Implementation of TPM Methodology in Worker Fatigue Management - A Macroergonomic Approach

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Abstract. The article describes the use of TPM pillars: Focused Improvement, Autonomous Maintenance, Planned Maintenance, Quality Maintenance, Early Equipment Management and Training and Education, along with their implementation for the purposes of fatigue management. Among the various techniques used as part of TPM, the techniques that allow better control over the welfare and safety of workers are highlighted. The following methods proved particularly useful in fatigue management: Focused Improvement, where small groups of employees work together proactively to achieve a regular, incremental improvement in safety and fatigue management, as well as Training to establish responsible behavioral patterns in the management of fatigue of both employees and management. The article also presents a theoretical application of the Overall Labor Effectiveness (OLE) indicator, which is analogous to the Overall Equipment Effectiveness (OEE) indicator for the purposes of fatigue management.

Keywords: Ergonomic design · TPM in fatigue management · Systems engineering · Design for deficits

1 Introduction

Fatigue management is the next step in improving workplace safety. This process progresses along with developing operational excellence in other key areas of an enterprise, such as logistics, production and maintenance. Each has an effect on the enterprise achieving corporate success, and shortcomings in any of these areas can bring about a dangerous dysfunction of the whole system. With the implementation of excellence systems such as Total Productive Maintenance (TPM), enterprises achieve not only a common course of action, but also a common methodology. The applicability of TPM methodology and its related tools was observed while developing a fatigue management system for employees of bituminous coal mines. This, along with macroergonomic considerations of fatigue management, gives an opportunity to implement fatigue management into the context of occupational health and safety

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management systems, and based on that create high functioning decision support for stakeholders.

2 Fatigue Management in the Mining Industry

Interest in fatigue management is particularly evident in areas of human activity where the consequences of even the smallest errors due to fatigue can have tragic consequences. One such area is certainly bituminous coal mining, which both in Poland and around the world is subject to special supervision because of the threat to life involved in underground workings [1–4]. This situation arises due to the specific working conditions in this sector and is associated with the occurrence of virtually all natural hazards, the avoidance of which requires employees to have a significant level of psychomotor performance.

Management is a natural consequence of work performed under certain conditions and time. Increasing exhaustion resulting from undertaken effort (physical or mental–includes readiness for effort) [5] along with human capabilities, establish the curve of the potential to carry out tasks in a work system. The ability to work is multidimensional and its variability is due to both fatigue resulting from exertion and the natural variability in human abilities due to biological rhythms (Fig. 1).

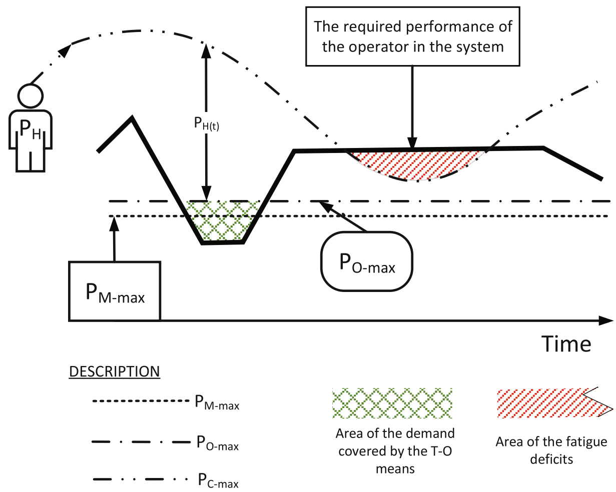

Fig. 1. Fatigue–concept of operator performance (source: own elaboration)

The operator's potential (performance level) supplements the technological and organizational solutions existing in the work environment ($P_{M\text{-max}}$ – maximum machine potential, $P_{O\text{-max}}$ – maximum organizational potential), thereby defining the human potential in that moment $P_{H(t)}$, which equates to the demand. The difference between the points on the curve of the required performance of the system and the curve of human potential, determines the level of excessive fatigue, which in a given industry is classified as satisfactory or unsatisfactory. In the event that technological and organizational measures exceed the requirements of the T-O system, the work system is temporarily self-sufficient and unattended. The operator remains on standby until the need arises (but monitoring itself is an operator's participation in the work system). This approach shows that fatigue management involves the appropriate administration of the course of human potential $P_{H,}$ and the supporting technological and organizational measures $P_{M\text{-}max}$, $P_{O\text{-}max,}$ in relation to the requirements generated by the work system and its immediate surroundings (Fig. 2).

