To cite this version :

Nicholas DE GALVEZ, Jacques MARSOT, Patrick MARTIN, Ali SIADAT, Alain ETIENNE - Proposition of an approach applicable during the design process of working equipment to identify potential hazards for workers - In: 26th CIRP Design Conference, Suède, 2016-06-15 - Procedia CIRP - 2016

Proposition of an approach applicable during the design process of working equipment to identify potential hazards for workers

Nicholas de Galvez[a,*], Jacques Marsot[a], Patrick Martin[b], Ali Siadat[b], Alain Etienne[b]

[a]*Institut national de recherche et de sécurité (INRS), 1 rue du Morvan, CS60027, 54519 Vandoeuvre Cedex, France*
[b]*Laboratoire de Conception Fabrication Commande, Arts et Métiers ParisTech, 4 rue Augustin Fresnel, Metz Technopole, Metz Cedex 3 57078, France*

Abstract

The work of product designers has to evolve in phase with the improvements made to technology and changes in regulations. They have to work on different aspects of a product such as its technological, legal, environmental and occupational safety implications. European directive 2006/42/CE promulgates safe machine design principles to prevent professional risks. These principles guide machine designers to reduce residual risks as much as the technological state of the art permits. Special machine designers are by definition confronted by a lack of specific standards relating to *a priori* risk analysis. The aim of this paper is to present an original approach to help them to identify hazards upstream and also throughout the design process.

This approach is based on the fact that hazards are linked to the presence of energies. Hazard identification can be done through the detection of parameters linked to energy sources and flows. The approach then feeds back information to designers about potential contacts between energies and workers, to highlight the need to add preventive measures.

We use the Functional-Structural Model is used to represent the machine energy architecture through the different steps of its lifecycle. Thus it is possible to identify every interface through which energies circulate. These interfaces are defined by two kinds of parameter: energetic parameters (linked to energy properties), and other design parameters.

This paper first presents a detailed classification of energetic parameters that are also indicators of the hazards present in the machine. We then present logical rules for processing these energetic parameters and others, in order to increase the accuracy of the hazard identification performed. To conclude, the results obtained from using this approach during the industrial design of a supply line is detailed to validate the pertinence of its application from the earliest design stages, with improved accuracy during the subsequent design stages.

Keywords: design; machine; working equipment; methodology; energy; hazard identification; risk; safety; worker; operator.

1. Introduction

The work of machine designers has evolved in line with the evolution of technologies, laws and society. They can no longer limit their work to the design of a solution that will only resolve a technological problem. Besides the latter, they have to simultaneously consider problems linked to financial, time-based, environmental and safety aspects [1, 2].

In 2014, out of the 621 111 work accidents declared in France, about 8% were associated with machines, and thus partially with production equipment, according to French statistics on professional accidents. Regarding these accidents in particular, and more generally occupational health and safety, design is a path of prevention whose advantages no longer need demonstrating and is known as "integrated prevention". This approach is codified by European directive 2006/42/EC, known as the "Machinery" directive, and by its associated standards. The prevention strategy recommended in these texts focuses on *a priori* risk assessment. It gives the machine designer the objective of obtaining the lowest possible risk level according to the state of the art.

However, except for some catalogue machinery for which specific standards exist (known as type "C") and which are subject to this risk assessment, special equipment designers must rely on transversal standards (types “A” and “B”), and especially standard NF EN ISO 12100 related to general design principles.

It is important to underline that in France, production equipment is mostly designed and manufactured by small and medium enterprises (according to the 2014 data of French Chambers of Commerce and Industry). Therefore, since designers belonging to these SMEs are not specialized in prevention and have no formal resources or tools adapted to perform *a priori* risk assessments, they are limited on the one hand to the risk families closest to their field of experience (e.g., mechanical) and, on the other hand, to carrying out this assessment at the end of the project, once all the technical solutions have been selected. Furthermore, the information required for risk assessments (severity of harm, frequency, exposure, probability of occurrence, possibility of avoidance) are not just linked to design data, thereby widening the gap between design and safety. Occupational health and safety requirements are thus treated as constraints of adaptation and correction instead of design.

