Measuring the Human Aspect: The Key for Managing the Complexity in Production

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Abstract. The application of cyber-physical systems and smart factory projects in production has increased the automation levels in manufacturing and assembly. Contrary to what might be expected, as a result additional qualifications and skills for shop floor employees are an expected norm. Apart from technical skills, requirements like high flexibility in an uncertain, dynamic and highly complex production environment explain the prevalence of overburdened employees at the workplace. For companies to compete in the global market amidst increasing complexity and changing demographics, managing the employee wellbeing could well be the success factor for high performance organizations.

The work specifies the concept of production complexity and discusses the existing approaches and methods in evaluation of mental workload, followed by the introduction of a framework for measuring human factors related to production complexity. The framework augments the ongoing effort to develop a practical tool to assess and design complexity on the shop floor.

Keywords: Human factors · Mental stress · Production complexity · Complexity management · Systems performance

1 Introduction

The quest for higher productivity, supported substantially by lean production concepts and global sourcing, led to growing interdependencies on the shop floor as well as in global supply chains, resulting in increasingly sophisticated and complex production systems [1, 2]. Besides, the dynamics of the systems are intensifying, driven by volatile markets and political scenarios as well as shorter product life cycles [3].

A production system designer needs to consider the increasing variety of elements and their intensity of interactions for work allocation and robust system design. The application of cyber-physical systems [4] and smart factory projects in production is seen as the panacea for improving the adaptability of the system. The advent of cyber-physical production systems [4] reinforces the comprehensive transformation of working conditions in modern production in recent decades that has resulted in increased skill demands of production employees. However, the existing skill sets of employees

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as well as the existing management tools and methodologies might be inadequate to deal with the increasing system complexity [5].

There is a magnitude of studies focusing on quality and productivity improvement through the eyes of the management, reacting to declining productivity. In stark contrast, there is a notable scarcity in studies investigating the views and feelings perceived by the operator [6].

Contrary to the expectations, the increased sophistication of the sub-systems has resulted in increasing challenges for the operator. Physical workloads of the working person have a declining trend, but psychological workloads are continually increasing and are gaining in importance. In the recent decade, there has been an increase in incidence rates for mental illnesses and their associated costs [7]. A major reason may be the increase of complexity in production.

"If you cannot measure it, you cannot manage it". The popularity of the quote from Deming [8] has reinforced the misconception that only objective, i.e. tangible results can be used as a basis for management. However, subjective i.e. intangible results, for example human behavior, could well be important indicators especially in case of socio-technical modern production systems.

The paper aims to examine the importance of the "human aspect" in measuring and managing complexity. Therefore, an analysis of the existing literature and industry practices of both complexity and mental stress assessment are conducted. Furthermore, the paper presents a three-way approach to measure complexity in production including a detailed assessment of the employee point of view for better work design and system performance.

This work is part of an ongoing project at KMP in conjunction with industry partners in order to provide a scientific and actionable framework for complexity management in production.

2 KMP Approach to Complexity in Production

A majority of the authors define and interpret complexity differently, i.e. either as a mathematical function [9–11], descriptive state [12] and perceived complexity [13], to name a few. Furthermore, the drivers of complexity are determined using a number of methodologies, namely mathematical models [9], operations research models [10] or an indigenous case specific approach [11, 12, 14]. There is a gap and lack of consensus in literature for the interpretation, measurement and management of complexity in production. For a detailed study and summary of the widely-used methodologies for measuring complexity, one can refer to [15, 16].

2.1 Defining Complexity

The KMP approach for defining complexity in modern production systems builds upon the existing theoretical [15], and empirical [16, 17] approaches. The KMP model states that the complexity of a system is determined by the four dimensions: *variety*, *dynamics*, *interdependence* and *uncertainty*.

Variety characterizes the multitude of elements, including the number of product and process variants. *Interdependence* focuses on the number and intensity of relations between different elements or subsystems, influencing process design and system structure. *Dynamics* characterizes the magnitude and velocity of temporal changes in the system and in the relationships of the elements. *Uncertainty* takes into account unknown influences or unpredictable external drivers, e.g. social or political events.

