INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

SCRM: A NEW DESIGN TOOL FOR IMPROVING SAFETY LEVEL OF MECHANICAL SYSTEMS

Fargnoli Mario, Pighini Umberto

Abstract

The aim of the present study has been the development of a Methodical Design approach to evaluate Safety Costs, in accordance with the EC Directives. The effectiveness of the study was tested on a redesign of a bending press.

Keywords: Design for Safety, Risk Analysis, Cost/Benefit Analysis, Life Cycle Costing, Methodical Design.

1. Introduction

During the last years attentions paid to Machine Safety has arisen to a primary importance in the European Community. In fact, in spite of the huge technical and technological progress achieved during the last 20 years, the number of accidents at work caused by malfunctioning or by improper use of a machine is increasing.

This new approach towards Machine Safety, which was greatly demanded by the European Community throughout the issuing of a series of new Directives since the beginning of the '90s on, is certainly an attempt to solve the problem of the critical situation of this field.

On the other hand, the growing number of interwoven regulations have brought to manufacturers growing costs as well, so that it becomes a hindrance to the final pursuing of a proper level of Safety: the link between Safety and Cost seems very strong, so that it is taken into account in the new review of the Directive "Safety of Machinery" (98/37/EC that codifies into one single text Directive 89/392/EEC, as modified by Directives 91/368/EC, 93/44/EC and 93/68/EC), for what concerns the application of ERS (Essential Health and Safety Requirements, Directive 98/37/EC, Annex I).

It is also important to emphasize the necessity to find some criteria to evaluate the maximum level to which the Safety of a Machine could be increased, thus making it economically feasible at the same time.

Data collected in different fields show that Cost increases in relation to Safety according to an exponential law. This fact imposes strong limits for the designer choices and he has to make use of all his inventiveness and creativity to increase MSs safety within acceptable costs.

This constraint has obliged, for instance, the designer to follow the fail-safe strategy instead of the former philosophy of safe-life, which is much more expensive. The study of this problem can provide Design Rules for the designer, as in the previous cases.

Within this task the great importance of Design stands out, as found out by the main Authors in this field [Birmingham et. al.; Hundal; Main et al.; Wang & Ruxton], which allows to set the limits a designer should move within to find the optimum agreement between Safety and Cost.

2. Background

The pursuance of the recent European Union Instructions regarding Safety is a very complex task which involves all the people operating in a factory, thus clearly affecting the costs that the factory itself should bear [Ashford, Hallet, Hunter, Scheel]; particularly, these new standards significantly changed the role of designers and manufacturers.

2.1 Analysis of the statistics on accidents at work and studies on the pursuance of the European Directives in matter of Machine Safety.

The study, carried out with the support of the Safety Technologies Department of the ISPESL (Italian Institute for Prevention and Safety) of Rome, not only concerned data collection and analysis on accidents at work, but also a detailed study on the problems related to the pursuance of the new laws regarding Safety.

The inquiry performed within the national borders allows us to have a general outline on the reception of the new European Directives on Machine Safety, by all the operators who, within all their activity and function spheres, are more or less directly involved.

The results acquired can be at least satisfactory: in fact, even if some answers are redundant or evasive (as will be fully explained further on), we had a fair level of communication both with Public Institutions (ISPESL, ASL, Italian Work Ministry, Italian Ministry for the Productive Activity), and with private companies (machines manufacturers, users, consulting and training Societies, etc.).