To solve this issue, we propose a method to assist special machine designers to systematically identify hazards, an essential step of risk assessment. To be more efficient, this approach must verify the four following characteristics:

- generic: faced with the different hazard types, the design process implemented and the type of machine;
- inductive: based on the design parameters (causes) to identify hazards (effects) through parameters used in risk assessment methods (e.g., NF EN 1005 for ergonomic hazards or directive 2001/59/EC for chemical hazards);
- dynamic and traceable: monitoring the evolution of system characteristics and the configuration of components from the outset and during the different design stages;
- integration and/or compatibility with current design elements: ensuring interoperability and ease of use through monitoring and indicators in order to quantify and use data.

2. Literature review

For the sake of this paper clarity, we define and organize the main terms linked to design based on the literature. Thus we consider that a design approach is a set of design phases (e.g., architectural design) that structure design activities (e.g., drawing creation). The latter are composed of five design tasks, sources of design data (e.g., parameters, intermediate objects). The intermediate objects (IO) punctuate and link the design activities and guarantee the design parameters maturity [3-5].

2.1. Design approaches

Different works on design have been identified in the literature to cover a lot of problem the designer can meet: design process management, decision-making, environmental or safety problems [2]. These works can be approaches, methods or tools and can cover all or a part of the design process [6-9]. Consequently, a wide range of elements structure the designer’s work. However, according to [5], design activities can be divided into five generic tasks: creation, dimensioning, representation, optimization /evaluation and validation.

To maintain the generic objective toward the design process followed by designers, the method will therefore use these elementary tasks, intermediate objects [3] and the parameters generated from them, since they are independent from design approaches and activities. This point is essential as the enterprises targeted are mostly VSE/SMEs which do not follow well a formal design approach.

2.2. Risk prevention in design

Numerous articles on risk reduction in the design process were found in the literature [10, 11]. We focused this literature review on hazard identification since it belongs to the risk analysis process.

Research works on integrating risk analysis in production system design mainly focuses on two paths: the design process organization and risk evaluation, but in both cases these works present limits regarding the problematic of this paper.

Works that focus on the design process mostly propose methods that call on collaborative project reviews [12, 13]. The reduction of risk in general, and the identification of hazards in particular, are based on cooperation between the different actors during these project reviews. Therefore this type of approach does not guide the designer in decision-making when they work independently in front of their workstation [14]. Furthermore, when these project reviews are performed using numerical mock-ups or physical prototypes, this type of approach must be sufficiently advanced in the design process to analyze the risks [15].

Regarding studies on risk assessment and evaluation [11, 16], i.e. the determination of an index used to classify potential risks, they are generally specific to a single type (e.g., mechanical risk [17]). Moreover, these methods are focused on the combination of the different parameters involved in assessing risks. These parameters are similar from one method to another. As recommended by standard NF EN ISO 12100, these parameters include severity of harm, frequency/ duration of exposure, probability of occurrence of a hazardous event and the possibility of avoidance. The main differences between the proposed methods concern the number of levels used to evaluate these parameters and how they are combined (e.g., matrix, graph, numerical equation, abacus, chart). Consequently, these works do not provide an answer to the previously highlighted problem, which aims to identify hazards.

Analysis of the literature nonetheless made it possible to identify four approaches that *a priori* provide an answer to this paper problem and satisfy the expected criteria (generic, inductive, dynamic and integrated):

- Coulibaly *et al.* [18] proposed a Risk Factor (FRis) indicating whether a risk is present or not. This paper has the same goal but FRis indicator requires parameters that are not naturally created during the design process;
- The “PAG” multi-agent system [19] is a system to analyse the performance of working situations based on numerical mannequins. Its integration in the designer’s tools is ideal,

but since it is based on a virtual mannequin, it intervenes too late in the design process.

- The "IRAD" method [20] proposes the simultaneous development of technical and safety functions. It guides designers throughout the design process and deals with all kinds of hazards. However, it does not describe how hazardous phenomena are identified.
- The work situation model "MOSTRA" [21] facilitates the inclusion of multi-viewpoint data through the notion of risk, but it does not define the direct link between design parameters and hazardous phenomena and it is a model without data processing.

Through this literature analysis, we concluded that none of these works satisfied our need to identify hazards throughout the design process.