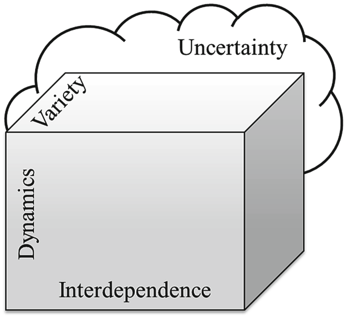

Fig. 1. Complexity dimensions of the KMP-model of complexity

Complexity is structural, i.e. inherent property of a system that persists in a system even in absence of external agents [17]. Undetected complexity in production has a multitude of effects. Inability to view and assess complexity can result in system level degradation, lack of control for the management and overburden on employees. The dimensions of complexity however cannot fully be measured directly, as each dimension has many tangible and intangible aspects. For example, variety stands for number and heterogeneity of parts, product variants, suppliers, processes and working steps, but also of employees. Moreover, some dimensions are hard to determine, e.g. interdependence. Hence, there is a need to look beyond the dimensions, performance indicators and results of the system in order to measure complexity.

2.2 Measuring Complexity in Production - the Human Aspect

In literature, complexity is primarily modeled and measured either through information diversity [9] or through an entropy model [18] of the system. Following the analysis by Mattson [13], both the information diversity and entropy model approach, though complementary, are abstract, therefore difficult to understand and use in practice. Existing methods and complexity measurement models [2] use objective data to assess complexity. However, trying to chart all aspects of complexity in a production plant is an inherently illimitable task. An extensive study [14] of the existing complexity management methods showed that several methods rely on production data either observed or collected from the shop floor that may not be easily available. In addition, there is a gap and lack of consensus [2, 13] in literature on the interpretation, measurement and management of complexity in production.

However, measuring the complexity dimensions via objective, i.e. metric data may provide a basis for benchmarking, but does not help to assess the criticality of the complexities found or to decide on appropriate management measures. Instead, in order to identify the need for action, the analysis has to focus on the resulting *perceived complexity*.

As depicted in Fig. 2, perceived complexity comprises measurable aspects of the resultant system complexity as well as aspects that can only be appraised by and in conjunction with the humans involved. The perception of this subjective complexity however will heavily depend on the human aspect, which includes personality and competences of the employee as well as working conditions and management culture. To successfully design and manage a production system, studying how employees perceive their work is crucial [14].

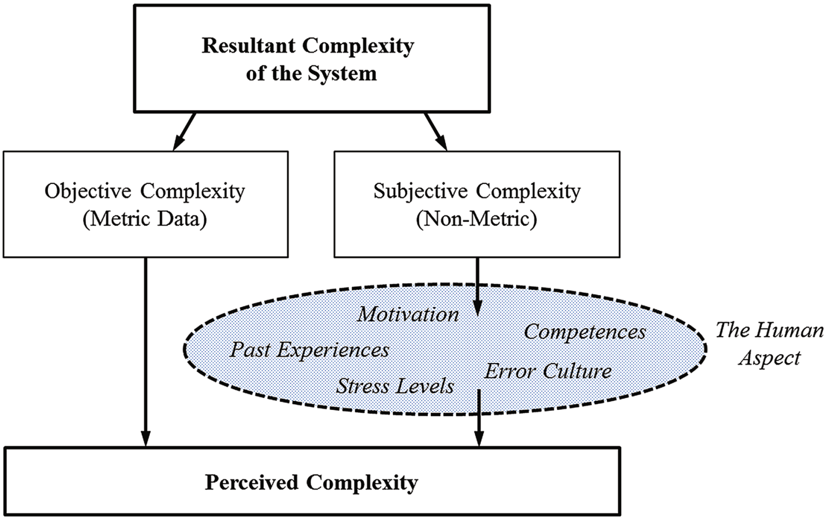

Fig. 2. Perceived complexity and the role of the human aspect

Therefore, the KMP approach aims to assess the perceived complexity by analyzing and putting together information from three different views: subjective assessments of employees in production and of production managers as well as metric data from the shop floor. Within these views, attention is given similarly to the consequences and the drivers of complexity.

