Intensity Function in Evaluation of Production Process Stability

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Abstract. Modern, highly competitive market demands from enterprises that the production processes are realised efficiently. Any downtime results in missing order delivery times, which entails enforcing contractual fines and losing customers. The companies must, therefore, strive to identify and compensate for any factors destabilising efficient course of the production process. Therefore, the following paper describes results of stability analysis of a production process by means of hazard function. The summary of modern trends in reliability analysis was followed by description of event history analysis methods and their practical application in analysis of historical data obtained from a manufacturing enterprise.

Introduction

Disruption is an inevitable part of a production process. At the commencement of production, the production process is assumed to be stable and devoid of problems. Nevertheless, practice shows that a considerable number of factors hindering the progress of the process can occur during production. The bigger the scale of production disturbance is the higher intensity of nervousness and disorganisation will be observed. Great effort should be, therefore, made to identify and compensate for the factors disrupting the process prior to their occurrence [1, 2].

Among numerous factors regarded as generating instability in production processes this is failure of equipment in the stock of tools that is the most commonly indicated to be at risk [3, 4]. At present, there can be observed a distinctive trend in analysis of machine reliability and prediction of their potential future failure [5]. The research in the field finds application in both maintenance and production planning [6]. Therefore, there exists a constant need for developing tools for the study of machine stock reliability. The present paper presents the application of life table and hazard function in analysis of data regarding machine reliability and its applicability in determining the stability of production process. This approach can be used further in the field of operations management, especially to prepare the production plans insensitive to interruptions which occur during the manufacturing process.

Literature Review

Nowadays, a marked increase can be observed in the volume of the body of literature regarding technological machine failure analysis. Researchers apply the existing knowledge predominantly in predictive maintenance, however, there are more and more frequent
applications of the knowledge in production scheduling. The approach which aims at elimination of potential disruptions in manufacturing is known as robust scheduling [7, 8].

Literature describes several approaches in analysis of technological machine failure with regard to robust scheduling of tasks in production. The most common approach, as presented by the majority of researchers, is to base on probability distribution, in which case typical parametric distributions are taken into account, i.e. normal, triangular and exponential and combinations of the three [7, 9, 10]. Furthermore, a number of researchers attempt to analyse technological machine failure from the viewpoint of robust scheduling based on such indices as: MTTF (Mean Time To Failure), MTBR (Mean Time Between Repair) and MTTR (Mean Time To Repair) [11, 12]. Unfortunately, a sizeable extent of researchers resort to test data and/or data obtained from their own assumptions. However, a different method is applied in paper [13], whose authors attempt to devise their own solution for failure prediction, which represents another group of approaches. The method in question employs MTBF, MTTR and MTTF (Mean Time To First Failure) parameters. Their values are determined by means of theory of probability, and are predominantly based on Weibull distribution parameters. More frequently, nevertheless, the solution to problems of production scheduling under uncertainty is based on actual datasets for a given process. Authors of papers [7, 8, 14] underline the importance of scheduling production in existing production environments, i.e. with the application of actual data.

The process of machine failure should be, therefore, approached individually for each production enterprise. Such a solution appears substantiated inasmuch as each manufacturing environment exhibits individual features, hence their uncertainty parameters will display an individual character as well as variation. No solutions exists that would enable analysis and inference to be based on historical machine failure frequency data. It is, therefore, imperative that typical parametric probability distributions should be abandoned in favour of non-parametric distributions.

Investigation of Intensity Function

Justification for the Study

It has been observed that analysis of machine reliability with a view to producing robust schedules is a popular and current issue. The overwhelming majority of published works concern the analysis of parametric models of survival processes. This was one of the reasons why we decided to conduct the analysis of actual data for the technological machines reliability in order to monitor trends in machine failure and to determine non-parametric models of machine failure time. The presented results constitute one of the stages for developing a method for scheduling production tasks by means of prediction analysis tools.

Analytic Techniques Applied in the Study

The study results presented in this paper were obtained from survival analysis and event history analysis. The applied method employs a selection of statistical techniques for data analysis, which allowed us to determine survival analysis model for a particular item or event, and to use the obtained data to determine standards of reliability [15]. At the base of survival analysis there is the process of “survival”, which essentially includes two events: the beginning and the end.
This with regard to machines translates to the beginning of work and the point of machine failure.

The study employed one of the techniques for the analysis of history of events: life tables. This technique represents a group of long-established methods for survival time data analysis. The data is divided into a number of intervals and put into a proper table. For each interval several indices are calculated: the number of cases that entered the respective interval "alive," the number of cases that failed (uncensored observation – index 1), and the number of cases that were lost (censored observation – index 0). Thus obtained data can serve to compute the number of cases at risk, the proportion failing or surviving. Such statistical information can be also applied to obtain probability density, hazard rate or median survival time.