However, some of them agreed on the hypothesis that hazardous phenomena are linked to energies [20, 22, 23]. On this basis, hazard identification can be performed through the identification of energy sources and flows.

3. EZID : Energy analysis for systematic haZard Identification during Design

Based on this hypothesis, we propose a method to identify hazards by analyzing the parameters linked to energies in four steps: machine modelling, relevant hazard type identification, identification of consequences and, finally, significant hazard identification.

3.1. Step 1: machine energy flows modelling

The first step of EZID is to represent the machine through its energy flows. The literature includes different models that allow this kind of representation [24-26] and the Functional-Structural Model (FSMo) is considered as relevant [27, 28].

It is based on four elements (cf. Fig. 1.):

- frontiers: delimitation of a physical element of the machine or the worker and their environment;
- functional surfaces: energy exchange interfaces (contains the data about properties of the energies and surfaces);
- links: association of two functional surfaces that do not belong to the same component (can be conductive (C), semi-conductive (SC) or insulating (I));
- internal links: association of two functional surfaces belonging to the same component. They can also be conductive, semi conductive or insulating.

The FSMo was developed to analyze the different kinds of energy flows in existing complex systems and then to follow the design process of a product from its initial structure. As it allows modelling workers with the same elements, it also provides a global and uniform view of the different energy flows within a man/machine system. It has already been subjected to computerization. Therefore, it corresponds to the desired characteristics of our approach: generic, dynamic and compatible with current design tools and methods.

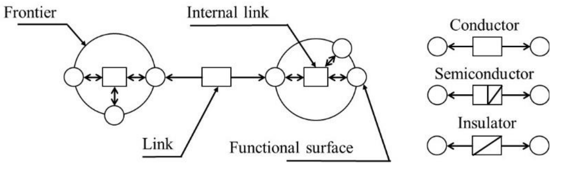

Fig. 1. Functional-structural model (FSMo)

The identification of hazard sources linked to these energy flows thus becomes systematic by identifying all the functional surfaces of the system. Finally, the designer's goal will be to limit or remove the potential energy flows linked to the worker.

The next step of EZID uses the elements and parameters linked to energies stored in the functional surfaces to identify the relevant hazard (hazard which is identified as being present at, or associated with, the machine according to NF EN ISO 12100). Some of these parameters are based on generalized variables described in the Bond Graph model and detailed in the next section.

3.2. Step 2: Relevant hazard type identification

During the risk assessment, the energy properties are used to estimate the severity of harm parameter [29], confirming the hypothesis that hazards are linked to the presence of energies. Based on this, we choose to use the concept of generalized variables [30] to express the energy properties. It distinguishes energetic parameters into two categories: generalized effort (ge) and currents (gc). They correspond to the source and the flow of energy, respectively. These parameters are also linked to the power P through the following relation: $P=f(ge, gc)$.

Mechanical, electric, thermal hazards, and those linked to physical nuisances (noises, vibrations, radiation) can be linked directly to energy parameters (e.g., potential energy, kinetic energy, electric currents). However, the bond-graph theory does not cover every kind of energy and therefore not every kind of hazard. In addition, certain kinds of hazard do not estimate severity of harm through direct energy parameters. It was then completed with the parameters used for severity of harm in risk assessment. Some parameters were replaced with other that are more frequently used by designers based on NF EN ISO 12100 (mechanical), NF EN 60204 (electric), NF X35-112 (thermal), NF EN 62471 (light radiation), NF EN 60825 (laser), NF ISO 2631 and NF EN ISO 5349 (vibration), NF EN ISO 9612 (ISO 11688) (acoustic), directive 98/24/EC (chemical), NF EN 1005 (ergonomic) and (directives 2004/40/EC) PR NF EN 50505 (EM fields) and 2013/59/EURATOM (ionizing) (cf. Table 1).

Based on these standards, workers can receive and transmit (voluntarily or not) energy. Consequently, a functional surface will always appear on each frontier to represent the unintentional transmission of energy from the worker to the machine. Another and forever present functional surface is that linked to weight, since every subsystem has a mass.