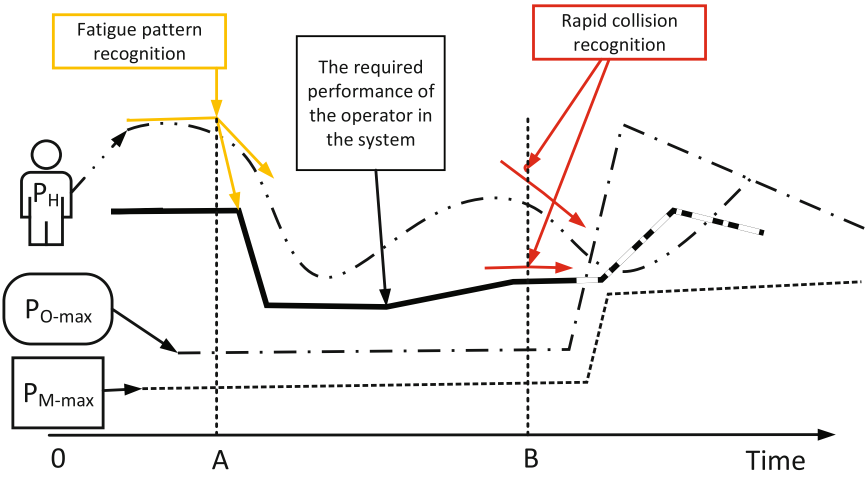

Fig. 2. Fatigue–prevention of operator fatigue (source: own elaboration)

In practice, there is a number of factors associated with the external environment that are crucial to take into account when applying systems and process fatigue management [6]. Basic problems contained in fatigue management include:

- recognition of the symptoms of fatigue before it reaches a level high enough that it threatens the safety of the work system–a number of publications exist on the methods for efficient and non-invasive detection of fatigue [7–9] or systems to recognize performance exhibiting fatigue [10]–a comparison of systems can be found [11], however, subjective measures based on self-reporting are also used [12–14], and are recognized as an efficient tool for the detection of fatigue,
- allocation of tasks to employees in a way that maximizes their potential to perform work, optimizing the risk of fatigue leading to undesirable situations,
- an operator's return to equilibrium from a fatigue state, allowing one to return to performing operations (a way to restore an employee back to work in the system), which is related to the issue of situational awareness and the ability to re-assume responsibility for the tasks performed by the operator (if the system detected a level of fatigue that made it impossible to continue working safely–so-called back in the loop [15]),

- ensuring an appropriately low initial level of fatigue through the management of environmental factors outside of work,
- integration of fatigue management into a company's other activities, in a way that enables the achievement of the aforementioned goals.

In view of the wide range of the above-mentioned mentioned issues, this article presents the ability to systematize activities in a fatigue management system through the use of the TPM approach.

3 TPM and Its Use in Fatigue Management

A modern approach to operation maintenance is the TPM (Total Productive Maintenance) program. This management philosophy includes all employees in the effective management and maintenance of machinery through the elimination of any sources of losses following the client's requirements [16]. The general idea of TPM is to organize repairs within the production team to improve performance of maintenance and production staff and re-design and reconfigure equipment in a manner that makes it more reliable and easier to maintain. This achieves equipment reliability, preventing human terror, and eliminating accidents, which are the main goals of TPM [17, 18]. A desirable side effect of TPM is increasing employee morale and job satisfaction, which also increases worker safety [19]. To achieve this goal, the so-called TPM pillars are used: Focused Improvement, Autonomous Maintenance, Planned Maintenance, Quality Maintenance, Early Equipment Management and Training and Education. All these pillars can be used for the purposes of fatigue management. Among the various techniques used as part of TPM, the techniques that allow better control over the welfare and safety of workers should be highlighted. Some methods of TPM proved particularly useful in fatigue management: Focused Improvement, where small groups of employees work together proactively to achieve a regular, incremental improvement in safety and fatigue management, as well as Training to establish responsible behavioral patterns in the management of fatigue of both employees and management.

