

MIT Open Access Articles

Approach for a Risk Analysis of Energy Flexible Production Systems

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Simon, Peter, Yannik Zeiträg, Johannes Glasschroeder, Timothy Gutowski, and Gunther Reinhart. "Approach for a Risk Analysis of Energy Flexible Production Systems." *Procedia CIRP* 72 (2018): 677–682. © 2018 The Authors.

As Published: <http://dx.doi.org/10.1016/j.procir.2018.03.073>

Publisher: Elsevier

Persistent URL: <http://hdl.handle.net/1721.1/119506>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of use: Creative Commons Attribution-NonCommercial-NoDerivs License



51st CIRP Conference on Manufacturing Systems

Approach for a Risk Analysis of Energy Flexible Production Systems

Peter Simon^{a*}, Yannik Zeiträg^a, Johannes Glasschroeder^a, Timothy Gutowski^b, Gunther Reinhart^a

^aFraunhofer Research Institution for Casting, Composite and Processing Technology IGCV Provinenstr. 52, Building B 1, 86153 Augsburg, Germany

^bMassachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, MA 02139, USA

* Peter Simon. Tel.: +49 821 90678-183; fax: +49 821 90678-199. peter.simon@igcv.fraunhofer.de

Abstract

The steadily growing share of volatile renewable energies in power generation poses a major challenge for energy producers and consumers. One possibility for increasing grid stability and thus the security of electricity supply is Demand-Side-Management (DSM). Since a load adjustment in the manufacturing industry is often followed by an intervention in the production process, logistic targets in production can be adversely affected. In order to evaluate the risk that occurs for energy flexible manufacturing companies, an approach based on existing evaluation methods is developed.

© 2018 The Authors. Published by Elsevier B.V.

Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.

Keywords: energy flexibility; flexible productionsystem; production risks; renewable energies

1. Introduction

In the course of the energy turnaround, the currently still predominant share of energy generation from non-regenerative sources is replaced gradually by sustainable sources, such as solar, air and water power [1, 2]. However, these have a certain dependence on environmental and weather conditions, which lead to fluctuations in energy production [2]. To ensure the security of electricity supply, there must be a balance between energy supply and demand. One possibility for solving the present problem is the consumer-side load adjustment to the fluctuation in energy supply [3]. A relevant consumer is the manufacturing industry, as it is responsible for the main share of electricity consumption worldwide [4]. By adapting loads to energy prices, production systems can contribute to balancing supply and demand and at the same time save energy costs. Companies often don't know about their energy flexibility, which is required for the implementation. Since energy flexibility is often followed by an intervention in the production process, its implementation might have a reaction to the risk situation of the production system. In addition penalty fees exist, for not delivering a promised change of load. None of the existing approaches to evaluate energy flexibility takes this aspect into account. For

this reason, an approach for the risk evaluation of the energy flexibility of production systems is presented in this paper.

2. Definitions and fundamentals

In this chapter, the two terms *energy flexibility* and *production risks* are first defined and subsequently assembled to form an evaluation model.

2.1. Energy flexibility

The current literature of energy flexibility can be divided into two groups, those involved in the identification and evaluation, and the group of authors developing possibilities for the implementation of energy flexibility.

Identification and Evaluation

Based on the general definition of flexibility, energy flexibility can be defined as the ability of a production system to adapt itself fast and without great expenses to changes in the energy market [5]. There are different ways, so-called **Energy Flexibility Measures (EFM)**, to adjust the loads of a production system. All EFM by [5] are shown in Table 1 with a short description and their associated symbol.

Table 1. Energy flexibility measures (EFM) according to [5]

Name	Description	Symbol
Adaptation of process starts	Delayed or brought forward start of a process	
Adaptation of machine scheduling	Production of a product on another machine	
Adaptation of order sequence	Aligning the sequence of orders with a different energy demand to energy prices	
Adaptation of staff free time	Aligning of staff free time to energy prices	
Adaptation of shift times	Aligning of shift times to energy prices	
Interruption of processes	Interruption of a running process and restart of the same process later	
Adaptation of process parameters	Production of parts using different process parameters	

One possibility for evaluating energy flexibility is the analysis at the machine level of production. Therefore, a measure-based approach is used in which, based on a top-down analysis of the entire factory, individual machines and stations are examined [5]. For this purpose, it is analyzed which states a machine can occupy, which energy requirement arises and which possibilities exist to change the respective state by applying measures. As a result, this evaluation approach provides key performance indicators to evaluate the energy flexibility of individual machines, to select the most effective measures and to identify the optimization potential in terms of energy flexibility [5].

