Usability of Machinery

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Abstract. In our interrelated world with global market the responsibility and hence the potential to improve machinery safety lays on several actors including designers, manufacturers, end users and regulatory, standardization, representative, lobby organizations. On one hand according to the "free movement of goods" concept machinery safety is regulated like the safety of other products, including involvement of notified bodies, conformity assessment and international standards with mandatory requirements. On the other hand the provision of a safe and healthy workplace is a well respected value therefore national regulations are there on the use of tools including machinery in workplaces by workers. In both area the basic concept of safety is the management of risk, but the two approaches differ due to the differences in the quantity and diversity of machinery handled and due to the knowledge on target group and on the use. Although there several ways to link design and usage including e.g. standardization, acquisition, user-oriented design, the risk of machinery at the workplaces is not eliminated and workplace accidents with machinery still occur. This paper shows how risk assessment at workplaces and risk assessment in machinery safety should be connected, how knowledge of workers can be utilized in the design and how in general usability methodology evolved in software ergonomics can be applied in machinery design to improve workplace safety.

Keywords: Machinery safety · Usability inherently safe design · Inherently safe design · Foreseeable behavior · Ergonomics standards · CERA

1 Introduction

The U.S. Bureau of Labor Statistics reported 59,830 nonfatal occupational injuries and illnesses involving days away from work in 2015 where machinery was identified as the source of injury or illness (Table 1) [1]. Work equipments, including hand tools and machinery was responsible for more than 100.000 injuries or illness just in the US in a single year.

European statistics on accidents at work (ESAW) [2] show that fatal accidents due to working equipments including operating machine and working with hand-held tools happen relatively rare, but the total number of fatalities is still over hundred in the EU (Table 2). Accidents with machinery leading to more than tree days away from work happened 40,918 times. Both table include incidence rates of accidents interpreted as the number of accidents per 100,000 workers in a year period.

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Table 1. Number, incidence rate, and median days away from work for nonfatal occupational injuries and illnesses involving days away from work, US 2015

Source of injury or illness	Number	Incidence rate	Median days away from work
Machinery	59,830	54	7
Hand tools	52,030	47	5

Table 2. Workplace accidents in Manufacturing in the European Union (28 countries) in 2014

	Operating machine		Working with hand-held tools		Total	
	Number	Incidence rate	Number	Incidence rate	Number	Incidence rate
Fatal	71	0.22	29	0.09	574	1.78
4 or over days away from work	40,918	127.03	51,671	160.41	619,921	1,924.5

Boy and Limou [3] gave several examples when labor inspectors and other public authorities or notified bodies found machinery used in workplaces non meeting essential safety and health requirements. This study also suggest that these cases are not special and manufacturers frequently neglect requirements.

Although criteria used in the Composite Ergonomics Risk Assessment CERA [4] implement safety and health requirements laid down in harmonized standards, and should be assessed and decreased in the design process, just a few risk assessment ended without any reds. CERA was created to assess ergonomic risks resulted from bad postures [5], manual handling [6], force extension [7] and repetitive movements [8] at workplaces. The risk is unacceptable almost at every machine handling operation due to bad postures and these twisted/tilted/awkward postures act as contributing factors of other ergonomic risk decreasing the acceptable manual lifting weight limit or force limits or movement frequency. Since the EN 1005 standard series contains several independent assessment neither CERA provide a final score, but sums the number of greens/yellows and reds according to the relevant risks. CERA become popular in Hungary and was used for hundreds time. The shocking experience is that the question is not whether the workstation is acceptable or needs improvement but the number of reds, or how to explain to employers that the tool they are using shouldn't be installed at the first place due to the lack of compliance of health and safety requirements of machinery.

Several manufacturers work in close collaboration with their consumers, register every piece of machinery sold and its operators, the designer knows the real user behavior and this knowledge is fed to the design process and applied. Although the best collaboration should be expected when the personnel responsible for the safety in design and the personnel responsible for the operational, the workplace safety, is the same, these in-house machinery productions often lead to shortcuts, and some requirements is omitted like no conformity assessment is made or no technical documentation is done.

In real designing for human error is not easy partly because that errors are hard to predict partly because the use proper methods requires extensive expertise and are too expensive for non safety-critical cases [9]. The number of accidents related to machinery at workplaces and the wide spectrum of practices and examples of non-conformities should mean that the link between the design and use is random and indirect, and information on use required in the design phase is not accessible or incomplete.

2 Design and Operation

The ILO code of practice on Safety and health in the use of machinery fits together design and operational phases [10]. The life cycle of a machine starts on the left with design and ends on the right with decommissioning. Designers, suppliers and manufacturers are the key actors on the production side while workers play the user role and employers bear responsibility for safety on the operational side.