Table 1 presents objectives for each of the pillars of TPM with the corresponding actions for fatigue management. Analogously to TPM, where undertaken actions provide continuous and effective machine operation, in fatigue management the same goals are implemented for the employee. In fatigue management, maximizing employee efficiency does not equal maximizing employee effort but its optimization.

The indicators used in TPM methodology may also be implemented in fatigue management. One example would be the Overall Labor Effectiveness (OLE) indicator, which is analogous to the Overall Equipment Effectiveness (OEE) indicator. OLE accumulates three workforce factors [21]:

- Availability: the percentage of time the workforce spends making effective contributions,
- Performance: the amount of product delivered (in mining companies amount of produced coal per shift, team etc.),
- Quality: the percentage of perfect or saleable product produced (quality of produced coal).

Table 1. The application of TPM in fatigue management (own elaboration based on [20]).

TPM pillar	TPM goal and tools	Use of TPM in fatigue management
Autonomous maintenance	Fostering operator ownership–own: cleaning, lubricating, tightening, adjustment, inspection	Anti-fatigue self-control, recognition of states preceding chronic fatigue
Focus improvement	Systematic identification and elimination of losses (5-whys, FMEA, OEE implementation)	Recognition of losses related to human labor, detection of operations that cause unnecessary fatigue, burdening the employee without providing adequate work results
Planned maintenance	Preventive Maintenance (PM) and Predictive Maintenance (PdM)–used tools (PM check sheets, MTBF)	Constantly striving to limit fatigue-inducing factors. Use of MTBF as an indicator of the adequacy of scheduled tasks (repair is understood as the time that will be needed to be able to return to performing work)
Quality maintenance	Zero defects approach M-optimization (machine/man/material/money)	Optimization of work factors and its surroundings in order to reach the absence of overload in any undertaken action
Education & training	Multi-skilling of employees Aligning employees to organizational goals. Periodic skill evaluation and updating	Training and awareness of employees in relation to activities of fatigue management. Staff multitasking to ensure appropriate conditions for rotation and uniform division of load among employees
Safety & environment	Ensure safe working environment	Measures to improve the safety culture, even in the case of high-risk work (mining)
TPM in administration	Improve synergy between various business functions	Enhancement of the tribes and silos value-added approach, improvement in department synergy

The use of OLE indicator in fatigue management involves compiling its value with workplace conditions and the studied work factors. Achieving system synergy (using the remaining TPM tools) allows one to search for losses or unproductive activities. Thus, actions within the work system will be verified according to their impact on the productivity of the workforce.

An important advantage of TPM in fatigue management may be actions that mitigate losses. Examples of the application of particular categories of losses are presented in Table 2.

Losses may seemingly appear to provide relief in a work system by providing unscheduled breaks, however, because they appear randomly and are unpredictable

Table 2. Scope of the application of TPM in fatigue management (own elaboration based on [20]).

Type of loss	Nature of losses, which should be detected and eliminated as part of fatigue management
Breakdown/failure	Working with inefficient/broken equipment
Set-up and adjustment	Breaks due to changeovers improperly utilized
Reduced speed	Working slower than the projected speed of equipment - hardware
Idling and minor stoppage	Stopping flow in the work system which requires corrective action on the part of the operator
Defect and rework	Fatigue resulting from the need to fix defects at work and re-perform/re-work tasks
Start-up	Working during start-up, a long period of adjusting pace after resuming work
Tool changeover	Loss of time and labor on performing tool changes due to damage or wear outside the scheduled period of service
Distribution/logistic	Lack of automation of highly repetitive tasks leading to inefficient human labor
Line organization	Unsynchronized production line causing downtime on the job
Measurement and adjustment	Multiple repetitions of measurement and control tasks
Management	Losses arising from waiting for a decision–instruction, course of action–losses resulting from inadequate division of competences
Motion-related	Lack of motion economy, unnecessary tasks and transitions

they result in increased time pressure during operation (making up losses), and will consequently decrease employee performance.

4 TPM in a Fatigue Management Integration System

Activities in fatigue management (detection of early symptoms, the allocation of tasks in order to reduce the effects of fatigue, etc.) require the application of process changes in the employee management system, which can be included in the following list of requirements [22]:

1. Detailing the scope, objectives and tasks of individual processes–which will help direct focus on how to conduct employees to limit their fatigue by making decisions based on the results of monitoring of selected characteristics of the physical and mental state of employees when performing specified actions.
2. Conducting an in-depth analysis of labor standards and the preparation of changes that reduce the risk of fatigue of workers employed in specific work positions.
3. Introducing cyclical extensive analyses of accidents resulting from fatigue and decision-making on the basis of these findings - to supplement existing procedures or developing new ones.