Every parameter in this table is available to the designer and can be used during the design process. Thus they describe the energy flows in the FSMo. To identify the relevant hazard types, EZID will compare the energetic parameters defined in the FSMo with the reference parameters capitalized in Table 1. Thus the energetic parameters are the primary indicators to identify hazards.

Greater precision for most hazard types is not necessary. However, for mechanical and chemical hazards, it is possible to obtain useful information on the consequences.

Table 1. Extended generalized efforts and currents.

Type of hazard / *Corresponding energy*	Generalised effort	Generalised current
Mechanical (translation) / *Kinetic energy, potential energy*	Force (N)	Velocity (m/s)
Mechanical (rotation) / *Kinetic energy*	Torque (Nm)	Angular velocity (rad/s)
Mechanical (pneumatic / hydraulic) *Elastic/static energy*	Pressure (P)	Flowrate (m^3/s)
Electric/*Electric*	Voltage (V)	Intensity (A)
Thermal/*Thermal*	Temperature (K)	Heat flow (J/s=W)
Radiation / *(electro-magnetism)*	Electric field (V.m^{-1}) Magnetic field (Tesla)	Electric flow (V.m) Magnetic flux (Weber)
Radiation /*(light)*	Wavelength (m) Irradiance (W.m^{-2}) Radiant exposure (J.m^{-2}) Radiance (W.m-2.sr^{-1})	Spectral density (W.m^{-1})
Radiation / *(laser)*	Wavelength (m) Laser class	
Radiation / *(ionizing)*	Dose (Sv) Dose-per-unit intake (Sv.Bq^{-1})	
Vibration / *Vibration*	Acceleration (m.s^{-2})	Exposure time (s)
Acoustic / *Acoustic*	Noise level (dB(A))	Exposure time (s)
Chemical / *Chemical - biological*	Level of threat Concentration (mol.L^{-1})	Exposure time (s)
Ergonomic / *Worker*	Effort (N)	Velocity (m/s) / Action frequency

3.3. Step 3: Consequences identification

A consequence is a description of the damage caused by a hazard. For example, mechanical hazards can cause a wide range of damage as mentioned in NF EN ISO 12100, such as piercing, impact or severing, and chemical hazards can create various types of damage linked to the risk phrases of the products identified in directive 2001/59/EC.

For the designer, it is important to know these consequences in order to select specific preventive measures for the damage and integrate them in the design instead of selecting maladjusted generic measures.

These consequences are created by combining the energetic parameters of Table 1 and complementary parameters that describe the functional surface characteristics such as position (e.g., relative position between two parts, trajectory), geometric (e.g., dimensions, edge, surface state) and intrinsic (e.g., material state) parameters.

We use the root-cause analysis (cf. Fig. 2.) for each hazard types to identify the corresponding energetic and complementary parameters, and the combinations that lead to its consequences [29]. By observing the appearance of these complementary parameters, it is possible to know if damage exists or is in the process of occurring.

At this stage, designers know the relevant hazards in detail, but they do not know if they will lead to any risks. It is necessary to improve the results of the identification to obtain feedback on the significant hazards (hazard which has been identified as relevant and which requires specific action by the designer to eliminate or to mitigate the risk according to the risk assessment according to NF EN ISO 12100) [31-35].

3.4. Step 4: Significant hazards identification

Some energetic parameters must be subject to legal threshold values to protect users from harm. For example, it is forbidden to let a worker handle a mass over 25kg often without equipment to assist them [36]. To complete the identification, EZID uses the threshold values defined in standards and directives to characterize significant hazards.

Since Table 1 is based on the energetic parameters already included in risk estimation methods, all the legal threshold values (when they exist) are linked to them. Some of these values are absolute (e.g., chemical occupational exposure limit values) [37] and others depend on design parameters such as material characteristics for thermal hazards according to NF EN ISO 13732.

To verify if a relevant hazard is significant, the method compares the values of the energetic parameters present in the machine with the threshold values. When they do not exist, the hazard is directly considered as significant.

So far, EZID performed a complete identification of the hazards in the machine, and differentiated those that are certain to represent risks from the others. The data fed back to designer must contain the localization of significant hazards (functional surfaces), their types and the damage if possible. Relevant hazards do not have to be fed back but they must be capitalized and updated if their corresponding energetic or complementary parameters are modified.

