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A Universal Approach to Categorize Failures in Production

K. Knüppel, G. Meyer, P. Nyhuis

***Abstract*—** The increasing interconnectedness and complexity of production processes raise the susceptibility of production systems to failure. Therefore, the ability to respond quickly to failures is increasingly becoming a competitive factor. The research project "Sustainable failure management in manufacturing SMEs" is developing a methodology to identify failures in the production and select preventive and reactive measures in order to correct failures and to establish sustainable failure management systems.

***Keywords*—** Failure categorization, failure management, logistic performance, production optimization

I. Introduction

Dealing with complexity and increasing calls for flexibility will become central challenges for producing enterprises in future [1]. Production processes are becoming more complicated and there is a greater likelihood that failures will occur as a result. Increasing complexity in technologies and processes will probably multiply the number of potential failures. The susceptibility of processes to failure may also rise in the wake of a greater connection and networking of production processes because disturbances in upstream processes will obviously affect downstream processes and cause further problems there [2]. The resulting failures reduce the performance of production systems [3]. Enterprises should therefore deploy suitable methods to identify their failures more quickly and to permanently rectify such [2], [4], [5]. Improved identification of the causes of failures in enterprises should therefore offer great opportunities to remedy these in the long term. Research undertaken by KLETTI in this context has shown that the majority of such failures (some 80 per cent) can be traced back to around 20 per cent of main causes [6]. An obstacle to setting up an efficient failure management system, however, has been seen in the great amount of work required to identify the causes of such failures and a lack of descriptions of failures that occur [4], [5]. Whilst large companies generally have the resources needed to introduce failure management systems, this still poses a challenge to small and medium-sized enterprises (SMEs) [3].

Working together with ten producing enterprises, a methodology is being developed by the research project "Sustainable failure management in manufacturing SMEs". The aim is to help SMEs to systematically identify failures and their causes and to propose preventive and reactive action to rectify failures. Producing enterprises can use the methodology to establish a sustainable failure management system for their production processes.*

As a first step, the typical failures in producing enterprises were collected in a database. This was done by surveying the enterprises involved in the research project about their main failures during project meetings and visits to their facilities. A new approach to categorize all kinds of individual failures was developed on the basis of existing ways to categorize failures [7]. This database is used in what follows to establish whether there are interdependencies between the main failures in an enterprise and the characteristics of its production system. The goal is to help identify and locate potential failures in enterprises with similar characteristics.

II. Failures in Production

The terms "disturbances" and "failures" associated with production are not unambiguously defined in the literature. The definitions often differ in dependence on the academic discipline. According to HEIL, "Disturbances are temporary situations in the chain of value creation, in which a directly established deviation from the optimum course of the process and/or its outcome is created by the effects of failures on the factors of production and their combination process" [2]. The following definition derived from this has been adopted in the research project: "Failures are events which lead to non-conformities in planned processes in production (e.g. workforce deficits, quality problems, mechanical breakdowns, etc.) [2].

There has been no uniform categorization of failures and their causes up to the present time. It would seem that the multi-faceted nature of failures - together with their differing causes - make it necessary to categorize these in a suitable manner in order to be able to systematically rectify causes and to prevent failures. An Ishikawa diagram is an example of an approach to the categorization of failures. This method assigns possible causes of errors/failures to the categories Man, Machine, Material, Method and Milieu (environment) [8]. The so-called 7-Ms of quality management were developed up by adding the terms Management and Measurability [9]. HIRANO deploys similar terms: Information, Material, Machine, Method and Man [10]. It may also be feasible to categorize failures by the different disciplines involved in production systems: Technology, Logistics, Organization and Man [11]. Apart from differentiating between disciplines, there are other means to define failures.

WARNECKE and JACOBI differentiate between external and internal failures in production. The causes of external

Konja Knüppel is research associate at the Institute of Production Systems and Logistics, Leibniz University of Hanover, Garbsen, 30823 Germany (corresponding author to provide phone: 0049-511-762-18192; fax: 0049-511-762-3814; e-mail: knueppel@ifa.uni-hannover.de).