4. Developing a fatigue factor monitoring system, simultaneously aimed at distinguishing fatigue factors and work positions particularly exposed to the risk of excessive influence of a particular factor.
5. Developing a final list of positions and tasks particularly causing an increase in fatigue, which will form the research sample during the implementation of an employee fatigue management system.
6. Implementing a monitoring system by: selecting the scope of the application of the system, guidelines for its use, those responsible for its use, conducting training for users, support during its first application.
7. Detecting relations resulting from new solutions and introducing them to a schema of IT and physical links between components of the system.
8. Developing a set of measures and norms for an assessment of fatigue at analyzed workstations and periodically comparing the achieved results.
9. Developing measures or indicators testifying to the effectiveness of the worker fatigue management system.
10. Supplementing the description of operations (procedures, instructions) with new or modified activities related to limiting fatigue, but also to carrying out an extended analysis of accidents, training and tutorials, operation of the fatigue factors monitoring system, systematic analysis of data on fatigue factors and decision-making with regard to the prevention of the consequences of fatigue in individual employees as well as an analysis of the system's performance indicators.
11. Confronting the introduced procedural changes with employee representatives, and hence ensuring their acceptance and success in the implementation of changes.
12. Determining which actions are indispensable for employee fatigue management, assigning them clearly defined responsibilities, incorporating them into duties as well as informing the employees.
13. Conducting training and tutorials among staff in order to create favorable attitudes and behavior towards the fatigue management system.
14. Conducting a series of training sessions on improving the quality of sleep and reducing stressful factors and raising individual abilities to limit fatigue resulting from the performed work.

The above-mentioned activities of various strategic level (micro-, meso- and macroergonomic) [23] may be sorted according to a scheme of implementation supported by the TPM method. Despite the fact that ergonomics in fatigue management at the level of work positions will be a very important factor in limiting fatigue, e.g. by adapting the work space [24] or the mental strain of operators [25, 26] there are sought ways to integrate these activities to achieve a higher purpose which is the safety and welfare of workers [27, 28]. A plan for the systemic implementation of fatigue management with the use of TPM is presented in Fig. 3.

Activities related to individual management functions undertaken independently will not have a significant impact on improving fatigue states in workers. The TPM approach may be applied to systematize management activities.

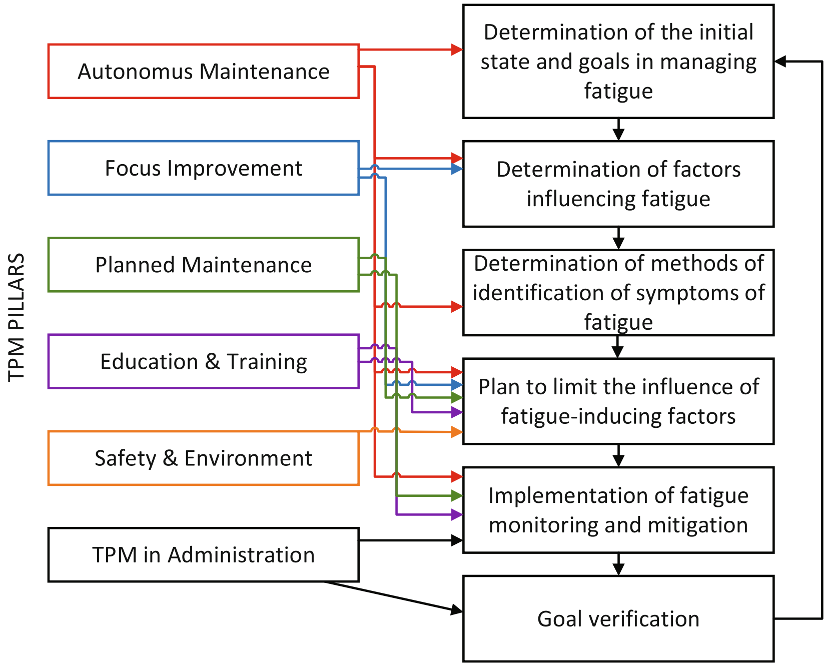

Fig. 3. Fatigue management implementation plan (source: own elaboration based on [29])