The objective complexity is assessed through complexity-related key performance indicators (KPI), which combine a re-evaluation of existing KPI and the implementation of new indicators obtainable from the prevalent IT systems in production.

2.3 Correlating Work Motivation, Stress and Complexity

Human motivation is defined as “the set of processes that arouse, direct, and maintain human behavior towards attaining some goal” [19]. The first impulse of the employee will be to understand the given task. In case he or she can identify himself with the task, the employee will judge the importance of this task with respect to the current situation of the day, career and life. The approach developed towards the task depends on the personality (pull) and previous experience of the employee [20].

Based on the attitude developed in the previous state, the employee decides to achieve this task depending upon his skill, will power, habit and self-efficacy [19, 20]. Individually, stress reactions of the individual employees to the specific performance requirements will arise. These reactions can be positive as well as negative, depending on the employees' available resources in terms of their abilities, character traits, and mental attitudes. Stimulus, such as warming and activation effects express positive responses.

The negative consequences, on the other hand, have a detrimental effect and are the trigger for effects such as mental fatigue, a monotony state and a psychic saturation. Taking into the account the limited capacity of the brain to retain things and multi task [21, 22].

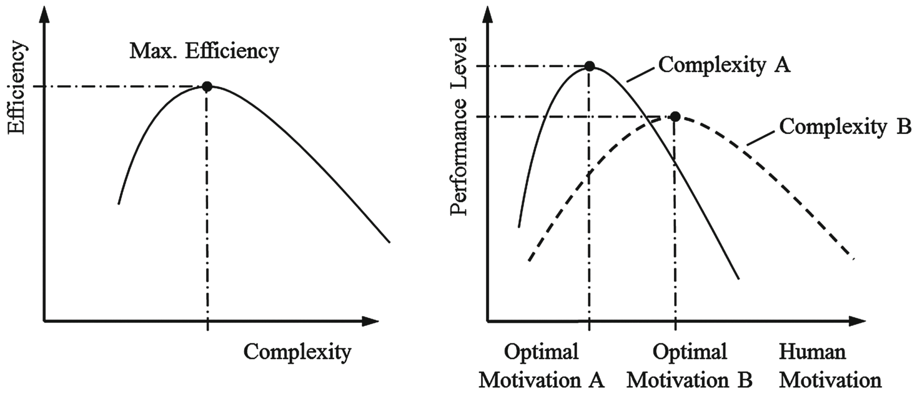

Fig. 3. Qualitative dependence of production system efficiency on complexity level (*left*) and dependence of employee performance level on human motivation and complexity of the task (*right*) [21, 22].

On the system level, efficiency is dependent on complexity (Fig. 3). Furthermore, it is suggested that there exists an optimum complexity level corresponding to the maximum efficiency. Figure 3 also proposes that human performance level and motivation are correlated and there exists an optimum motivation level corresponding to optimum performance. Both are highly influenced by the complexity of the task. Hence, there exists an optimum complexity level (intangible as of now), co-determining human performance and system efficiency. These correlations will provide the theoretical basis for further empirical studies to measure human aspects for management of complexity.

3 Measuring the Human Aspect

Human aspects as well as human factors and ergonomics have an effect on the quality of work [23]. The employee workload will be influenced by physical, psychological factors and competencies. The human aspects provide increased opportunities for participation, employee control and learning [23]. The effect of human factors and physical factors, although important, is beyond the scope of this work. In the following subsections, we discuss the existing models and instruments to measure the psychological factors.

