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Ergonomic criteria in the investigation of indirect causes of accidents

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Abstract

Guidelines on ergonomic deficiencies may be derived from accident reports which commonly name employees as being directly at fault (direct causes of accident). The root causes of accidents found of significance for prevention purposes include the misalignment of workstations with the psychophysical capabilities of workers. Such causes lead to the engagement of ergonomists. Accident analysis tools and detailed specifications of direct accident causes have been used to develop a concept of a method for identifying ergonomic deficiencies. The accident investigation methods and tools used to classify accident causes by means of specified criteria make it possible to identify ergonomic deficiencies at each stage of assessment. The author has additionally described a concept of an expert system which supports the investigation of occupational accidents from the ergonomic standpoint. The accident investigation methods identified in this paper are TOL, Job Safety Analysis (JSA), "What if …", FMEA, STEP, OARU (Occupational Accident Research Unit), FTA, the Ishikawa Diagram, the energy transfer method, „4xwhy", MORT, KIK, WAIT (Work Accident Investigation Technique), as well as the ILCI and TRIPOD models. A concept has also been offered for using network methods to establish a hierarchy of ergonomic incompliances.

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Keywords: Ergonomic criteria; Causes of accidents; Investigation of indirect causes of accidents

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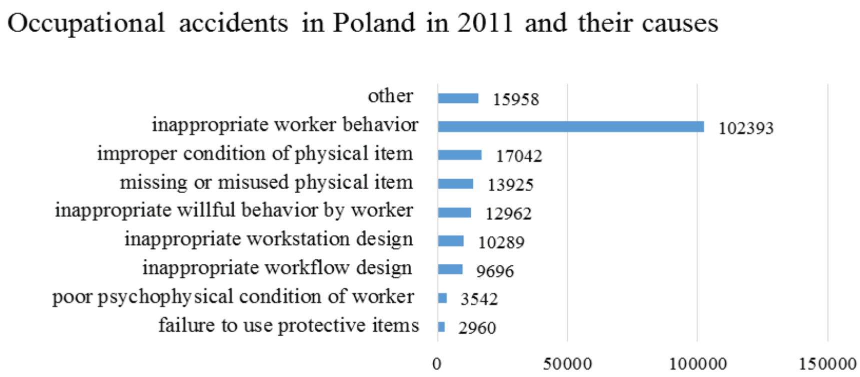

Fig. 1. Top causes of accidents at work in Poland in 2011 [7].

1. Occupational accident investigation requirements applicable in Poland

In the event of accidents at work, the Polish law (art. 234 § 1 of the Labor Code; Regulation of the Council of Ministers of July 1, 2009 on the ascertainment of occupational accident circumstances and causes – Official Journal 105, Item 870 [36]) requires that:

- measures be taken to fully prevent accidents or reduce their impact;
- first aid be provided to any victims;
- accident causes and circumstances be ascertained by the prescribed procedure;
- proper measures be taken to prevent recurrence.

The responsibility for investigating accident circumstances and causes rests with an employer-appointed investigator team comprised of an occupational health and safety officer and a social labor inspector.

Investigation findings are recorded in a “Report on the circumstances and causes of accident at work” (whose template is provided in the Regulation of the Minister of Economy and Labor of September 16, 2004 (Official Journal 227, Item 2298) [37]). A section of the Report has been dedicated to accident causes, some of which may be attributed to the employer. The law stops short of prescribing the methods and instruments to be used in the investigation. This affects investigation thoroughness and results in worker behavior being blamed for accidents [7]. Further investigations go as far as to ascertain the direct causes of accidents without specifying the underlying reasons which indirectly contribute to their occurrence.

The most popular accident investigation methods are [13, 18, 41]:

- the TOL method (determination of technical, organizational and human-related causes),
- Job Safety Analysis (JSA),
- the “what if” method,
- Failure Mode and Effects Analysis (FMEA), also known as Failure Mode and Criticality Analysis (FMCA),
- the STEP method,
- the OARU (Occupational Accident Research Unit) method,
- Failure Tree Analysis (FTA),
- Event Tree Analysis (ETA),
- the Ishikawa diagram,
- deviation analysis,
- the energy transfer method,
- the “4 x why” method,
- the MORT method,
- the KIK method,

- the WAIT (Work Accidents Investigations Technique) method,
- the Heinrich model,
- the ILCI model,
- the TRIPOD model,
- Hazard and Operability Studies (HAZOP),
- Process Safety Analysis (PSA),
- Cause and Consequence Analysis (CCA) combining FTA and ETA,
- Human Reliability Analysis (HRA).

