figure 4: FMEA results for engine lubrication and cooling of harvester John Deere 1070D
Corrective measures are set and results are evaluated until the level of risk is not lower or the same as acceptable level of risk (acceptable level) for individual causes (objectives) of each system. Acceptable level of risk is qualified as the decision to accept results and probability of the exact risk. The maximum level of LR/P for FMEA method is 1000 points. As acceptable level of risk there are set 500 points which are not obtained in current analysis.

The FMEA method is realized as a team work of specialists representing maintenance (day and week maintenance steps) and repairs.

Final data from operational reliability are further used for implementation of FMEA method and maintenance of
the machine. They are used as input data. There are mostly failures collected during research. The data are treated according to the system given by the producer.

6 Discussions

The evaluated objects are divided into groups, subgroups, parts and components. There are asked questions focused on probability of raising the failure for every symbol (symptom) where during observation of operational conditions during the research period of time was cause a failure minimum once. In the team of specialists there were solved...
questions of a failure probability and possible causes, significance of the failure for a user and detection possibilities. Significance of the failure was taken to consideration also the downtime due to the total downtime of the machine with emphasis on loss of profit. The answers were obtained from recent experience of individual specialists and results of operational reliability while individual probabilities were evaluated by values according to criteria mentioned in the Slovak Technical Standard STN EN 60 812 - Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA).

There are compared results obtained during evaluation and final results and on the basis of the final result of the acceptable risk there are taken appropriate measures which bring positive improvements. For better understanding the results are demonstrated in the graphical form. These results create a part of a document which reflects progress and conditions of analysed objects and processes in the company. This progress enables to evaluate the machines and objects in time \textit{i.e.} to get progress for future. It enables horizontal and vertical design of FMEA records. The records in vertical level enable to analyse new and new findings. The positive point of this method is a team work which helps share knowledge and experience obtained during machines running.

The characteristics of the machine used in the real conditions in accordance with defined properties define the quality which should be obtained. The user mostly requires durability of machines in operation. During research and technical lifetime of the machine there is durability verified mostly by statistical methods. The meaning of quality is supported by operational reliability. It gets also a special dimension and it is longer lifetime [7, 8].

FMEA method is a tool for elimination of downtime in operational reliability system and a preventive too for ensuring maintenance of objects. Recommendations rising up from the method are very wide. The first recommendation is preventative activity in the system of maintenance. In the future with higher age of machines there is necessary to re-evaluate and set up shorter terms of operational maintenance for machines because it is defined by a curve of failures intensity. For easier diagnostics of individual elements in the system it is useful to implement new and modern methods of technical diagnostics [18].

For further use of the FMEA method in the organization (not only as the subject of the dissertation thesis), it would be good to consider the introduction of supporting software, such as. APIS IQ, to simplify the use of this method. It is clear that the input costs for the application of this method (purchase of software, staff training) would be returned to the organization in the form of eliminated faults, optimization of parts replacement time, shorten downtime and, last but not least, repeatable failures would be more transparent, on the basis of which the stock of spare parts becomes more efficient (especially in the case of the harvester head, where downtime due to wear or mechanical damage to the cutting device most often occurs as a result of operation).

7 Conclusion

Application of FMEA method enables bigger flexibility in case of unexpected situations and optimization of human abilities. At the application of FMEA there are always a lot of problems to solve. They can be summarized as fear from changes, illogical ideas during analysing, missing data or knowledge which can create insufficient scheme of reliability. For successful implementation and realization of this task in other companies there can be recommended following points:

- Preparation of the realization plan for application of FMEA method
- Creation of experienced and skilled working team
- Creation of scheme of operational reliability (definition of researched groups within the machine, etc.)
- Analysis of possible failures and causes
- Proposal of possible measures
- Repetition of analysis to obtain acceptable level of risk
- Implementation of results into practice and documentation of observed machines and devices
- To do taken measures in real conditions which will bring the positive input of taken measures

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References