3.1 Human Psychological Factors

The effect of technological advancements, automation and lean production tools in a production environment is not always as predicted and may interfere with the human aspects and employee wellbeing [23]. There are empirical evidences suggesting that lean production implementation may result in increased stress at work [23]. Therefore, despite the presence of sophisticated production control tools, there is a need to measure human psychological factors to understand the causes for increasing stress levels at work. Repeated exposure to stress can result in strain that affects the physical, mental and emotional health. Moreover, the measurement of stress and the causes helps in proactive detection of discontent at work, optimal work allocation and better system performance.

Cranwell-Ward [24] describes job stress as the physiological and psychological reaction that occurs when individuals meet a threat or challenge and the individuals' perception, whether consciously or subconsciously, is that it is beyond their immediate capacity. The identification of psychological stresses at workplaces is helpful to identify whether the work areas and work characteristics are already positive and healthy. There exist a number of models and theories such as the Demand Control Support Model by Karasek [25] and the Effort-Reward-Imbalance Model [26], ASSET [27] and Lazarus [28] to name a few. The Karasek model proposes that high job demands are not harmful in themselves, but when accompanied by low decision latitude would result in psychological strain. The aforementioned models and theories are limited to specific cases, focus on the specific relationship between external demands (stressors) and bodily processes and not universally applicable especially for production industry. Hence, the theoretical construct of human psychological factors is blurred and undefined [23, 29].

3.2 Measuring Stress at Work

Observation, data collection, standardized interviews, moderated group discussions are some of the several possibilities for data collection in order to determine the human Psychological factors and employee wellbeing. The selection of the method of investigation cannot be generalized, since the nature of the production and the circumstances in production, the load factors considered as well as experiences and preferences of the company must be taken into account. A combination of several methods for collecting data can be useful in order to improve the plausibility of the data.

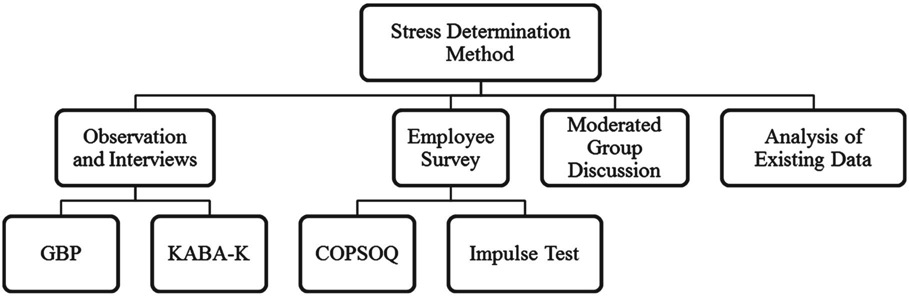

Fig. 4. Overview of analysis instruments for measuring stress

In Fig. 4, four different analysis instruments are presented, which are particularly suitable for evaluating the stress of production workplaces and are applicable to medium-sized as well as large companies. Qualified and trained personnel are needed for conducting observations, monitor the work in the production and determine the psychological stress.

A detailed employee interview often offers the advantage that a more detailed collection of information is possible, as questions are asked relatively freely. A disadvantage is that in an employee interview the employee's anonymity cannot be guaranteed or only insufficiently ensured [30], which causes many employees not to be critical about a situation [31]. An immediate supervisor or an authority with a likely conflict of interest should therefore not conduct the interview, better would be neutral operational functionaries or external experts. Still, data quality can be affected by the interviewer bias. Another disadvantage of employee interviews in practice is the significantly higher time and financial outlay compared to questionnaire procedures [32].

Still, interviews are necessary because some stress factors are very rare and may not be observed at all during the observation period. This is manifest for example in case of malfunctions in the work process, such as an unforeseen delay on the assembly line, which puts the affected employee under time pressure. In case of GPB, the psychological stress is assessed based on observation interviews in three stages [30, 32].

KABA-K is a method that is performed as an observation interview [30, 32]. The implementation consists of three procedural sections. First, the observer gives a description of the workplace and the work done. In the second section, an analysis of the human criteria such as the decision margin is carried out. The third part deals with the detection of psychological stress factors wherein the design of workplaces with regard to psychological stress is also evaluated. As the visibility of the observer is prone to influence results, it is important to conduct employee surveys along with observation interviews.