With the feedback on significant hazards, designers can continue the risk analysis process to obtain both risk assessment and evaluation. Once obtained, they have to choose the risk prevention/reduction solutions to be applied. If these solutions add new parts in the machine or replace some in the current design, it is necessary to update the FSMo and repeat the analysis so as to identify the consequences of such modifications.

EZID must be used until all the significant hazards are prevented and the machine is made as safe as possible.

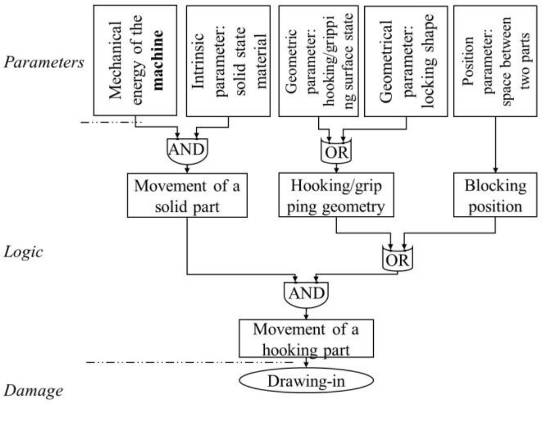

Fig. 2. Extract of logical rules to create a "drawing in" consequence of a mechanical hazard

4. Case study

4.1. Case and documents

To confront EZID with industrial reality, we studied the design of a supply line (structure, conveyors, actuator, metal gutter, photocells and trash box) with a shape recognition module (camera + controlled light) and a common area with a robot (cf. Fig. 3.). It was monitored from its requirements specification to the first prototype.

The intermediate elements of the industrial case provided were the requirements specification drafted by the customer, the 3D CAO models of the supply line with the bill of materials, and the reports on the prototype tests.

4.2. EZID application

4.2.1. Model

EZID was applied for each intermediate object. First, it has represented the machine in FSMo language. For the requirements specification, the machine was considered as a whole with a single frontier that exchanges energies with external parts. The FSMo was more complete for the CAD model and the prototype, with all the subsystems and parts.

4.2.2. Relevant hazard kind identification

As stated at the end of § 3.1, the identification of relevant hazards entails identifying the functional surfaces of each FSMo. As described in Table 2, 77 relevant hazards were identified in the requirements specification, 358 in the 3D CAD model and 445 in the final prototype. The identification of their type was done by comparing the energetic parameters with those in Table 1. These results cover the use, maintenance, assembly/ disassembly and transport lifecycle steps.

Mechanical hazards are linked to the shape/geometry, mass and movements of parts and the entire machine. The noise hazards are caused by the moving subsystems and the falling of metallic parts on the metal gutter. Radiation hazards are linked to the controlled light from the shape recognition module and photocells. Thermal and vibration hazards are caused by the motors and the actuator.

It is important to highlight the fact that hazards can be identified from the requirements specification. It is also important to note that the majority of hazards are not removed from the machine between the CAD model and the prototype.

It was also observed that the main solution for risk reduction was not to suppress them but to add safeguards.

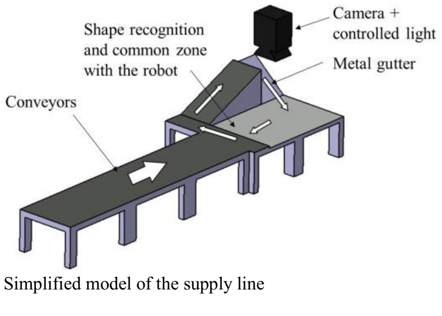

Figure 3. Simplified model of the supply line

Table 2. Results of the relevant hazards identification

Hazard kind	Requirements	CAD model	Prototype
Mechanical	71	256	314
Electric	0	18	18
Thermal	0	6	6
Noise	0	7	7
Vibration	0	6	6
Radiation	1	11	11
Ergonomic	5	61	90

4.2.3. Consequences identification

Due to the parameters needed, consequences can only be identified from the CAD model. Mechanical hazards were identified so EZID could feedback data about the consequences they caused. Most of them caused impacts (e.g., blunt shapes parts) or cutting (e.g., guide rails) damage due to their geometries and the unwanted energy provided by the worker or the accumulation of gravity potential energy during movements. The actuator and the roller-conveyor belt could draw-in or crush the worker. During their handling or use, impact damage could be worsen by crushing between two parts or between a part and the ground.