5 Conclusions

Fatigue management is a relatively new approach in the fields of management science and production organization. It seems that the next step on the road to excellence of production systems will be resource management in the context of achieving employee welfare. Fatigue management may also be a key factor in the issue of adapting work systems to an aging population. Work performed by the elderly will involve the need to ensure the safety of staff and work systems along with the immediate surroundings. This topic has been given a lot of thought in a number of publications in relation to micro- [30, 31] and macroergonomics [32]. Future work systems will require a much greater level of responsibility, hence the greater need for integration of various systems of business excellence and integration of proven systems such as TPM.

References

1. Homer, A.W.: Coal mine safety regulation in China and the USA. J. Contemp. Asia **39**, 424–439 (2009)
2. Bagherpour, R., Yarahmadi, R., Khademian, A.: Safety risk assessment of Iran's underground coal mines based on preventive and preparative measures. Hum. Ecol. Risk Assess. An Int. J. **21**, 2223–2238 (2015)

3. Piekarski, C., Seyl, G., Bardeleben J.: State of miners' health in Germany, applied occupational and environmental hygiene. In: The Second International Conference on the Health of Miners, vol. 12, pp. 815–819 (1997)
4. Konopko, W. (ed.): Work safety in bituminous coal mines (in Polish: Bezpieczeństwo pracy w kopalniach węgla kamiennego). Górnictwo i środowisko, vol. 1. Główny Instytut Górnictwa, Katowice (2013)
5. Soames-Job, R.F., Dalziel, J.: Defining fatigue as an condition of the organism and distinguishing it from habituation, adaptation and boredom. In: Hancock, P.A., Desmond, P. A. (eds.) Stress, Workload, and Fatigue, p. 471. Erlbaum, Mahwah (2001)
6. Mrugalska, B., Nazir, S., Tytyk, E., Øvergård, K.I.: Process safety control for occupational accident prevention. In: Arezes, P.M., et al. (eds.), Occupational Safety and Hygiene III, pp. 365–369. CRC Press, Taylor & Francis Group, London (2015)
7. Heinze, C., Trutschel, U., Schnupp, T., Sommer, D., Schenka, A., Krajewski, J., Golz, M.: Operator fatigue estimation using heart rate measures. In: World Congress on Medical Physics and Biomedical Engineering, pp. 930–933. Springer, Heidelberg (2009)
8. Krajewski, J., Trutschel, U., Golz, M., Sommer, D., Edwards, D.: Estimating fatigue from predetermined speech samples transmitted by operator communication systems. In: Proceedings International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, vol. 5, pp. 468–474. University of Iowa Public Policy Center, Iowa City (2009)
9. Trejo, L.J., Knuth, K., Prado, R., Rosipal, R., Kubitz, K., Kochavi, R., Matthews, B., Zhang, Y.: EEG-based estimation of mental fatigue: convergent evidence for a three-state model. In: Schmorrow, D.D., Reeves, L.M. (eds.) Augmented Cognition, HCII 2007. LNAI, vol. 4565, pp. 201–211. Springer, Heidelberg (2007)
10. Sadłowska-Wrzesińska, J., Gabryelewicz, I., Krupa, P.: The use of IT tools for the analysis and evaluation of psychomotor efficiency of employees. In: Oancea, G., Drăgoi,. M.V. (eds.) The 4th International Conference on Computing and Solutions in Manufacturing Engineering, CoSME 2016. MATEC Web of Conferences, vol. 94(06017) (2017)
11. Butlewski, M., Hankiewicz, K.: Psychomotor performance monitoring system in the context of fatigue and accident prevention. Procedia Manuf. **3**, 4860–4867 (2015)
12. Borg, G.A.: Psychophysical bases of perceived exertion. Med. Sci. Sports Exerc. **14**(5), 377–381 (1982)
13. Kaida, K., Takahashi, M., Åkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., Fukasawa, K.: Validation of the Karolinska sleepiness scale against performance and EEG variables. Clin. Neurophysiol. **117**(7), 1574–1581 (2006)
14. Belz, S.M., Robinson, G.S., Casali, J.G.: Temporal separation and self-rating of alertness as indicators of driver fatigue in commercial motor vehicle operators. Hum. Factors: J. Hum. Factors Ergon. Soc. **46**(1), 154–169 (2004)
15. Inagaki, T.: Smart collaboration between humans and machines based on mutual understanding. Ann. Rev. Control **32**(2), 253–261 (2008)
16. Misztal, A., Butlewski, M., Belu, N., Ionescu, L.M.: Creating involvement of production workers by reliable technical maintenance. In: International Conference on Production Research-Regional Conference Africa, Europe and the Middle East and 3rd International Conference on Quality and Innovation in Engineering and Management, ICPR-AEM 2014, pp. 322–327. Technical University, Cluj-Napoka (2014)
17. Jasiulewicz-Kaczmarek, M., Drożyner, P.: Preventive and pro-active ergonomics influence on maintenance excellence level. In: Robertson, M.M. (ed.) Ergonomics and Health Aspects, HCII 2011. LNCS, vol. 6779, pp. 49–58. Springer, Berlin Heidelberg (2011)
18. Grzybowska, K., Gajdzik, B.: Optimisation of equipment setup processes in enterprises. Metalurgija **51**(4), 563–566 (2012)