The code of practice expects designers, manufacturers, suppliers, employers, workers and their representatives to cooperate actively on safety and health in the use of machinery. The information of malfunctions, dangerous occurrences and accidents and diseases should be collected, reported at the workplace and feed back to designers likewise any new risks and measures taken to control end prevent recurrences. This gathered information on accidents and diseases is supposed to help manufacturers and designers to understand their product, users, the use, hazards better and should be used to improve the safety of machinery. The information provided from the feedback from workplaces allow designers to conduct a proper determination of limits of the machinery required by the mandatory risk assessment, covering the full range of uses of their machinery including the intended use and any reasonably foreseeable misuse as well.

3 European Regulations

In the European Union the Machinery directive regulates the machinery market according to the single market concept [11]. This directive requires all member states to operate the same processes and use the very same safety and healthy requirements when assessing safety of machinery. Core element of the directive are the conformity assessment, the involvement of notified (independent, assigned, registered) bodies, the CE mark with the declaration of conformity and harmonized standards. Harmonized standards are adopted by a European standardization body (CEN, CENELEC or ETSI) and published in the Official Journal of the European Union [12]. These standards are not binding but the safety and health level they require must be met. Over 700 Type C standards deal with defined types of machinery and describe detailed specific safety requirements. Type B standards like the EN 1005 covers specific aspects of machinery safety or contain safety requirements applicable in several types of machinery. For every type of machinery set requirements the single type A standard EN ISO 12100:2010 Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO 12100:2010) [13].

The essential health and safety requirements relating to the design and construction of machinery laid down in this directive adopt the provisions of EN ISO 12100-1:2003 when as part of the risk assessment requires the identification of intended use and any reasonably foreseeable misuse of the machinery, and the hazards that can be generated by the machinery and the associated hazardous situations. According to the directive 'intended use' means the use of machinery as planed and documented in the instructions for use and reasonably foreseeable misuse' means other ways of use which may result from readily predictable human behavior. Principles of safety integration of the directive states that risk not only related to the conditions foreseen but also to reasonably foreseeable misuse should be prevented and the remaining risks communicated [11].

In the EU the CE mark represents the marketability including the conformity and the ability to use at workplaces as work tool (Fig. 1).

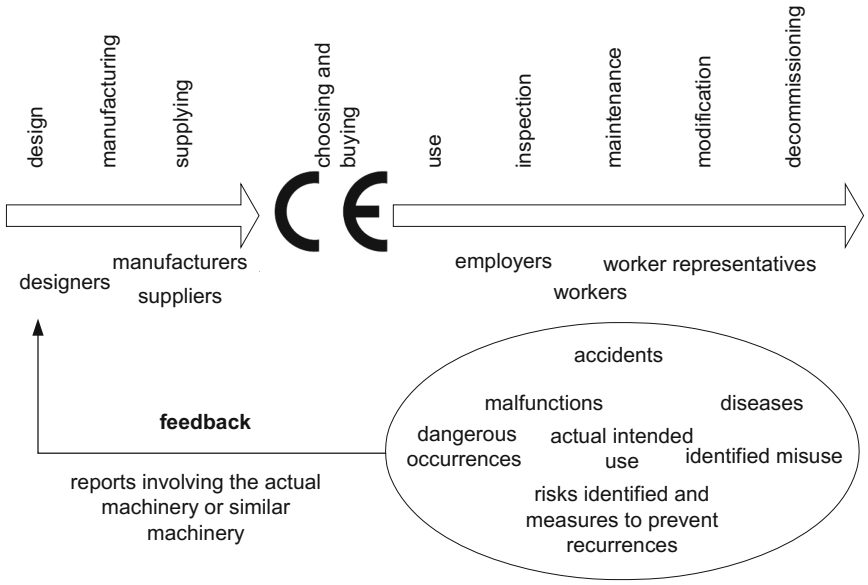

Fig. 1. Design and operational phases of machinery

The regulation on occupational health and safety matters follows a leveling approach, and member states have different legislations. The frame directive [14] and several other directives defines minimum requirements e.g. workplaces [15], fishing vessels [16], work with display screen equipment [17]. The directive on work equipment by workers [18] set obligations on employers and workers, and contains minimum requirements to work equipments. 'Work equipment' means here : any machine, apparatus, tool or installation used at work, and the 'use of work equipment' means activities like starting or stopping the equipment, its use, transport, repair, modification, maintenance and servicing, including, in particular, cleaning.

Performing the risk assessment required by the frame directive these minimum requirements often used in hazard identification.