4.2.4. Significant hazard identification

Through the comparison between energetic parameter values and threshold values, most of the relevant hazards did not become significant. Radiation, vibration, thermal, some noise and electric hazards were below threshold values and therefore did not create risks. This was guaranteed by the compliance of the commercial subsystems with the regulations. Mechanical hazards did not have threshold values and remaining ergonomic hazards were linked to the assembly phase for which data about assisting tools were lacking.

The number of significant mechanical hazards was the same between the CAD model and the prototype (cf. Table 3).

Table 3. Results of the significant hazard identification

Hazard kind	Requirements	CAD model	Prototype
Mechanical	71	24	24
Noise	0	7	7
Ergonomic	5	17	47

The analysis of the CAD model shows that the designer had already introduced safety measures to reduce the number of hazards. For example, access to the common area with the robot was restricted by safeguards and access to the transition area between two conveyors was also blocked by a safeguard.

Considering all these measures, the numbers of significant hazards was reduced once more. However, the number of ergonomic hazards increased because new parts were added to the machine. There were no more electric hazards since the components providing electricity meet current regulations. There were still 24 mechanical hazards linked to the mass of the parts and the lack of assembly data. However, there was still no valid solution for reducing noise from the CAD model.

With this feedback, the designer can continue the risk analysis process and then define preventive measures for the remaining hazards.

5. Discussion and Conclusion

This paper aims to present the EZID method that is based on the energy flows analysis to systematically help machine designer for the hazards identification during the design process. To do so, it uses the design parameters extracted from the intermediate objects.

To confirm its usability, EZID was applied manually with graphs and spreadsheets on an industrial case. Its application returns results about the hazards characteristics since the first design steps, and about their evolution throughout the rest of the design process. It also demonstrates its capability to identify every kind of hazards. Thus, it allows machine designers to suppress or treat them from the moment they are identified and no longer only at the end of the design process.

An improvement would be to incorporate the identification of combined hazards to return a complete feedback. Another one would be to include in EZID the different risk analysis methods to cover the whole risk analysis process.

In conclusion, the energy analysis to identify hazards is relevant and usable during the design process for all kind of machinery. To return an exhaustive feedback, EZID must be applied to all the machine lifecycle steps since the energies and the potential interactions between the machine and the operators are not the same. A software is currently developed to provide to machine designers a fully functional method.

6. Acknowledgement

This study is being performed in the framework of a PhD thesis in the joint INRS-ENSAM laboratory, the LC2S.