In our study we decided to focus on the analysis of intensity function $\lambda(t)$, which is also referred to as hazard function. Intensity is understood as a local characteristic of a given process, which denotes its instability in the sense of time of event occurrence. From the viewpoint of robust scheduling the data of this sort is invaluable and can be of use when striving for a robust schedule. If intensity is decreasing, then the longer the object functions the lower the probability that an event will occur in another interval. High values of the function in question denote an interval at which the risk of an event is high (Fig. 1).

![Figure 1. Hazard function model and its interpretation.](image)

Hazard function is closely linked to probability density function $f(t)$ (Eq. 1), cumulative distribution function $F(t)$ (Eq. 2) and survival function $S(t)$ (Eq. 3) [15].

$$f(t) = \frac{dF(t)}{dt} \quad (1)$$

$$F(t) = P(T \leq t) \quad (2)$$

$$S(t) = 1 - F(t) \quad (3)$$

where: $P(T \leq t)$ – probability of event occurrence in the interval $(0, t]$.

The form of hazard function $\lambda(t)$ (Eq. 4) depends on the form of the remaining functions. Statistical sets for event history analysis are capable of $\lambda(t)$ function estimation by means of standard parametric survival models.
\[ \lambda(t) = \frac{f(t)}{S(t)} \]  

(4)

In the present paper the focus, however, was on analysis of a non-parametric survival model obtained from empirical data.

**Historical Data Used in the Study**

The analysis presented in this paper was based on historical data regarding machine failure and technical faults of machines, obtained from one of the enterprises. The data was derived from Service Books of technological machines constituting a part of the stock of tools of a production company which works in the field of production and modernisation of machinery used in production and power industry. The service books stored records of maintenance data of 14 technological machines. The analysis was conducted for years 2012, 2013 and 2014. The interval of failure-free operation was expressed in days. Index “1” denoted occurrence of failure and “0” denoted no event (Fig. 2). In conducted analyses, the beginning of the year denoted the beginning of observation and the terminal event was the failure of a machine. Subsequent failures of a machine were not taken into consideration.

![Figure 2. The analysed data.](image)

**The Course of Study Works**

The presented analyses followed a sequence of procedures that enabled us to apply the obtained historical data properly. The works were conducted in the following stages:

1. Acquiring survival data. The process consisted in selecting relevant data for the reliability of the stock of tools from the existing documentation and summarising it in the convenient form of a table.
2. Calculating the number of days between the beginning of the year and the occurrence of failure. Suitable functions allowed us to calculate the time and express it in the form of the number of days.
3. Computing life tables and intensity function graphs. This was carried out by means of STATISTICA software (version 12) – the analysis was performed with tools offered by Survival Analysis module.
4. Analysis of results. The produced graphs of empirical hazard functions were collated in a single diagram and subjected to an individual and collective analysis. The results were analysed in such a form to facilitate the process and to allow determination of the properties of obtained functions.
Results of the Study

The main aim of the conducted research works was to produce diagrams and to perform analysis of intensity function for the process of existing technological machines failure. The obtained graphs were presented in Fig. 3.

As it was mentioned in the introductory section of the paper, hazard function allows determining a local characteristic of a given process. By analysing the graph above, it is instantly possible to define points where production was of an unstable character. With regards to 2012 data, certain regularity can be observed. There is a distinctly visible repeatability of periods where the intensity of failure hazard was increased, which were followed by periods of lower probability of failure occurrence. Similarly for the year 2013 there can be noted a period of increased stock of tools failure hazard, however, not all occurrences overlap with the 2012 data, as several of those are moved in time. In 2014 data a sharp increase of the hazard function value was observed in the vicinity of days 95, 140 and 254. In the remaining period of time the hazard function remained stable, hence the production, in terms of machine reliability, was stable in character.

An interesting conclusion can be drawn when analysing the collated graphs collectively. For all data in question, a distinct increase and drop in the intensity function can be observed between days 140 and 175 in all analysed years. It should be therefore inferred that, in that particular time period, special attention is indispensable, as the failure hazard then is significantly high. The data also shows that there in two of the analysed years the occurrence of machine failure was almost identical. This information could be invaluable for the Maintenance and Production Planning departments, as it evidently pinpoints periods when certain nervousness and disorganisation of the production process is set to occur.

Summary and Future Studies

The conducted analysis of statistical data gives a hint of how intensity function analysis results for the technological machines failure can be applied. The scope of its application, however, is considerably broader. The study confirms that the presented techniques can provide great support in determining local characteristics of the production process. Furthermore, the data
provides information that could be the base for the evaluation of production process stability with regard to machine failure.

Another stage of the research works will be to apply the obtained knowledge in the process of robust scheduling of production tasks. The collected data will constitute the source for predictive analysis of intensity function in the subsequent periods of production in the future, and will enable determination of rules for the identification of time periods at risk of machinery failure. The future studies should include the analysis of correlation between the amount of work conducted at production cells or between realised schedule and intensity function values.

References