Implementation

The implementation of energy flexibility requires the integration of energy costs as a further planning variable in production planning and control. The target system, consisting of the quality and time performance of the productions planning and control as well as the occurring costs, is augmented by energy costs [6, 7].

According to [6] the implementing of energy flexibility first requires the integration of energy data into production planning logic. As a result, an overall economic optimum can be found and the correct target specifications for production control can be generated. Based on a rough planning of the energy consumption per component and operation, the amount of energy provided by the energy supplier, as well as one's own energy production, a production and energy plan can be created. Based on this, a machine allocation plan and a proposal for order sequence can be generated for subsequent production control. The starting point of load management in is a roadmap that contains an energy consumption forecast. These timetables can be derived by optimizing the production plans in terms of energy costs, considering the flexibility potential and the fluctuating electricity prices.

Furthermore, the current literature contains a large number of approaches for optimizing a production plan with regard to the total costs, taking into account the energy resource [8].

2.2. Production Risks

According to [9, 10], production risks can be defined as deviations from originally defined production targets arising from disturbances in the production process.

The increasing complexity of companies in a rising dynamic of environments coupled with modern workplace organization concepts leads to an increase in the complexity of the cause-and-effect relationships of industrial risks [9]. The causality of risks is therefore a central challenge of risk evaluation and should be considered more closely. The cause-and-effect relationship of risks consists of potential risk factors that can form the causes of risks. Risk causes are to be understood as primary sources of risks that can be transferred to corresponding risk factors. Risk carriers represent elements of production and are therefore the location of the risk effects. Potential risk effects ultimately influence the target system and lead to a negative deviation of previously defined goals [9]. Fig. 1 schematically shows the relationship between the causes and effects of risks in production.

In current literature, there are many approaches for managing risks in production. All of them are divided into four phases: identification, evaluation, management and control. The focus of this work is the identification and evaluation of risks. Possible approaches are therefore presented below.

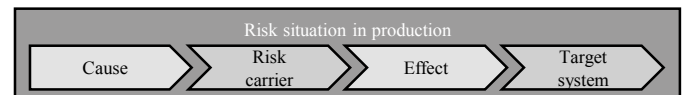


Fig. 1. Cause-and-effect chain of the risk situation in production [9]

Identification

Basically, current literature in this field describes the need to record as many risks as possible in the risk identification phase. According to [10], this is a major challenge due to the complexity of production systems. This problem can be solved by the use of process-oriented models of production systems. The identification of risks takes place systematically and therefore ensures the identification of a large number of risks. In addition, risk identification can be supported by using an advanced Failure Mode and Effects Analysis. Using this method, individual risks can be subjected to an initial quantitative evaluation. Therefore, the extent of damage and the probability of occurrence must be determined. If no meaningful result can be determined based on the evaluation of individual risks, interactions between individual risks should be examined. For this purpose, and to answer the question of which risks must be taken into account in the later risk evaluation, a categorization of production risks into production-technical object classes takes place. These classes consist of production objects, procurement objects and market objects in the highly abstracted model of the production system. These object classes also serve as tools for identifying risks. Production objects can be subdivided according to [10] into the following subclasses (Table 2):

Table 2. Subclasses of production objects according to [10]

Name	Example
Station	Equipment, Machine, Tooling
Transport	Forklift, Driverless Transport System (DTS)
Staff	Production Staff
Buffer	Shelf storage, Pallet storage
Information	Production Schedule, Energy Price

Evaluation

According to [10], the evaluation of production risks can be done using the sales development, the development of the material flow or the development of the Overall Equipment Effectiveness (OEE). First, all data required for the risk evaluation is collected and subdivided into organizational data and process data. The organizational data consist of a specific process number, information about follow-up processes and the description of the process. Process data include information about material flow, throughput times, resource requirements, process costs and risks. Since information in the production regarding machine costs, staff costs, downtimes, etc. is usually present, a possible downtime or other time delays can be easily quantified by a quantitative risk evaluation. In doing so, it is assumed that the extent of damage can be evaluated in the event of a production risk arising from the resulting reduction in yield, which can be quantified for example with the costs for machine downtime [10]. To calculate the extent of damage, the probability of occurrence must be evaluated.