The results of this first research phase could be summarized in the following items:

- most of the accidents are caused by the great confidence of skilled users, who steal off the safety devices and because of the lack of attention during maintenance or setup operations;
- there are still a lot of former machines in relation to the new Directive, and there are quite a lot of them in small and medium enterprises, and most of them are not even updated according to the new Directives, mainly because of economical reasons;
- the performed analysis singled out that the absence of “specific rules”, linkable in coherent times, with technological innovation in the field of manufacturing equipment, even if there are lots of Standards in this field, is felt (in a more or less intense way) by all the people interviewed. This lack, together with the habit of a sectorial attitude related to the legislation which preceded the European Directives (i.e. Italian D.P.R. 547/55),generated huge problems as regarding the interpretation of the Minimum Safety Requirements, to which we sometimes give a role of guidelines in machine design and construction. This interpretation, together with, according to what most of the interviewed people said, an incomplete classification of machines in Annex IV, represents a huge difficulty for the correct individuation and evaluation of risks. In this field are favourably taken into account the studies which are being performed for the development of new Technical Standards, proper for this field;

- often a further difficulty towards a more complete introduction in companies of all the precepts and guidelines of the EC Directives is the market structure that leads to accepting incomplete conformity conditions to support low costs and/or a faster production.
- An incorrect interpretation of the ESR, together with a not complete classification of machines in example in Annex IV, represents a huge difficulty for the correct individuation and evaluation of risks. The absence of "specific rules" for each kind of equipment, also considering that small companies seldom have huge mass productions: in fact they regard special and unique manufacturing or limited to few pieces.

2.2 Analysis of Safety Devices and Components

On the basis of the definitions of the "Machine Directive" (98/37/EC), the most common safety devices were considered, which nowadays are on the market and that have been classified as the criteria explained in the EN 954:1996. On the basis of the study we carried out it comes out that such classification should not be understood as hierarchical, and the designer does not choose the device belonging to the higher category class . For instance, it should be noticed that a category 4 device is not often safer than one of a lower level; moreover not all the machines are suitable to high category safety devices. For example a perfectly working mechanical safety device could be considered as belonging to category 1, and equally or even more useful than one belonging to category 3 or 4. In order to make the choice we should consider what result we want to achieve in relation to the type of machine we have.

2.3 Analysis of Costs related to Safety

It is usual to divide costs related to safety into direct costs and non-direct costs. To the first class belong the costs related to safety, of which we have specific account in the budget estimation (insurances, claims for damages, individual safety devices, workers , costs for specific safety plants, etc.), to the second class belong the costs related to the "lack of safety", which usually have not a direct relation with this budget (costs for: occurrence of an accident on work, lack of production, legal costs, overuse of energy, etc.).

On the other hand, considering the total cost made up of the two principal elements - preventive cots and the costs following accidents – we can see that an increase of the costs related Safety prevention leads to a reduction in accidents and consequently further costs; such a reduction does not however follow a proportional law since, as mentioned above, even simpler and cheaper measures can lead to a notable reduction in accidents, whereas more complex and expensive may only lead to insignificant reduction.

3. Methods

Since every necessary action to increase the safety level of Mechanical Systems strictly depends on its cost, the study on the following Design Tools (showed in details in Figure 1) was taken further:

- Design Methods for the improvement of Safety.
- Techniques and Criteria for Risk Evaluation.
- Inter-classes Design Methods (Methods not directly connected to Safety and Cost, but anyway useful for the improvement of Mechanical Systems properties).

- Design Methods for Cost evaluation.
- Techniques and Criteria for Economic Evaluations of Designs.

Beside this, the study of the Standards regarding Safety was analysed, both the Directive "Safety of Machinery" (98/37/EC et al.) and the "Harmonised Standards" (EN 1050; EN 291; EN 292; etc.).