Each of the above methods and instruments can be used to sort accident causes. Each of them requires a thorough approach. Each comes with particular advantages and disadvantages [14, 18, 38, 39].

To support accident investigations, one can draw up a list of highly detailed ergonomic criteria based on checklists (such as the Dortmund checklist), etc. Each of the above methods proposes designing tools to support assessments. The following section suggests modifications to the selected methods.

2. Ergonomic assessment criteria applicable to the identification of indirect causes of occupational accidents

Ergonomic assessment criteria have been laid down, among others, in international, European and Polish standards, such as:

- the draft standard PN-88/N-08007: Ergonomic certification of machinery and equipment: ergonomics of technologies and the organization of machine operation; ergonomics of the work space in man-machine systems; ergonomics of information and decision-making in man-machine systems; ergonomics of the physical, chemical and biological work environment [31];
- the repealed standard PN-81/N-08010: Ergonomic principles for the design of work systems: design of work space and work factors (dimensional alignment, design for working postures, allowable and optimal forces, body motion trajectories, design of signaling and control equipment); work environment design (specifications for ventilation systems, thermal conditions, lighting, acoustic conditions, vibrations, dangerous substances, harmful radiation); Workflow design (scope of tasks, job enrichment, employee turnover, break planning, personal growth) [29];
- the repealed standard PN-83/N-08015 Ergonomics. Terminology. General concepts: ergonomic anthropometric requirements; ergonomic physiological requirements; ergonomic psychophysical requirements; ergonomic hygienic requirements[30];
- PN-EN 614-1:2006+A1:2009: Machine safety – Ergonomic design principles – Part 1: Terminology and general principles: design friendly to special-needs persons; accounting for human body dimensions, body postures, body movements and physical strength; accounting for mental capacities of humans (interactions between operators and machines, control signals and items); accounting for the human impacts of physical work environment (noise and vibrations, heat, lighting) [19];
- PN-EN 614-2+A1:2010: Machine safety – Ergonomic design principles – Part 2: Interactions between machine design and work tasks [20];
- PN-EN ISO 6385: 2005 Ergonomic principles in the design of work systems: workflow design; work task design; job design; work environment design; work equipment, hardware and software design; workplace and workstation design [27];
- PN-EN ISO 12100:2012: Machine safety – General design principles – Risk assessment and mitigation [28];

One may also distinguish detailed criteria covering selected aspects of work environment relations such as:

- PN-EN 894:2010: Machine safety – Ergonomic requirements for control indicator and item design [21];
- PN-EN 1005+A1: Machine safety – Physical capabilities of man: Part 1: Terms and definitions (2010) [22]; Part 2: Manual moving of machines and their parts (2010) [23]; Part 3: Recommended border values for machine

operation (2009) [24]; Part 4: Assessment of working body postures and motions relative to machine (2009) [25]; Part 5: Assessment of risks involved in performing highly repetitive activities (2007) [26];
- ISO 11226:2000: Ergonomics - Evaluation of static working postures [9];
- ISO 11228 Ergonomics — Manual handling: Part 1: Lifting and carrying (2003) [10]; Part 2: Pushing and pulling (2007) [11]; Part 3: Handling of low loads at high frequency (2007) [12].

For each of the areas named next to the standards, detailed rules have been developed covering the management of work environment relations and analysis methods.

3. Ergonomics in occupational accident investigation methods

The Statistical Office of the European Communities requires the collection of accident statistics on [18, 35]:

- the work environment;
- the activities and tasks performed;
- physical activities (material agents involved in physical activities);
- deviations;
- contact with material agents;
- material agents.