Based on the structured approach and the practicality of its application, the risk identification and evaluation method according to [10] serves as the basis for the approach to the risk evaluation of energy flexibility presented in this paper.

3. Conception of the method

EFMs usually have an influence on the ongoing production process. According to [6], a deviation of the planned energy consumption represents a disturbance in the production process. Therefore, the need for fault management is derived from energy flexible production systems. However, prior to the implementation of energy flexibility, it appears to be useful to identify and quantify the influence and the disturbances of load adaptations on the production. This increases the evaluation granularity, which allows for a more accurate estimation of the expected economic benefits. For this purpose, it is necessary to consider the given risk situation of production systems.

Fig. 2 shows the effect chain of energy flexibility and production risks. Besides the described effect of EFMs on the risk situation in production, the production risks can also influence the characteristics of EFMs. These characteristics are determined by the production process. Since the production process is affected by influencing the risk situation, there is, again, an effect on the characteristics of EFMs. Therefore, two causes and effects must be considered for the subsequent evaluation of, on the one hand, the effect of EFMs on production risks and, on the other hand, the resulting influence on the characteristics of EFMs.

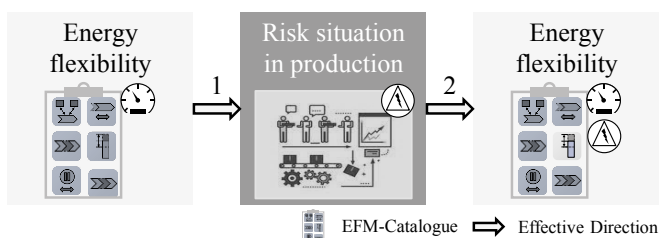


Fig. 2. Assignment of energy flexibility in the cause-and-effect chain of the risk situation in production

Characteristics of EFM

EFMs’ characteristics can be essentially divided into the three dimensions of energy flexibility state, cost and time (see Table 3). The first characteristic is the load adaption, which describes the difference of the required power in the initial state and in the target state of a production station. An EFM can only be activated if the affected system is in the initial state of the EFM. The availability of an EFM therefore indicates the probability of being able to execute an EFM. The time characteristics of an EFM describe how long the change from the respective initial state to the target state lasts (activation time) and how long this target state has to take / can be taken (minimum / maximum duration). Additionally, it has got to be considered how long it takes to change back to the initial state (deactivation time). The individual values of the time characteristics of an EFM depend on the technical and organizational conditions of the machine and the production system. Moreover, EFMs have an impact on costs, such as material, wage and storage costs. Material costs include all additional energy and operational material costs incurred by the EFM, as well as tooling costs. Wage costs are incurred through additional planning, setup and maintenance activities. Storage costs arise from costs for fixed capital, for example due to an extension of the storage period.

Table 3. Characteristics for energy flexibility measures (EFM) [11]

Dimension	Characteristics	Unit	Abbreviation
A) State	Load adaption	W	ΔP
	Availability	-	β
B) Time	Activation time	min	t_{act}
	Deactivation time	min	t_{deact}
	Minimum duration	min	t_{min}
	Maximum duration	min	t_{max}
C) Cost	Costs	€	K

Fig. 3 shows the entire cause-and-effect chain, starting from energy flexibility through the risk situation in production, back to the characteristics of EFMs. Thereby individual EFMs have an initially influence on the causes of production risks. A possible cause may be, for example, the wear of a machine. Furthermore, causes can be bundled into so-called risk factors. Due to the corresponding risk carriers of production (see chapter 2.2), causes / factors have an effect, which manifests itself either in the form of downtime or defects.

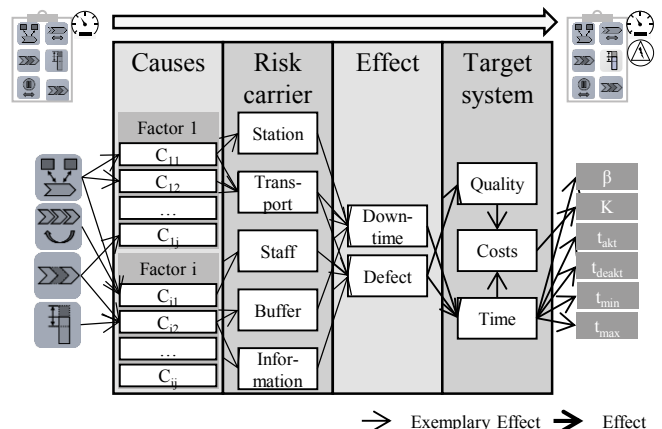


Fig. 3. Cause-and-effect chain of the risk situation in production considering energy flexibility

These effects, in turn, affect a company's target system, which generally consists of quality, time and costs. Ultimately, the deviations of the target system affect the characteristics of EFMs.