Gerrit Meyer is research associate at the Institute of Production Systems and Logistics, Leibniz University of Hanover, Garbsen, 30823 Germany (e-mail: meyer@ifa.uni-hannover.de).

Prof. Peter Nyhuis is director of the Institute of Production Systems and Logistics, Leibniz University of Hanover, Garbsen, 30823 Germany (e-mail: nyhuis@ifa.uni-hannover.de).

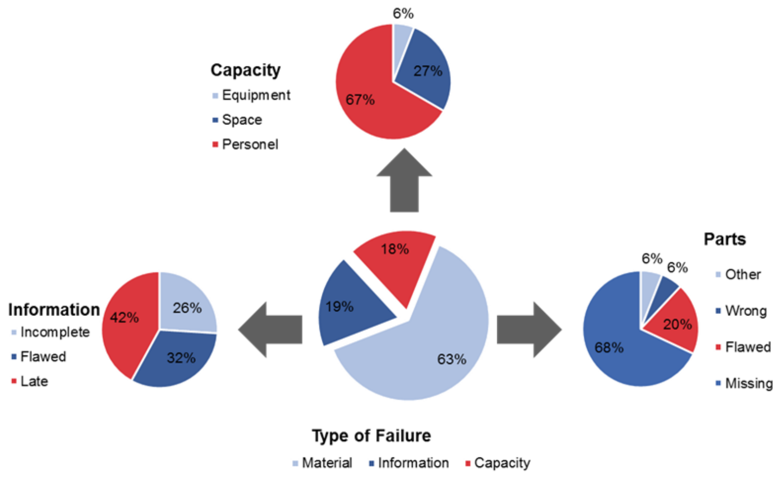

Fig. 1 - Types of Disturbances and their Frequency [10]

disturbances (e.g. power cuts, political decisions) do not lie in the production process itself. Although it is impossible for enterprises to eliminate the causes of such, their knock-on effects can be mitigated by taking suitable remedial action. On the other hand, the causes of internal failures do lie in the production process itself. These can be influenced and their causes can be rectified by taking appropriate action [12]. Figure 1 summarizes possible categories of failures, as derived from LEHMANN [13].

Similarly, DIENSTHOFF differentiates between Equipment, Material, Man (administrative) and Man (machine operatives). In the argument concerned here, the majority of failures can be traced back to human mistakes. Case studies have confirmed this conclusion. DIENSTHOFF investigated the manufacturing processes in eleven heavy engineering works in 1970 and analyzed over 10,000 disturbances. His findings showed that some 35% of failures there could be attributed to "human mistake (machine operatives)" [14].

It soon becomes obvious that there are many alternative ways to categorize failures and their causes. They may describe what failed, how something failed or where a failure occurred. However, as these differences are viewed separately by each author, there is no holistic approach with which to describe and assign the huge variety of production-related failures. For this reason, the research project decided to develop an approach which combined the different approaches to categorization.

III. Approach to Categorize Failures in Production

As a general rule, every failure can be roughly described by asking the following questions:

- What has failed?
- How did it fail?
- Where did the failure occur?

These questions can be answered and a clear categorization made for all failures using the approach depicted in Figure 2. An example failure, namely "Production worker operates a milling machine incorrectly", is discussed in the following. The first step is to briefly describe the failure. The failure in this example was described as 'incorrect operation of a machine'.

As a second step, the category Object is determined to establish what caused the failure. In the example cited above, 'Human' would be the fitting attribute for this category because the failure occurred due to a worker`s actions. The third step, namely the category Type of failure, establishes whether the Object did not perform his job at all, or only did so at an insufficient level. If a worker was absent or not available for some other reason, 'Availability' would apply as the attribute because the worker was not able to perform his job properly. Although the worker performed his work in the example, this was not done in the desired manner, so that 'Condition' should be selected as the attribute. In the fourth step, the category Location describes the place in the enterprise in which the observed failure occurred. 'Production' would be the fitting attribute in this case. In summary, the example failure is characterized as follows: 'Human – Condition – Production'. As a further example, the failure "Missing work instruction at an assembly workplace" can be categorized as: 'Information – Availability – Assembly' [7].