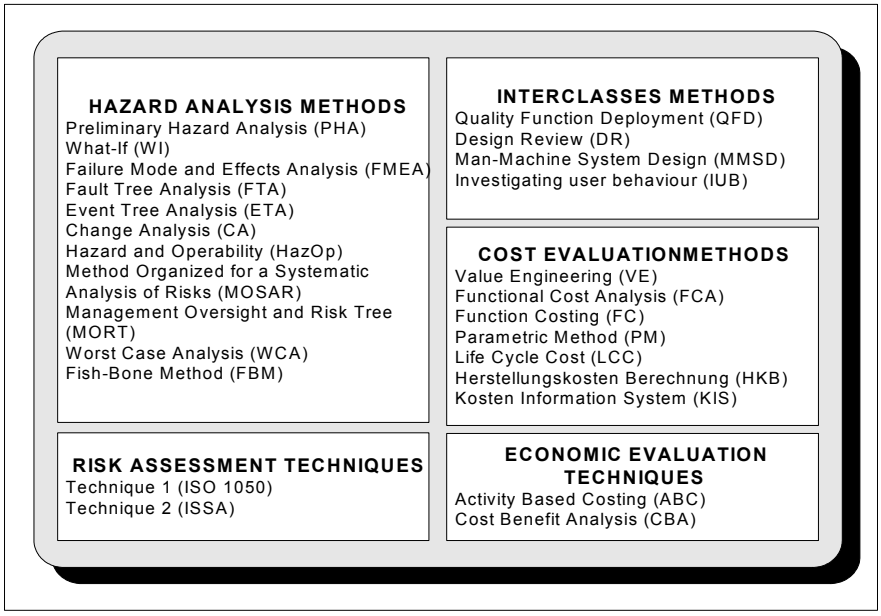

Figure 1. Design Tools

4. Results

4.1 Safety/Cost Ratio Methodology

The result of the present study was the development of a Design Methodology (SCRM - Safety/Cost Ratio Methodology) which consists in a methodology aimed at evaluating, for every component, part or Mechanical System, both the correct Safety level and the Cost related set, that can be applied during the decision making stages of the Design Process.

The implementation of the SCR Methodology consists of the following main steps:

1. Detecting the risks connected to the use of the machine (R_j)
2. Defining a series of feasible solutions (S_{kj}) for each detected risk
3. Valuing the cost for each of these possible solutions (C_{kj})
4. Linear combination of the feasible solutions and evaluation of the total Safety Level
5. Valuing the total cost related to any combination (Cost Level)
6. Choice of the best combination and "bottom up" control.

A detail of the Safety/Cost Ratio Methodology can be seen in Figure 2.

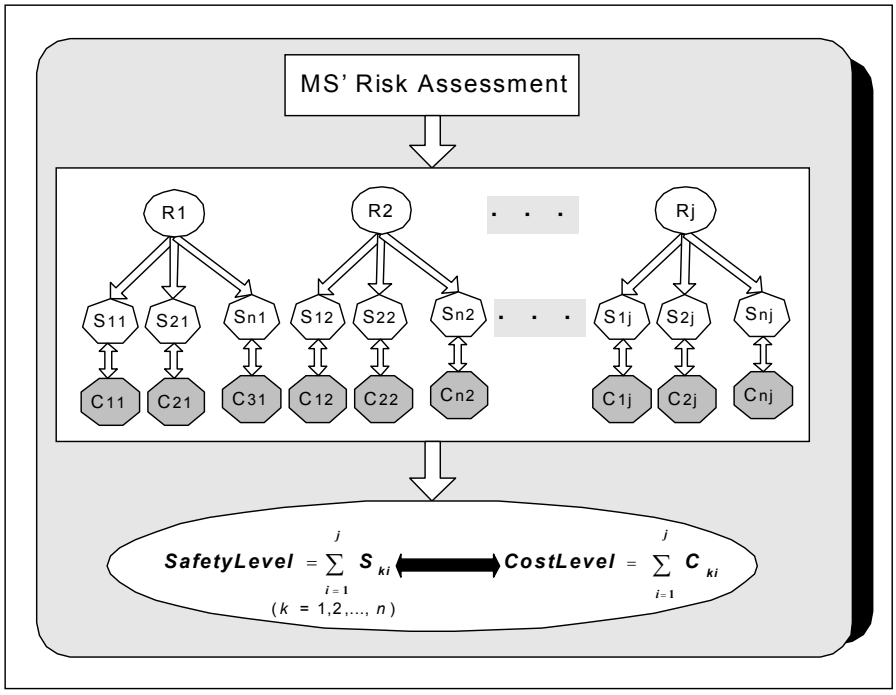

Figure 2. Safety/Cost Ratio Methodology scheme.