In the next chapter, an approach is presented for evaluating the described cause-and-effect chain of energy flexibility and production risks.

4. Risk analysis of energy flexible production systems

Analogous to the previously described occurrence of energy flexibility in the context of the risk situation in production, the risk evaluation of energy flexibility is divided into four strategies (see Table 4). Each strategy can be assigned to one of the effective directions (see Fig. 2), and the dimensions of energy flexibility, shown in Table 3.

Table 4. Strategies for the risk analysis of energy flexible production systems

Strategy	Effective Direction
Strategy to Evaluate the impact of energy flexibility on Production Risks (SEPR)	1
Strategy to Evaluate the Availability of EFMs under Risk (SEAR)	2A
Strategy to Evaluate the Time characteristics of EFMs under Risk (SETR)	2B
Strategy to Evaluate the Costs of EFMs under Risk (SECR)	2C

Fig. 4 shows the sequence of the presented strategies for the risk evaluation of energy flexibility. In addition, the documents required as input as well as the documents resulting as output are assigned to the respective strategies. In the following sections, the individual strategies for the risk evaluation of energy flexibility are presented in more detail.

4.1. Strategy for Evaluating the Impact of Energy Flexibility on Production Risks (SEPR)

The objective of the first strategy is to identify and evaluate the impact of certain EFMs on the risks involved in the considered production system, and to document these in a risk inventory. First, the current risk situation in the considered production must be analyzed. The basis for this is the method presented in Chapter 2.2 according to [10]. Therefore, potential risks are identified by using creativity methods as part of a risk workshop. A systematic implementation as well as the explicit allocation of production risks to the respective process element are guaranteed by process modeling.

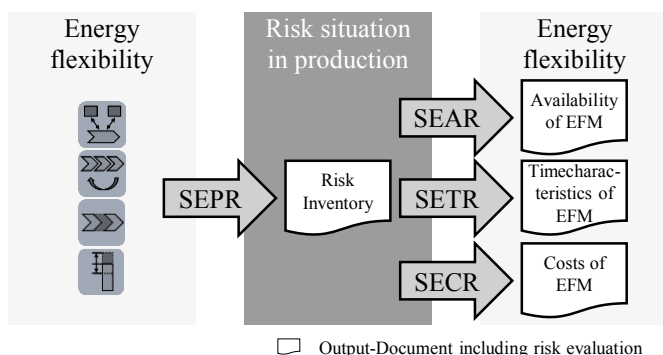


Fig. 4. An overview of the methodology for risk evaluation of energy flexibility

In addition, a fault tree analysis is carried out in order to identify the cause-effect relationship as well as for the complete determination of the possible causes of each production risk. Subsequently, the identified production risks are quantitatively evaluated. On the one hand, the probability of occurrence and, on the other hand, the extent of damage arising in the event of occurrence must be determined. For this purpose, an observation period t_o is initially defined. Based on the frequency of a risk event occurring during this period, the probability of occurrence can be estimated. To determine the frequency of occurrence within a certain period and the extent of damage, three approaches are available according to [12]:

- observations during machine operation
- expert estimates
- experiments in the laboratory

Ultimately, all identified and evaluated production risks are documented in a risk inventory with their specific probability of occurrence and extent of damage as well as their assignment to the process element and production object. The production risks are subdivided analogously to the subdivision, which was carried out in Chapter 3, into quality defect risks and production downtime risks. For further evaluation, the characteristics of production downtime risks are given the index i and the quality defect risks the index j .

After analyzing the initial production risks without considering the influences of energy flexibility, all potential influences of EFMs on the previously identified and evaluated production risks are recorded. Subsequently, the effects of EFMs on the remaining production risks have to be evaluated. For this purpose, the previously prepared fault tree analyses are used. During a workshop, the effects of EFMs on the respective production risks are estimated quantitatively by production experts. It is also conceivable that new risks arise because of EFMs. These must also be identified and determined during the workshop. For the subsequent risk evaluation, however, these can be considered exactly as existing risks with a probability of occurrence of 0% without considering EFMs. Finally, the risk inventory will be supplemented by the results of the SEPR.