The COPSOQ [33] survey measures dimensions related to work tasks, the organization of work, interpersonal relations at work and potential work stressors. COPSOQ measures the exposure to workplace psychological risk factors, for example psychological demand, insecurity at work, double exposure, low self-support, low social esteem.

The IMPULS-Test [34] is a computer-based employee survey, which measures twenty-five items under five feature areas, each with five questions on work requirements, environmental conditions, tasks and procedures, perspectives and participation.

The test questions are to be answered in two phases i.e. for the real situation and for the desired situation. The differences between the real and the desired situation are used to identify possibilities for improvement. This procedure however is often too complicated to apply in practice [30, 31, 34].

A group discussion offers the possibility of a deep insight into the subject matter and can be implemented relatively easily and quickly without great preparation compared to employee surveys. However, group discussions require a high degree of willingness to communicate and a trusting environment that is not always given. Depending on group dynamics, moderated group discussion is not always directly relevant.

It is sometimes possible that data already available in operations can be used to assess the psychological stress at workstations in production. Here, in particular, available health reports and disability data are available. Lastly, an advantage of the analysis of existing data is that no separate effort is required to determine the data. However, it is possible that the nature and quality of the data is insufficient for evaluation of psychological stress at production workstations and therefore non-trans-ferrable [30, 32, 33].

The analysis instruments for assessing mental stress have to be evaluated on several quality parameters, especially *reliability*, *validity* and *objectivity*. Reliability of the assessment method ensures the measurement results are reliable and reproducible. Validity deals with the legitimacy of the measurement method. A valid measurement method ensures the measurement of the actual dimensions. Objectivity ensures unbiased results, i.e. the results obtained are not dependent on the person performing the measurement [32].

All the aforementioned analysis instruments, as depicted in Fig. 4, have their own set of merits and limitations. Some of the instruments are strong on checking many possible sources of stress and the corresponding strain. However, in order to correlate stress levels to task and system complexity, these instruments have to be expanded and adapted to include the measurement of complexity-specific stressors.

4 Practical Implications and Future Studies

4.1 Practical Implications

Measuring perceived complexity helps in reducing the misalignment in expectations about existing standards that can be the source of growing pains and discontent for the plant. We propose to use a combination of observation, data collection, standardized interviews and moderated group discussions to measure the human aspects.

Semi-structured subjective interviews [20] are planned to be conducted in two phases. Furthermore, category types, ordinal and continuous open ended questions are being formulated taking into context the cultural sensitivities of the implementation plant. The KMP approach proposes to look at the system through the system results, employee view and management rating.

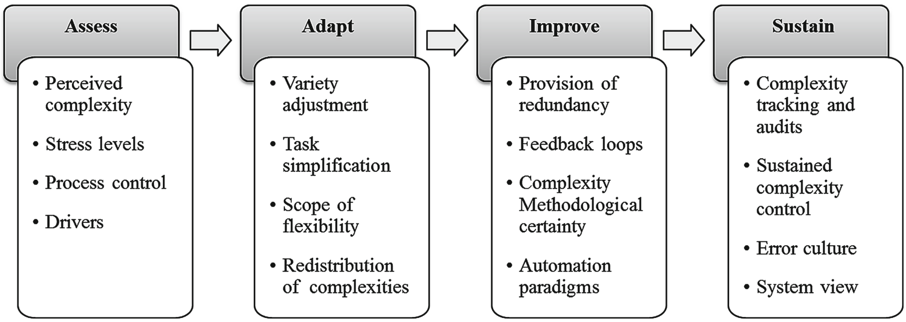

Fig. 5. KMP-framework for complexity management in production

The KMP framework as seen in Fig. 5 presents a clear, concise approach for the management of complexity. We highlight the advantages of each phase and reiterate that the assessment of complexity-induced stress for the employees can give evidence on complexity levels and complexity drivers. Areas wherein complexity-induced stress causes system degradation could be analyzed and subsequently optimized. The KMP complexity approach makes it possible for the system manager to link the causes and effects in order to assess the system behavior as a whole and to influence system performance and system control.