The feedback from the workplaces to the manufacturers only provided through the market surveillance process, but no direct link required like the involvement of manufacturers in accident investigation or worker surveys on the use of machinery.

4 Human Machine Interface

The EU-OSHA report on the human machine interface (HMI) as an emerging risk summarized that field studies are needed to understand organizational and environmental factors to reduce the risk related to human machine interfaces. It states that usability engineering not recognized despite the it's competitive advantage, and users are involved mostly is validation tests Steps to be taken are e.g. [19].

- improvement and harmonization of accident investigation and reporting,
- usability tests should be applied and extended beyond normal operation, including emergency situations,
- understanding the specifics of various worker groups,
- improving user-friendliness systems,
- determination of the financial consequences of optimal HMI,
- developers, users and suppliers must increase collaboration.

The definition of 'usability' means the ability of a machine to be easily used owing to, among others, properties or characteristics that enable its function(s) to be easily understood [13]. The definition of usability is broader however. Usability also means 'the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use' [20], likewise foreseeable use means the "use of a product that is capable of being known or anticipated in advance based on a supplier's best knowledge about the product" in the consumer product safety approach [21]. These differences should be bridged and the broader usability approach implemented to guarantee the safe design aimed by the user feedback.

The responsibility for identification of all plausible scenarios can easily be omitted when the manufacturer conducts the assessment and issues the declaration of conformity not being aware several other relevant harmonized standards. When approval authority are involved the type approval procedure lays the responsibility primarily with them, so and designers are not forced to consider the implications of their design [22].

By using a participatory design paradigm, manufacturers can understand user needs from the start of the design process, e.g. use-ware-methods was adapted from web-design by consumer industry, and later penetrated industrial areas [23].

5 Feedback Method

The new EN 16710-2 Ergonomics methods – Part 2: A methodology for work analysis to support design [23] provide a methodology and framework to analyze and understand end users' performance with machineries. The work system is describe with the work activity in focus, and thanks to the system approach it contains both technical and human

inputs on the left and outputs on the right (Fig. 2) technical and organizational means (e.g. machinery, premises, work organization, maintenance policy) and personal resources (e.g. age, gender, training), economic performance results (quantitative or qualitative) and positive-negative/short term/long term effects on worker (e.g. performance, health, safety) respectively.

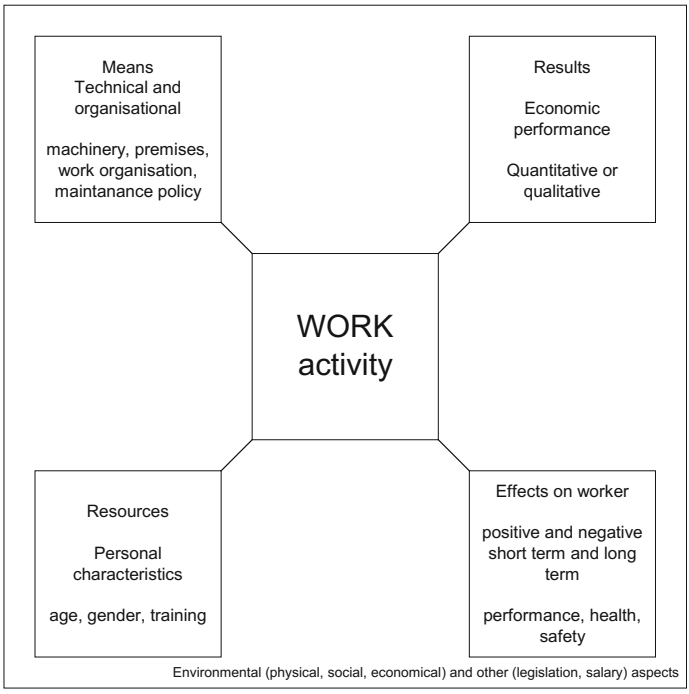

Fig. 2. "The activity focused work system" based on EN 16710-2

A recent European technical report describes the Feedback method to understand how end users perform their work with machines [24]. The feedback method is a structured way to solicit skilled workers opinion [25]. The under laying idea is that some workers have training and work experience on the installation, operation, maintenance of the machinery in question and their knowledge can be distilled and documented in a standardized way. The process mentioned lead by a specialist trough the following steps:

- preparation, collection of information related to the machine in question,
- observation of workplaces where this machine is used,
- structured interview with skilled workers,
- result validation,
- documentation.