If accidents are defined as sudden events leading to injury and/or death [15, 16, 18, 32, 33], one may distinguish a preliminary phase which precedes the accident proper. During that phase:

- technical objects fall out of alignment with the psychophysical capabilities of workers;
- the processes carried out by workers are organized improperly resulting in the deterioration of physical, mental and social well-being (as in the definition of health [34]);

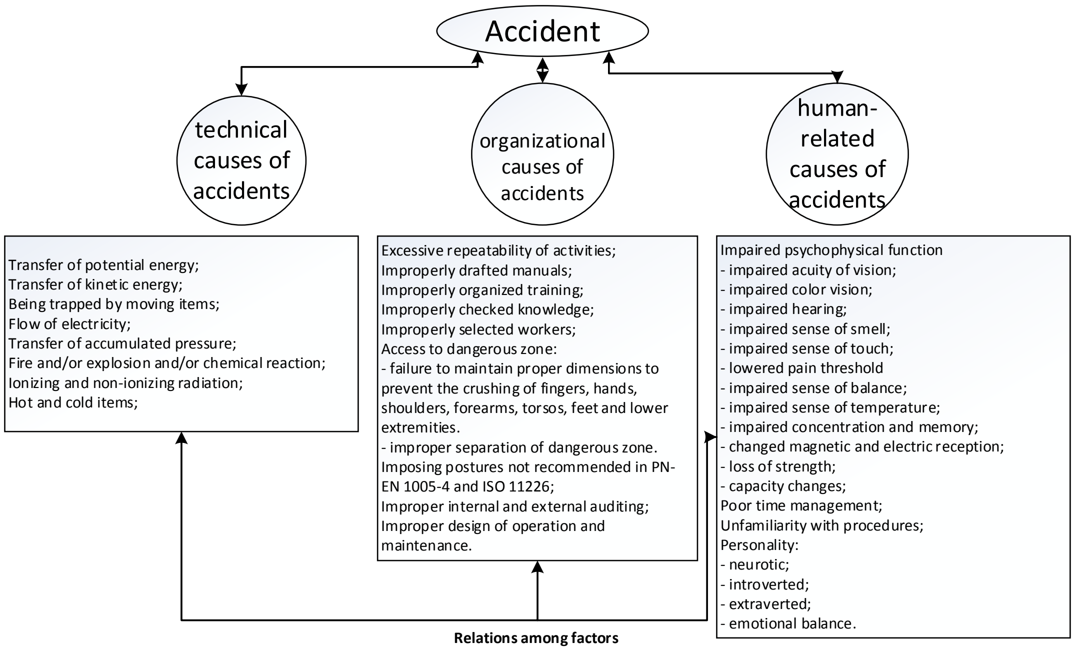

Fig. 2. Sample accident cause classification [author's work based on [18].

- the reliability of workers is compromised in specific environmental conditions.

By means of this classification, accident causes can be sorted with the use of the TOL method (technical – organizational – human-related causes) [8, 18].

The relations among the indirect causes of accidents (Fig. 2) which come into play during the pre-accident phase take the form of mutual impacts. As such impacts reach various levels, they may trigger accident events. The ultimate number of factors and impact types vary forcing accident investigators to develop complex algorithm-based structures. Mutual links among them push the system to assume varying shapes (Fig. 3).

Complex algorithm-based structures generating solutions to decision-making problems are frequently referred to as artificial neural networks (or neural networks for short) [17]. These make universal approximation systems which reflect multidimensional data sets, have an ability to learn, adapt to changing environments and generalize the acquired knowledge, which makes them an artificial intelligence system.