4.2 Challenges

Mental stress can result from a large number of stress factors of which many, but not all, are related to complexity. Therefore, employee stress level can be an indicator for system, process or task complexity, but a specific link can only be established when the major potential complexity drivers are explicitly screened within the assessment process.

Upon confirmatory factor analyses, data collection and cleaning, a scale needs to be determined which is reliable, adaptable and intuitive for use on the shop floor. A seminal study [35] looking to measure the complexity of the manual assembly process with the help of sixteen questions, unique scales and criteria highlights the challenges and difficulties involved in designing an industry usable tool. Apart from being a case specific questionnaire, there were issues related to similarity of questions, clarity on the scales and criteria [35].

Finding a balance between academic rigor and practical usage, while limiting the implementation effort, is a challenge. We have developed a standardized approach, which integrates different analysis instruments. The emphasis lays on developing a standardized questionnaire for multiple industry partners supported by observations, analysis and interviews to be implemented in conjunction with company-specific tools and practices.

We are currently working on extending the lean production framework in order to integrate the KMP complexity management framework for direct use on the shop floor.

5 Conclusions

The notion of complexity management is extended beyond the classical variety management approach. The works extends the contributions of the existing approaches [14–16, 33] to complexity management. Furthermore, a clear definition of complexity in production is presented (Fig. 1) and the notion of perceived complexity is explained, reducing the ongoing ambiguity in literature.

With the help of rigorous analysis of existing approaches and feedback from our industry partners, we have developed a unique practice-oriented methodology to measure complexity in production that is focusing on perceived complexity. Our methodology links human behavior to organizational performance and underlines the importance of taking into account the perceived emotions of the shop floor operator along with the existing metrics. A three-dimensional approach to complexity assessment in production has been presented. The KMP approach proposes that production complexity needs to be identified, redistributed and managed, resulting in better work design and system performance.

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References

1. Tücks, G., et al.: Komplexität in der Fertigung beherrschen. Complex. Manag. J. **1**, 9–14 (2011). Aachen
2. Efthymiou, K., et al.: Manufacturing systems complexity analysis methods and review. Int. J. Comput. Integr. Manuf. **30**, 1362–3052 (2016)
3. Hon, K.K.B.: Performance and evaluation of manufacturing systems. CIRP Ann. Manufact. Technol. **54**(2), 139–154 (2005)
4. Monostori, L.: Cyber-physical production systems: roots, expectations and R&D challenges. Procedia CIRP **17**, 9–13 (2014). Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems
5. Ashby, W.R.: Requisite variety and its implications for the control of complex systems. Cybernetica **1**(2), 83–99 (1958)
6. Juravich, T.: Chaos on the Shop Floor: A Worker's View of Quality, Productivity, and Management, pp. 6–100. Temple University Press, US (1998)
7. Badura, B., Schröder, H., Klose, J., Macco, K.: Fehlzeiten-Report 2009: Arbeit und Psyche: Belastungen reduzieren – Wohlbefinden fördern, German Edition. Springer (2010)
8. Mallory, R.E.: Quality Standards for Highly Effective Government. Trafford, Washington, DC (2014)
9. Sivadasan, S., et al.: An information-theoretic methodology for measuring the operation al complexity of supplier-customer systems. Int. J. Oper. Prod. Manag. **22**(1), 80–102 (2002)
10. Kumari, M., Kulkarni, M.S.: A complexity based look-ahead mechanism for shop floor decision making. In: Proceedings of the 48th CIRP Conference on Manufacturing Systems, vol. 41, pp. 63–68 (2016)
11. De Toni, A.F., et al.: Complexity measures in manufacturing systems. In: Proceedings of the European Conference on Complex Systems. Internationale Universitaire, Paris, France, pp. 1–20, 14–18 (2005)