An example for this strategy could be the long term interruption of a paper machine due to a prognoses of high electricity prices and the occurring risk of additional maculation. The workshops hold during the SEPR have to identify the higher probability of this occurring risk and document it in the risk inventory.

4.2. Strategy for Evaluating the Availability of EFMs under Risk (SEAR)

The second strategy examines the impact of production risks on the availability of EFMs. The goal is to calculate the availability of EFMs while considering the occurring risks. An EFM can only be carried out if the affected machine is in the required initial state, which is considered by the availability characteristic (see Table 3). The previous step showed that production risks can increase due to energy flexibility. This may result in increased downtime. If a

production station is in a non-operational or faulty state, it is not possible to activate an EFM, which makes the EFM unavailable. To calculate the availability of an EFM under risk, it is first necessary to determine the reduced duration due to increased production risks t_m^R , in which the considered production station works in the initial state of the considered EFM. For this, the increased probability of occurrence of production risks $(p_{m,i}^{t_o} - p_i^{t_o})$ due to the energy flexibility is multiplied by the corresponding extent of damage D_i and subtracted from the risk-free time t_m (see equation 1).

$$t_m^R = t_m - \sum_{i=1}^I ((p_{m,i}^{t_o} - p_i^{t_o}) * D_i) \quad (1)$$

According to equation 2, the availability of EFM under risk can be calculated by dividing the reduced time due to production risks t_m^R by the observation time t_o .

$$\beta_m^R = \frac{t_m^R}{t_o} \quad (2)$$

4.3. Strategy for Evaluating the Time Characteristics of EFMs under Risk (SETR)

The objective of this strategy is to evaluate the time characteristics of EFMs while considering occurring risks. Production risks that occur during the execution of an EFM have an influence on the time characteristics of the respective EFM. In the following, the individual time characteristics (see Table 3) are analyzed in more detail.

Activation Time

If a failure occurs on the affected machine during the activation of an EFM, the EFM cannot be activated as planned. In order to activate the EFM nevertheless, first, the corresponding failure must be rectified and afterwards, the EFM must be reactivated. As an indicator for considering the duration to repair a failure, the **Mean Time To Repair (MTTR)** can be used. It is assumed that the activation of the EFM must be completely repeated and not continue at the point at which the fault has started (see Fig. 5). To calculate the activation period under risk, the time of occurrence of a fault must also be taken into account. For example, it is possible that a production station has the disorder mostly at the beginning of the activation because the startup process is particularly critical here. To consider this fact, the factor $\rho_{m,act}$ is introduced for an EFM, which can take values between 0 and 1 and corresponds to the proportion of the average failure-free activation duration in the entire activation period. The activation duration in the case of failure can be calculated using equation 3.

$$t_{m,act}^{failure} = (1 + \rho_{m,act}) * t_{m,act} + MTTR \quad (3)$$

By considering the probability of occurrence of a fault during the activation of an EFM $p_{m,act}^{failure}$, the activation time under risk can be calculated according to equation 4.

$$t_{m,act}^R = p_{m,act}^{failure} * t_{m,act}^{failure} + (1 - p_{m,act}^{failure}) * t_{m,act} \quad (4)$$

Minimum Duration

If a production disturbance occurs during the minimum duration of an EFM, a change into the initial state is not feasible. The occurrence of the production disturbance

prolongs the so far past minimum duration by the duration of the disturbance. If the **MTTR** is shorter than the fraction of the minimum duration that elapses after the time of occurrence of a disturbance, the minimum duration of an EFM remains unchanged. An example of the minimum duration of an EFM in the event of a fault is shown in Fig. 5. Analogous to the activation time, a factor for considering the average time of occurrence of a failure is also introduced for the evaluation of the minimum duration $\rho_{m,min}$. The minimum duration in the case of a failure $t_{m,min}^{failure}$ can be calculated according to equation 5.

$$t_{m,min}^{failure} = \begin{cases} t_{m,min} & \text{if } MTTR \leq (1 - \rho_{m,min}) * t_{m,min} \\ \rho_{m,min} * t_{m,min} + MTTR & \text{if } MTTR > (1 - \rho_{m,min}) * t_{m,min} \end{cases} \quad (5)$$