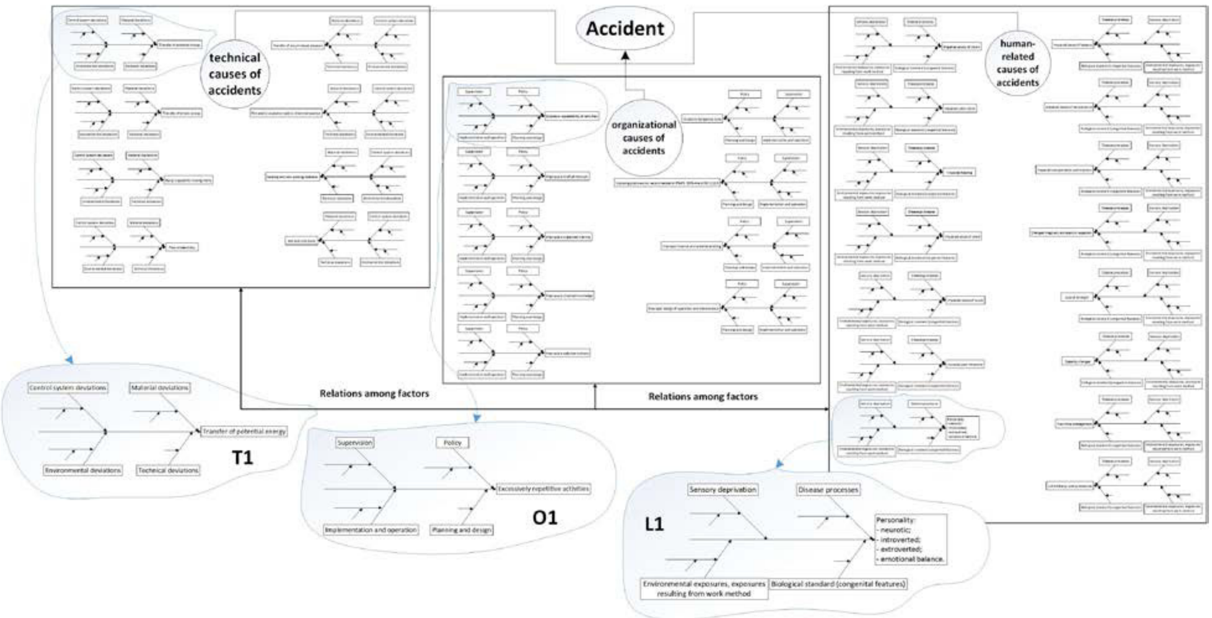

Fig. 3. Sample detailed classification of accident causes [author's work based on [18]].

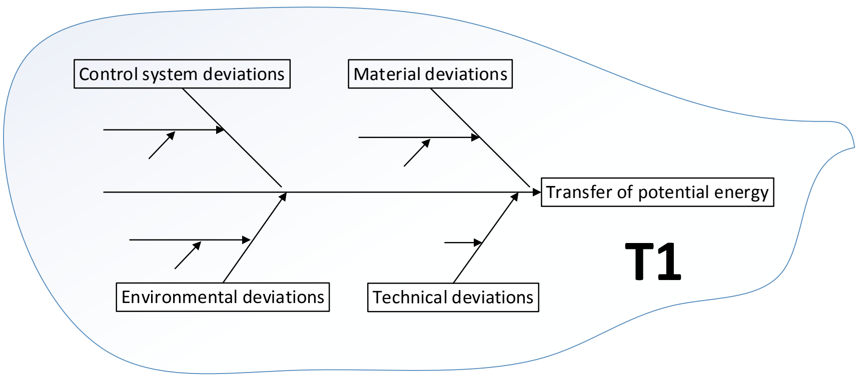

Fig. 4. Sample detail T1 from drawing 3 [author's work].

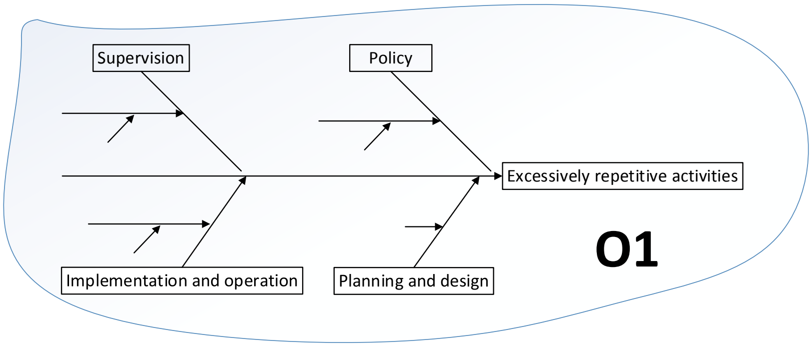

Fig. 5. Sample detail O1 from drawing 3 [author's work].

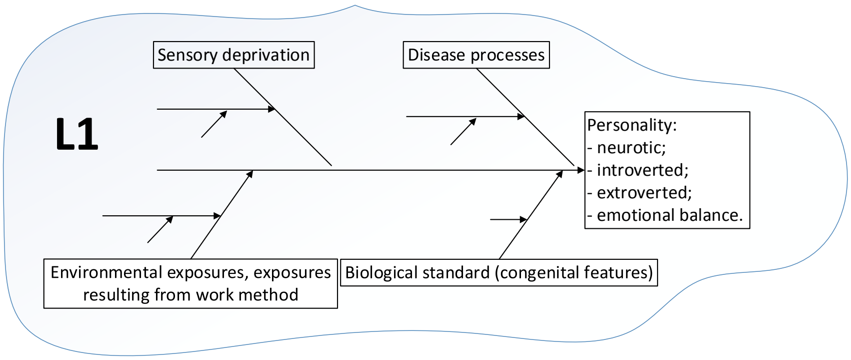

Fig. 6. Sample detail L1 from drawing 3 [author's work].