19. Mrugalska, B., Arezes, P.M.: An investigation of safety design practices of metal machines. Work: A J. of Prev. Assess. Rehabil. **51**(4), 747–755 (2015)
20. Ahuja, I.P.S., Khamba, J.S.: Total productive maintenance: literature review and directions. Int. J. Qual. Reliab. Manage. **25**(7), 709–756 (2008)
21. Kronos: Overall Labor Effectiveness (OLE): Achieving a Highly Effective Workforce. http://www.workforceinstitute.org/wp-content/uploads/2008/01/ole-achievinghighly-effective-workforce.pdf, Accessed 20 Sep 2016
22. Butlewski, M., Misztal, A.: Direction of process management in a worker fatigue management system. The Małopolska School of Economics in Tarnów Research Papers Collection (in Polish: Kierunki zmian procesowych w systemie zarządzania zmęczeniem pracowników). Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie, **3**(31), 71–82 (2016)
23. Butlewski M., Tytyk E.: The assessment criteria of the ergonomic quality of anthropotechnical mega-systems. In: Vink, P. (ed.) Advances in Social and Organizational Factors, pp. 298–306. CRC Press, Taylor and Francis Group, Boca Raton (2012)
24. Vujica-Herzog, N., Vujica Beharić, R., Beharić, A., Buchmeister, B.: Ergonomic analysis of ophthalmic nurse workplace using 3D simulation. Int. J. Simul. Model. **13**(4), 409–418 (2014)
25. Butlewski, M., Slawinska, M.: Ergonomic method for the implementation of occupational safety systems. In: Arezes, P., et al. (eds.) Occupational Safety and Hygiene II, pp. 621–626. CRC Press, Taylor & Francis Group, London (2014)
26. Górny, A.: Minimum safety requirements for the use of work equipment (for example of control devices). In: Arezes, P., et al. (eds.) Occupational Safety and Hygiene, pp. 164–165. Portuguese Society of Occupational Safety and Hygiene (SPOSHO), Guimarães (2013)
27. Górny, A.: Ergonomics in the formation of work condition quality. Work J. Prev. Assess. Rehabil. **1**(supp. 1), 1708–1711 (2012)
28. Górny, A.: The use of working environment factors as criteria in assessing the capacity to carry out processes. In: Oancea, G., Drăgoi, M.V. (eds.) The 4th International Conference on Computing and Solutions in Manufacturing Engineering, CoSME 2016. MATEC Web of Conferences, vol. 94(04011) (2017)
29. Total Productive Maintenance. http://isoconsultantpune.com/total-productive-maintenance/, Accessed 20 Jan 2017
30. Lis, K.: The labour market and material environment design. In: Vink, P. (ed.) Advances in Social and Organizational Factors, pp. 603–612. CRC Press, Taylor & Francis Group, Boca Raton (2012)
31. Butlewski, M.: Practical approaches in the design of everyday objects for the elderly. Appl. Mech. Mater. **657**, 1061–1065 (2014)
32. Butlewski, M., Tytyk, E., Wróbel, K.: Macroergonomic model of quality of life of elderly employees for design purposes. In: Vink, P. (ed.) Advances in Social and Organizational Factors. AHFE Conference, pp. 252–260 (2014)