By considering the probability of occurrence of a fault during the minimum duration of an EFM $p_{m,min}^{failure}$, the activation period can be calculated under risk according to equation 6.

$$t_{m,min}^R = p_{m,min}^{failure} * t_{m,min}^{failure} + (1 - p_{m,min}^{failure}) * t_{m,min} \quad (6)$$

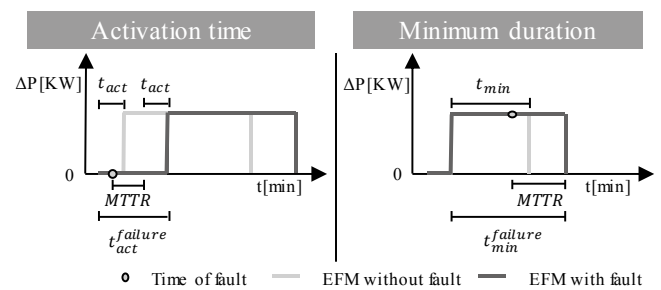


Fig. 5. Effect of a failure on the activation time (l.) and the minimum duration (r.) of EFM

Maximum Duration

A production disturbance during the execution of an EFM inevitably leads to a change from the target state of the EFM to a failure state. In this case, the EFM is prematurely terminated, which reduces the maximum duration. According to [6], the maximum duration of an EFM is also determined by interactions related to the material flow. To consider this aspect in the risk evaluation of energy flexibility, a detailed distinction of cases is required. For a detailed description and the equations to calculate the maximum duration under risk, refer to Simon et al. 2017 [13].

Deactivation Time

If a failure occurs during the deactivation of an EFM, the affected system cannot return to its initial state as planned. Since an EFM has already been completely executed at the time of deactivation, a failure has only an effect on the subsequent operation of the production. This effect has already been considered by SEAR in form of the availability of an EFM and should therefore not be evaluated separately.

4.4. Strategy for Evaluating the Costs of EFMs under Risk (SECR)

The objective of the last strategy is the quantification of the costs of EFMs while considering the occurring risks. In relation to the subdivision of production risks into quality

defect and production downtime risks, which was introduced in Chapter 4.1, the resulting costs are evaluated separately.

Quality defect costs

Quality costs can be subdivided into error prevention, quality inspection and error costs [14]. The approach to the risk evaluation of energy flexibility developed in this paper is intended to enable an evaluation of the actual situation of a production system. An impact on the error prevention and quality inspection costs would cause a change in the production system. Therefore, only the error costs are considered. Depending on the location of discovery, error costs can be subdivided into internal and external error costs. For their evaluation, reference is made to relevant literature. By assigning the identified quality defect risks of the extended risk inventory to the categories of quality defect costs, the internal error costs C_j^{IE,t_o} and external error costs C_j^{EE,t_o} can be calculated and added up. Considering the new risks and the increased probability of occurrence due to an EFM over the defined period of observation $p_{m,i}^{t_o}$ equation 7 can be used to calculate the quality defect costs C_m^{QD,t_o} .

$$C_m^{QD,t_o} = \sum_j \left(\left(\frac{P_{m,j}^{t_o}}{P_j^{t_o}} - 1 \right) * (C_j^{IE,t_o} + C_j^{EE,t_o}) \right) \quad (7)$$

Production downtime costs

According to current approaches in technical production literature, production downtime costs can be evaluated by the maintenance costs which are divided into direct and indirect costs. The impact of energy flexibility on directly measurable costs has already been recorded in the evaluation method of [5] in the form of staff and material costs. Indirect maintenance costs represent a decisive factor for the monetary evaluation of production downtime costs due to the fact that they can amount to three to five times the direct maintenance costs [15]. The determination of indirect maintenance costs is usually very complex in practice, which is the reason why many companies evaluate them in a simplified way via the reduction in added value.

To calculate the reduction in value, the downtime D_i , machine-hour rates MHR_i and the capacity utilization of the machine ρ_i are required. The utilization must be considered, as a standstill will only have a negative effect if the machine is currently processing an order [16].