4.2 Safety Cost Ratio Approach

The results of the analysis with the SCRM have been integrated in the overall product design process when the improvement of the Safety level leads to substantial design changes or when designing new Mechanical Systems.

For this integration general available design methods and techniques, above mentioned, were implemented within the Methodical Design Process of the School of Rome. In particular, all the steps into which the Design Process is divided were singled out, and for each one of them the Design Tools that can be more conveniently used were considered, so that the designer can make the right choice in each phase of the Design Activity.

5. Case Study

To verify the effectiveness of the study performed, the developed Methodology and Approach were implemented to a real case. In particular we have chosen a machine tool, a hydraulic bending press, which is very common in mechanical carpentry workshops and in all companies in which they need bending metals within their productive cycle.

In the first phase of the Design Process , all necessary data to understand and explain the problem were collected; in particular we considered customer's requests, standards regarding the safety of the machine, statistics of user accidents, characteristics and typologies of main existing safety devices.

The results obtained were then integrated in those reached by using the Investigating User Behaviour method (IUB) and the Man Machine System designing method (MMSD), applied with the aim of defining problems of ergonomic character, concerning the use of the press. In particular the MMSD method was used during the second phase of the IUB method to in order to increase the efficiency of the latter.

The information collected, especially those related to customer's requests, laid the basis to identify the first Design Specifications through the application of the first matrix of QFD method.

At this point, in order to improve the safety of the machine from the beginning, we applied the Preliminary Hazard Analysis method that allowed us to detect the main risks linked to all the life cycle phases of the machine and to carry out, for each risk, the evaluation of hazard level through the application of Technique 1 (ISO 1050). The output of these analyses was used to work out in the "List of Requirements", which is the final step of this phase.

During the second phase of the Design Process the mechanical system starts to take on a more concrete shape and now it is possible to apply several methods for Safety and Cost: in this case, we used the FMEA and FCA methods, which seemed necessary to carry out a careful technical and economic valuation of the mechanical system.

Through FMEA analysis it was possible to identify the main modes of failure of the machine and to determine, for each one, the probability of occurrence, the relevance and the detectability, which makes it possible to detect the corrective measures.

On the other hand, FCA was used to determine what the characteristics (materials, reliability, maintainability,…) that more influence cost of safety devices are.

Furthermore, before concluding the second phase of the design process, a further study was carried out using SCRM: in fact, starting from the chosen concept, we found different solutions regarding the safety devices used. In this case we also made use of a double valuation : we in fact calculated both the safety level and the cost of its implementation.

During the third phase some general characteristics such as materials and dimensions were defined in order to attain a further detailed design. Then, once this task was done, it was possible to carry out a further analysis aiming at the improvement of the system. In this case, as the study is based on matters of Safety and Cost, we carried out a check of the main risks, and in order to make this evaluation effective, we used the evaluation Technique n.2 (ISSA), in order to consider not only the risk directly linked to the machine, but also the ones related to working environment and to user skills.

Analysing the results obtained it's clear that the best solutions aimed at increasing the level of the mechanical system safety, ensuring its conformity to standards (ESR), are the following:

- the modification of the hydraulic circuit;
- the application of a mechanical safety device able to block the mobile column both in case of accidents, and during the maintenance phases, which resulted in being the most dangerous.

In particular, we have thought of developing the design of the second solution because its realisation is much simpler on an already existing machine, as in our case.

In Figure 3 we can see the scheme of the device, made up by a bolt, moved by a simple auxiliary circuit, and its position in the machine.

The results we achieved were all satisfactory: in fact, repeating the safety assessment we have seen that the Safety and Reliability levels increased in a significant way. Furthermore it has been estimated that the cost of the realisation of this modification is very low (less than 100 euro).