References

1. Lu SCY, Suh NP. Complexity in design of technical systems. CIRP Annals - Manufacturing Technology; 2009. 58(1):157-160.
2. Suh NP. Complexity in Engineering. CIRP Annals - Manufacturing Technology; 2005. 54(2):46-63.
3. Boujut JF, Blanco E. Intermediary Objects as a Means to Foster Co-operation in Engineering Design. Journal of computer supported collaborative; 2002. 12 (2):205-219.
4. Scaravetti D et al. Structuring of embodiment design problem based on the product lifecycle. International Journal of Product Development; 2005. 2(1):47-70.
5. Godot X et al. Methodology to develop a geometric modeling process according to collaborative constraints. International Journal on Interactive Design and Manufacturing (IJIDeM); 2014. p. 1-17.
6. Lutters E et al. Tools and techniques for product design. CIRP Annals - Manufacturing Technology, 2014. 63(2): p. 607-630.
7. Mathieu L, Marguet B. Integrated Design Method to Improve Producibility based on Product Key Characteristics and Assembly Sequences. CIRP Annals - Manufacturing Technology; 2001. 50(1):85-88.
8. Suh NP, Cochran DS, and Lima PC. Manufacturing System Design. CIRP Annals - Manufacturing Technology; 1998. 47(2):627-639.
9. Tomiyama T et al. Design methodologies: Industrial and educational applications. CIRP Annals - Manufacturing Technology; 2009. 58(2):543-565.
10. Bergström J, van Winsen R, Henriqson E. On the rationale of resilience in the domain of safety: A literature review. Reliability Engineering & System Safety; 2015. 141:131-141.
11. Liu HC, Liu L, Liu N. Risk evaluation approaches in failure mode and effects analysis: A literature review. Expert Systems with Applications; 2013. 40(2):828-838.
12. SCY Lu et al. A scientific foundation of collaborative engineering. CIRP Annals - Manufacturing Technology; 2007. 56(2):605-634.
13. Badri A, Nadeau S, Gbodossou A. Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation. Accident Analysis & Prevention; 2012. 48(0):223-234.
14. Hale A, Kirwan B, Kjellén U. Safe by design: where are we now? Safety Science; 2007. 45(1–2):305-327.
15. Kjellén U. Safety in the design of offshore platforms: Integrated safety versus safety as an add-on characteristic. Safety Science; 2007. 45(1–2):107-127.
16. Etherton JR. Industrial Machine Systems Risk Assessment: A Critical Review of Concepts and Methods. Risk Analysis; 2007. 27(1):71-82.
17. Hu J, Zhang L, Liang W. An adaptive online safety assessment method for mechanical system with pre-warning function. Safety Science; 2012. 50(3):385-399.
18. Coulibaly A, Houssin R, Mutel B. Maintainability and safety indicators at design stage for mechanical products. Computers in Industry; 2008. 59(5):438-449.
19. Shahrokhi M, Bernard A. A framework to develop an analysis agent for evaluating human performance in manufacturing systems. CIRP Journal of Manufacturing Science and Technology; 2009. 2(1):55-60.
20. Ghemraoui R, Mathieu L, Tricot N. Design method for systematic safety integration. CIRP Annals - Manufacturing Technology; 2009. 58(1):161-164.
21. Hasan R et al. Integrating safety into the design process: elements and concepts relative to the working situation. Safety Science; 2003. 41(2–3):155-179.
22. Haddon W. Energy damage and the 10 countermeasures strategies. J Trauma; 1973. 13(4):321-331.
23. Kjellén U. Prevention of accidents through experience feedback. CRC Press; 2000.
24. Marca, DA, McGowan CL. SADT: structured analysis and design technique. McGraw-Hill, Inc.; 1987.
25. Mario S. Der Einsatz von Sankey-Diagrammen im Stoffstrom management. Beitraege der Hochschule Pforzheim; 2006.
26. Paynter HM. Analysis and Design of Engineering Systems. MIT Press; 1961.
27. Constant D. Contribution à la spécification d'un modèle fonctionnel de produits pour la conception intégrée de systèmes mécaniques. Thèse 1996, Université de Grenoble 1.
28. Roucoules L et al. Une approche au juste nécessaire de l'intégration métier, en conception vers des solutions alternatives innovantes. Ingénierie de la conception et cycle de vie des produits. ed Hermès; 2006.
29. de Galvez N et al. Design for safety: proposition of a model to detect hazards through energy flows analysis. In 48th CIRP Conference on Manufacturing Systems. Naples (Italy): Elsevier B.V.; 2015.
30. Borutzky W. Bond graph methodology: development and analysis of multidisciplinary dynamic system models. 2009: Springer Science & Business Media.
31. Khan FI, Abbasi SA. TORAP - a new tool for conducting rapid risk-assessments in petroleum refineries and petrochemical industries. Applied Energy; 2000. 65(1–4):187-210.
32. Pinto A. QRAM a Qualitative Occupational Safety Risk Assessment Model for the construction industry that incorporate uncertainties by the use of fuzzy sets. Safety Science; 2014. 63(0): p. 57-76.
33. Roman-Liu D. Comparison of concepts in easy-to-use methods for MSD risk assessment. Applied Ergonomics; 2014. 45(3):420-427.
34. Si H, Ji H, Zeng X. Quantitative risk assessment model of hazardous chemicals leakage and application. Safety Science; 2012. 50(7):1452-1461.
35. Standard, NF X35-112, NF EN ISO 13732, Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces. AFNOR; 2008.
36. Standard, NF EN 1005 - Safety of machinery - Human physical performance. AFNOR; 2008.
37. IFA. GESTIS International Limit Values. 2015; Available from: http://limitvalue.ifa.dguv.de/.