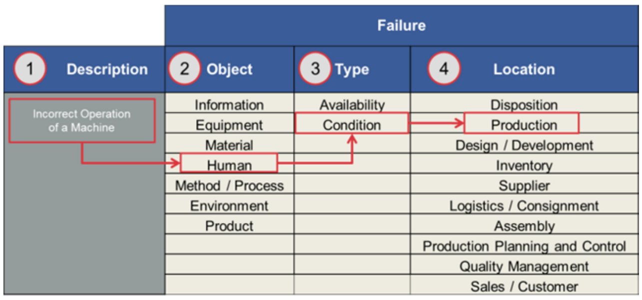

Fig. 2 – Approach for Categorizing Failures (example in red)

In order to validate the approach once it had been developed, numerous failures taken from the literature were imported into a database. These were supplemented with insights gained from interviews and observations in the industrial firms involved in the project. At the date of assessment, this database contained 270 different failures that had been categorized by users from the enterprises. It was demonstrated that the failures that occur in these enterprises could be systematically described and categorized using the developed approach. In the further course of the project, the database will be used as a basis to build up a catalogue of remedial action.

The next stage involved assessing the entries in the database to identify the main potential failures. It turned out that 'Human' (at 23% of the count) was the object of failure most frequently stated by the enterprises, whilst 'Equipment' at 21% and 'Information' at 20% were likewise often cited (fig. 3 left). The location of failure most commonly named were production at 26% and assembly at 15%. This was to be expected in view of the nature of the enterprises involved and because the staff questioned worked primarily in production-

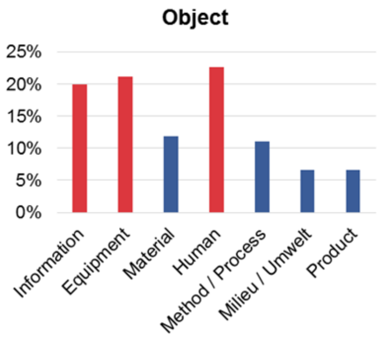

Fig. 3 – Distribution of Failures within the Category Object

related capacities (fig. 3 right). Where the type of failure was concerned, 'Condition' at 60% came in front of 'Availability' at 40%.

IV. Correlation Analysis of the Main Failures

In order to simplify the identification of typical failures and to derive suitable remedial action, an analysis was done to identify correlations between the main failures in the categories and the characteristics of a production system. Such were to be expected because the several characteristics of an enterprise can have an influence upon the nature and the frequency of failures [14]:

- Manufacturing process (e.g. milling)
- Type of organization (e.g. workshop production)
- Manufacturing sector (e.g. heavy engineering)
- Range of goods (e.g. one-off manufactures or small-series production)

A technical morphology was developed (see Figure 4) to describe the type of enterprises by sub-dividing the typological characteristics of their production system. The industrial sector, number of employees, method of production, depth of value creation, degree of automation, quantities of products, batch size and further criteria were selected as typological characteristics.

Each of these 27 typological characteristics was further sub-divided in different values. The industrial sector, for instance, was sub-divided into the values heavy engineering, automobile construction, electronic engineering, power engineering, mechatronic, metrology, furniture, metalworking industry and others. The method of production feature was broken down into customized manufacturing, one-off/small-series production, series production and mass production. This morphology was then used to characterize the enterprises whose failures had been recorded in the database.

The following correlation analysis examines whether there are interdependencies between the typological characteristics and the major disturbances described in the categorization. Each sub-division of the nature of operations category is examined to see whether enterprises in this sub-division often named certain features of the three categories of failure (Object, Type, and Location). The aim is to find out whether, for example, an enterprise involved in customized manufacturing stated certain objects of failure more often than those involved in mass production. Some of the most noticeable correlations are discussed below.