12. Gu, C., et al.: Reliability-oriented complexity analysis of manufacturing systems based on fuzzy axiomatic domain mapping. In: 10th International Conference on Axiomatic Design (ICAD2016), vol. 53, pp. 130–135 (2016)
13. Mattsson, S., et al.: Validation of the complexity index method at three manufacturing companies. In: IEEE International Symposium on Assembly and Manufacturing (ISAM), pp. 55–57 (2013)
14. Mattsson, S., et al.: Perceived production complexity - understanding more than parts of a system. Int. J. Prod. Res. **54**, 1–9 (2016)
15. Clark, J.B., Jacques, D.R.: Practical measurement of complexity in dynamic systems. In: Proceedings of the Conference on Systems Engineering Research, vol. 8, pp. 14–21 (2012)
16. ElMaraghy, W., et al.: Complexity in engineering design and manufacturing. CIRP Ann. Manufact. Technol. **61**, 793–814 (2012). Version 2
17. Banerjee, A., Brinzer, B.: Complexity management and modern production systems. In: 23rd International Conference European Operations Management (EUROMA), Trondheim, Norway (2016)
18. Deshmukh, A., et al.: Complexity in manufacturing systems, Part 1: analysis of static complexity. IIE Trans. **30**(7), 645–655 (1999)
19. Greenberg, J.: Behavior in Organizations, 10th edition, New Jersey (2010)
20. Banerjee, A.: Integrating human motivation in service productivity. Procedia Manufact. **3**, 3591–3598 (2015). AHFE Conference Proceedings
21. Dalhöfer, J.: Führung in komplexitätsmanagement, vol. 107, pp. 87–93 (2012). ZWF Jahrg
22. Heckhausen, J., Heckhausen, H.: Motivation und Handeln. Springer, Verlag (2010)
23. Conti, R.: The effects of lean production on worker stress. Int. J. Oper. Prod. Manag. **26**(9), 1013–1038 (2006)
24. Cranwell-Ward, J., Abbey, A.: Organizational Stress. Palgrave Macmillan, UK (1998)
25. Karasek, R.A.: Job demands, job decision latitude and mental strain: implications for job Redesign. Admin. Sci. Quart. **24**, 285–308 (1979)
26. Karasek, R.A., Theorell, T.: Healthy Work: Stress Productivity and the Reconstruction of Working Life. Basic Books, New York (1992)
27. Lazarus, R.S.: Theory-based stress measurement. Psychol. Inq. **1**, 3–13 (1990). Abstract-PsycINFO
28. Johnson, S., Cooper, C.: The construct validity of the ASSET stress measure. Stress and Health 19, 3 rd edn. Wiley InterScience, pp. 181–185 (2003)
29. Anderson, J.R.: Cognitive Psychology and its Implications, 3rd edn., New York (1990)
30. Siegrist, J.: A theory of occupational stress. In: Dunham, J. (ed.) Stress in the Workplace, pp. 52–66. Whurr Publishers, London (2001)
31. Poppelreuter, S., Mierke, K.: Psychische Belastungen am Arbeitsplatz, 4th edn. Erich Schmidt Verlag, Berlin (2012). ISBN 978-3-503-14123-4
32. Rudow, B.: Die gesunde Arbeit. Psychische Belastungen, Arbeitsgestaltung und Arbeitsorganisation, 3rd edn. Oldenbourg Wissenschaftsverlag, München (2014)
33. Kristensen, T.S., et al.: The copenhagen psychosocial questionnaire (COPSOQ) - a tool for the assessment and improvement of the psychosocial work environment. Scand. J. Work Environ. Health **31**, 438–449 (2005)
34. The IMPULS-Test. http://www.impulstest2.info/
35. Falck, A.: Criteria for assessment of basic manual assembly complexity. In: 6th CIRP Conference on Assembly Technologies and Systems (CATS) Procedia CIRP, vol. 44, pp. 424–428 (2016)

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