The relationship among work environment parameters may be expressed by reference to classical or complex networks [17] that are:

- unidirectional and single-layer,
- unidirectional and multi-layer,
- recurrent.

The neurons of a unidirectional single-layer network are located in a single layer that receives inputs through input nodes. A characteristic feature of a unidirectional multi-layer network is the existence of at least one hidden layer of neurons in an intermediary role in the transfer between input nodes and the output layer (Fig. 7).

A vital property of a neural network is its adaptability facilitating the design of its structure and the selection of network parameters to suit the task at hand. The object of learning is to make adaptations in the process of selecting weights so as to adjust network operation to environmental conditions defined in the form of specific requirements regarding the conversion of input into output data. In terms of the learning system of a neural network, one may distinguish learning that is [17]:

- supervised (involves "an external teacher") – in the input mode, the learning signals are accompanied by values desired at network output,
- with a critic (reinforcement learning) – entails selecting network weights by trial and error for best quality of learning which commonly depends on a single signal called critic that is generated in the adaptation process,
- self-organizing (unsupervised) – the learning follows a specific "philosophy" of network operation which allows for an association of changes in the network's input signals with network responses on the output side.

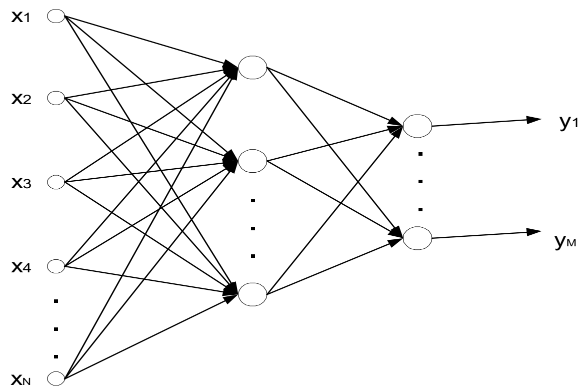

Fig. 7. Structure of a unidirectional multi-layer neural network where $x_1, \ldots, x_N$ is the input signal; $y_1, \ldots, y_M$ is the output signal (Source: [17]).

Neural networks may include two types of information:

- quantitative,
- verbal.

Verbal information occurs commonly in describing ergonomics and safety at work. Such information is understandable to humans but difficult to express numerically. Every verbal expression that is not clearly differentiated from others constitutes a fuzzy term.

When assigning – to verbal variables – specific numerical values whose proper functions describe the variability of parameters associated with them, one makes it possible to create learning systems which generate warnings in the pre-accident phase. The system structure that reflects such rules is similar to that of neural networks. The learning and testing also relies on methods used in neural networks. Learning networks which additionally rely on fuzzy logic concepts and relationships are referred to as neurofuzzy neural networks. During the learning process, such networks use both linguistic and numerical information and employ various ways of linking the two information types [17].

Relationships among ergonomic criteria which influence accident-phase effects during the pre-accident phase may be generated by network methods [1, 3, 4, 5, 6, 40].

4. Summary

For the purposes of further research, a network of links has been defined along with methods for the quantification of complex ergonomic criteria. Algorhythms were also created that define relationships among such criteria. Their primary role is to facilitate accident prevention. A major challenge is to define the impact of organizational and technical factors (and, in particular, environmental impacts and impacts resulting from ways of performing work) on employee fatigue (and especially on human factors in Figure 3). A change in the psychophysical condition affects a person's reliability and may lead to an accident when in contact with technical items that have not been fool-proofed.

An in-depth analysis of technical criteria applying to such machinery and equipment with which workers come into contact in the course of performing work shows what psychophysical condition a worker must be in to prevent accidents. A system of monitoring psychophysical parameters can be used as a basis for developing tools to design workflows and support decisions concerning e.g. the removal of a worker from a dangerous zone (and red-flagging any temporary declines in workers' psychophysical condition in the work environment).

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