The observation aims all the feed back elements suggested in the Design and operational phases of machinery (Fig. 1) and covers all aspects mentioned in the "activity focused work system" (Fig. 2) including all work phases in details from normal operation

to unplanned maintenance. Signs of misuse can be identified by gathering information on near-misses and accidents with the machine.
Some application show that the feedback method can be used to

- identify design errors or errors of existing standard in the design stage,
- verify and validate existing results,
- monitoring work efficiencies [25].

Based on the work analysis a group of skilled workers reconstructs the work activity and carries out a systematic analysis of each work activity producing e.g. a list of critical aspects of the machinery.

6 Conclusion

In spite of the effort made to reduce serious workplace accidents due to machinery use still happen. Wrong operator behavior is one of the frequently identified root causes of accidents. On the other hand wrong worker behavior means unidentified possible operators actions or the omission of foreseeing the operator behavior.

Harmonized standards on methods to collect data of use of equipments used in workplaces by workers to help designers understand the real use should improve risk assessments and leading to safer and healthier products.

There is no denying that like the feedback method usability methods are time and labor-intensive, but they allow designers to predict operator's activity and make a safer machinery such decreasing the equipment related risks at workplaces.

References

1. USDL-16-2130: Nonfatal Occupational Injuries And Illnesses Requiring Days Away From Work (2015)
2. ESAW European statistics on accidents at work. http://ec.europa.eu/eurostat/web/health/health-safety-work/data/database
3. Boy, S., Limou, S.: The Implementation of the Machinery Directive: A Delicate Balance Between Market and Safety. European Trade Union Technical Bureau for Health and Safety (2003)
4. Szabó, G.: Evaluation and prevention of work-related musculoskeletal disorders in Hungary. In: Waldemar, K., Ahran, T.Z. (eds.) Advances in Physical Ergonomics and Safety, pp. 195–202. CRC Press - Taylor and Francis Group, Orlando (2012). ISBN 9781439870389
5. EN 1005-4:2005+A1:2008: Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
6. EN 1005-2:2003+A1:2008: Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery
7. EN 1005-3:2002+A1:2008: Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation
8. EN 1005-5:2007: Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency

9. Halbrügge, M., Quade, M. Engelbrecht, K.-P., Möller, S., Albayrak, S.: Predicting user error for ambient systems by integrating model-based UI development and cognitive modeling. In: UBICOMP '16, 12–16 September 2016, Heidelberg, Germany (2016). ACM. ISBN 978-1-4503-4461-6/16/09. doi:10.1145/2971648.2971667
10. ILO: Safety end health in the use of machinery. ILO code of practice Geneva. International Labour Office, Programme on Safety and Health at Work and the Environment (2013). ISBN 978-92-2-127726-2 (web pdf)
11. 2006/42/EC Directive of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC
12. Commission communication in the framework of the implementation of the Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) - OJ C 332 of 09/09/2016
13. EC – European Council: Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (Framework Directive). Official J. L **183**, 1–8 (1989)
14. Council Directive of 30 November 1989 concerning the minimum safety and health requirements for the workplace (first individual directive within the meaning of Article 16 (1) of Directive 89/391/EEC)
15. Council Directive 93/103/EC of 23 November 1993 concerning the minimum safety and health requirements for work on board fishing vessels (thirteenth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC)
16. Council Directive of 29 May 1990 on the minimum safety and health requirements for work with display screen equipment (fifth individual Directive within the meaning of Article 16 (1) of Directive 87/391/EEC)
17. 2009/104/EC Directive of The European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work
18. The Human Machine Interface as an Emerging Risk. ISBN-13: 978-92-9191-300-8. doi: 10.2802/21813
19. ISO 9241-11:1998: Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs)—Part 11: Guidance on Usability
20. ISO 10377:2013: Consumer Product Safety—Guidelines for Suppliers
21. Jagtman, E., Hale, A.: Safety learning and imagination versus safety bureaucracy in design of the traffic sector. Saf. Sci. **45**(1–2):231–251 (2007). ISSN 0925-7535. 10.1016/j.ssci.2006.08.009
22. Zühlke, D.: Useware—Challenge of Present and Future. VDI Berichte Issue 1837, pp. 1–11+313 (2004). ISSN: 00835560
23. EN 16710-2: Ergonomics methods - Part 2: A methodology for work analysis to support design
24. CEN/TR 16710-1:2015: Ergonomics methods - Part 1: Feedback method - A method to understand how end users perform their work with machines
25. Strambi, F., Bartalini, M., Boy, S., Gauthy, R., Landozzi, R., Novelli, D., Stanzani, C.: End users "feedback" to improve ergonomic design of machinery. Work **41**(Suppl. 1), 1212–1220 (2012). doi:10.3233/WOR-2012-0305-1212