The production downtime costs C_m^{PD,t_o} due to an EFM can be calculated using equation 8.

$$C_m^{PD,t_o} = \sum_i \left(MHR_i * (p_{m,i}^{t_o} - p_i^{t_o}) * D_i * \rho_i \right) \quad (8)$$

Aggregation of risk costs

Finally, the individual production downtime costs and quality defect costs can be added up and assigned directly to the causative EFM. The result represents the additional risk costs incurred by an EFM in production. Therefore, they can be assigned to the costs of an EFM. The total risk costs caused by a singular performance of an EFM can be calculated by the sum of quality defect and production downtime costs divided by a certain number of performed EFMs over the defined period of observation $n_m^{t_o}$ (see equation 9).

$$C_m^R = \frac{C_m^{QD,t_o} + C_m^{PD,t_o}}{n_m^{t_o}} \quad (9)$$

Referring to the given example in section 4.1., the higher probability of an additional maculation have to be considered as additional quality defect costs and more specific as internal error costs. The monetary impact can be calculated with the help of formula (7).

5. Summary

This article first discusses the relevance of a risk evaluation of energy flexibility with respect to the evaluation granularity of EFMs and presents an approach to the risk evaluation of energy flexibility. Therefore two effective directions must be considered by implementing four strategies. To analyze the first effective direction, the impacts of energy flexibility on existing production risks must be evaluated. The second effective direction is analyzed with the help of three strategies, whereby the influences of production risks on the availability, the time characteristics and the costs of an EFM are evaluated. The results (output-documents) help companies evaluating their economic benefits by using their energy flexibility. Future works on that field need to focus on how to implement the approach in companies' e. g. with the help of software tools. In addition it's necessary to develop a tool for the evaluation of the economical overall situation.

References

- [1] BMWi. Fünfter Monitoring-Bericht zur Energiewende: Die Energie der Zukunft. Berlin, 2016.
- [2] Epex. http://www.epexspot.com/de/erneuerbare_energien/erneuerbare_energien_in_europa. 14.10.2017
- [3] Strbac G. Demand side management: Benefits and challenges. Energy Policy 36 (2008), p. 4419-4426.
- [4] IEA: Key World Energy Statistics. International Energy Agency (2014).
- [5] Graßl M., Reinhart G. Evaluating Measures for Adapting the Energy Demand of a Production System to Volatile Energy Prices. Procedia CIRP 15 (2014), p. 129-134.
- [6] Schultz C., Braunreuther S., Reinhart G. Method for an energy-oriented production control. Procedia CIRP 48 (2016), p. 248-253.
- [7] Keller F., Schultz C., Braunreuther S., Reinhart G. Enabling Energy-Flexibility of Manufacturing Systems through New Approaches within Production Planning and Control. Procedia CIRP 57 (2016), p. 752-757.
- [8] Beier J., Thiede S., Herrmann C. Energy flexibility of manufacturing systems renewable energy supply integration: Real-time control method and simulation. Journal of Cleaner Production 141 (2017), p. 648-661.
- [9] Steinmetz M.: Risikosituation und -handhabung in der Produktion. Ein Konzept zur Verbesserung der Risikosituation. München: TCW, 2007.
- [10] König R. Management betrieblicher Risiken produzierender Unternehmen. RWTH Aachen, 2008.
- [11] Simon P., Roltsch F., Glasschröder J., Reinhart G. Approach for a Potential Analysis of Energy Flexible Production Systems. Procedia CIRP 63 (2017), p. 580-585.
- [12] Hauptmanns U. Prozess- und Anlagensicherheit. Springer Berlin Heidelberg, 2013.
- [13] Simon P., Rösch M., Zeiträg Y., Klöber-Koch J., Glasschröder J., Braunreuther S., Reinhart G. Methode zur Bewertung von Energieflexibilitätsmaßnahmen unter Risikoaspekten. 10. Internationale Energiewirtschaftstagung an der TU Wien (IEWT), 2017.
- [14] DIN 55350. Begriffe zum Qualitätsmanagement - Teil 11: Ergänzung zu DIN EN ISO 9000:2005. Berlin: Beuth, 2008.
- [15] Kuhn A., Schuh G., Stahl B. Nachhaltige Instandhaltung. Trends, Potenziale und Handlungsfelder nachhaltiger Instandhaltung. Frankfurt am Main: VDMA, 2006.
- [16] Beth M., Konrad T., Forkert T., Munzinger C., Schopp M. Analyse und Bewertung der Kosten von Produktionsausfällen. Zeitschrift für wirtschaftlichen Fabrikbetrieb (ZWF) (2009) 104 Nr. 5, p. 371-378.