The larger the enterprise, the more frequently humans are said to be the object of a failure. Moreover, the environment as the object of failure was named by enterprises with more than 250 employees more often than by smaller firms.

With regard to the method of production, it appears that firms involved in one-off and small-series production are particularly confronted with failures attributable to the object information. In contrast, the more an enterprise tends towards mass production, the more that failures are put down to equipment.

At a higher level of automation - and also at higher quantities - equipment is likewise more frequently seen as the object of failures. Understandably, production and assembly are stated as the main locations of failure here.

Where batch size is concerned, it is noticeable that assembly (alongside production) is named more frequently as the location of failures as batch size increases. In contrast, there is nothing conspicuous about the objects for failures.

The more varied or complex the range of goods produced by an enterprise becomes, the more the human was stated to be the object of failures, whilst production decreases as the location of failure.

A clear correlation can be recognized between the position of the order penetration point and the culprit of failure. The further forward the order penetration point lies in the chain of value creation, the less equipment was said to be the object of failures. This is exactly vice-versa for information as the object.

	Typological Characteristic						
1	Industrial Sector						
	Heavy Industries	Automobile	Electronic	Power	Mechatronic		
	Metrology	Furniture	Metalworking Industry	Sonstiges			
2	Employees						
	< 10	< 50	< 250	>= 250			
3	Method of Production						
	Customized Manufacturing	One-Off/Small-Series Production	Series Production	Mass Production			
4	Depth of Value Creation [%]						
	0 – 15	15 – 30	30 – 45	45 – 60	60 – 75	75 - 90	90 – 100
5	Degree of Automation [%]						
	0 – 15	15 – 30	30 – 45	45 – 60	60 – 75	75 - 90	90 – 100
6	Quantity [per year]						
	< 100	< 5.000	< 20.000	>= 20.000			
7	Batch size						

Fig. 4 – Detail from the Morphology of typological Characteristics

A similar correlation can be recognized with regard to method of procurement. The more material is externally procured, the more failures are attributed to the object information, whilst correspondingly fewer are assigned to the object equipment.

The last interdependence worthy of mention is the object of failure stated regarding the type of the assembly process. On continuous assembly lines, human is named something like twice as frequently as in all other types of the assembly process.

Most of the correlations noticed, match with the findings from theory and practice. The contradictions found can be traced back to the small amount of enterprises surveyed. Yet in this sense, the research cannot be regarded as statistically sound because only 10 enterprises have participated in the survey up to the present time. A wider-ranging survey is required to take into account how often a failure occurs, and not only whether this is inherent to the enterprise in question. Only when this information has been gathered in the database - and when it also satisfies statistical requirements – will it be possible to use the correlations to delimit the main failures in dependence on the characteristics of the production system and to thus help users to make a preliminary selection of failures and remedial action.

V. Conclusion and Outlook

The increasing complexity of production processes and the need for greater flexibility raises the likelihood that failures will inevitably occur. Such failures will almost certainly have a negative influence on the achievement of business and logistics targets. Due to their limited resources, producing SMEs in particular, are faced with the challenge of having to set up an efficient failure management system aimed at identifying and rectifying any disturbances that occur and avoiding these over the long term. Implementation of such failure management systems requires a uniform categorization of the diverse failures and their causes. To this end, the research project "Sustainable failure management in manufacturing SMEs" has developed an approach which enables enterprises to categorize their failures in a clear manner using a three-stage methodology. This approach was used to collect and categorize a highly varied range of failures in a database.

With the aim of assisting enterprises in building up efficient failure management systems, the database was analyzed to identify possible correlations between frequently named categories of failures and the characteristics of the enterprises involved. The findings should enable typical failures and remedial action to be delimited in dependence on the characteristics of the enterprise concerned. However, the results still need to be refined by adding data from more firms to the database, including details of how often such failures occur.

The next step envisaged for the research project is to put together a catalogue of remedial action to enable enterprises to select suitable measures to rectify their particular problems. For this purpose, appropriate action will be allocated to the categorized disturbances in dependence on their categorization.

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