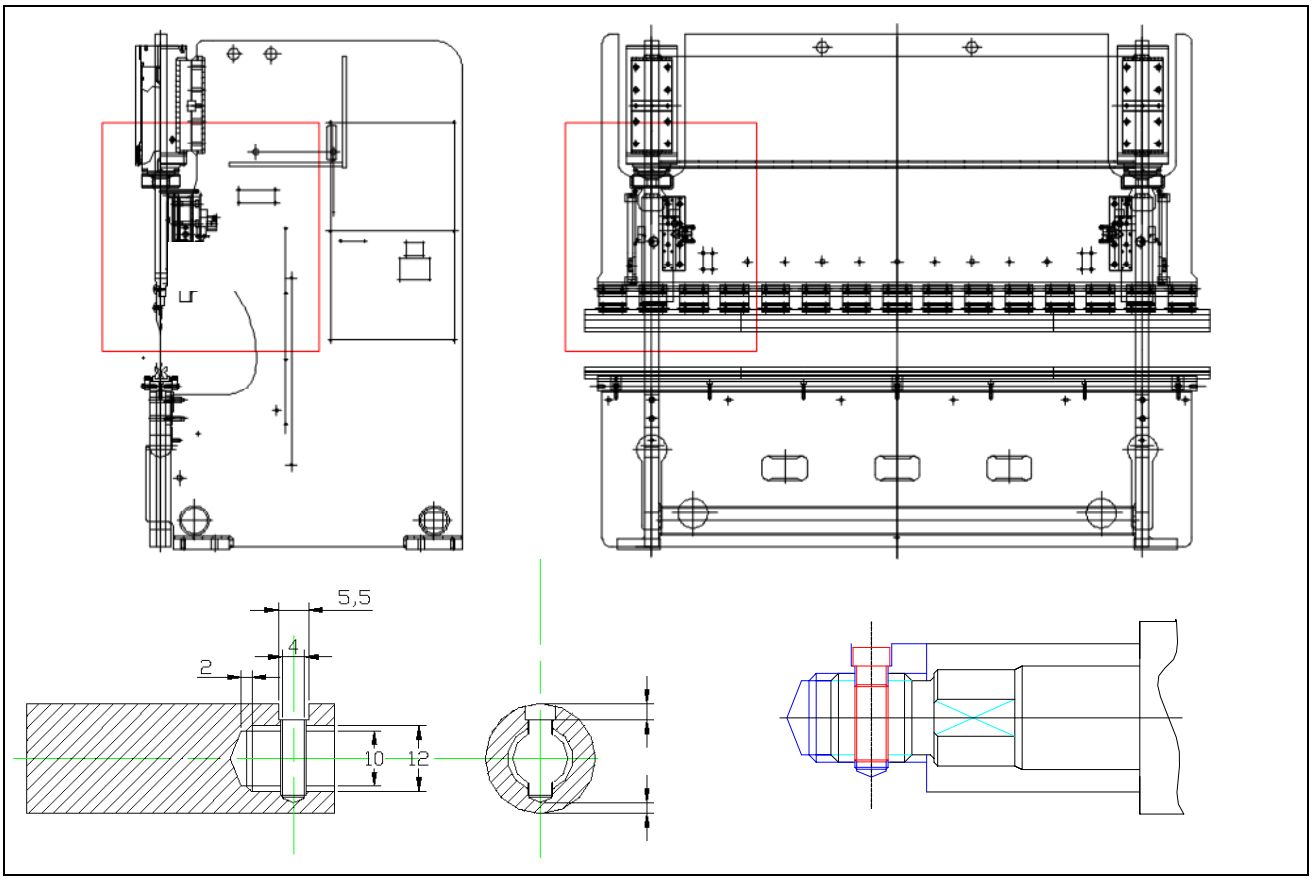

Figure 3. Scheme of the mechanical safety device.

6. Conclusions

The Methodology SCR allowed us to single out the main risks connected to the use of this machine, and to set the interventions that have to be carried out, analyzing at once the increase of costs related to such changes.

The result achieved was a Mechanical System which satisfies the requirements given and that, in particular, gives warranty of its Safety with regards both to the operator and to other people who may be nearby.

In fact the Methodology SCR allows not only a “top-down” assessment leading from hazards to components’ reliability, but also a “bottom-up” investigation of the influence of every design decision, involving both the manufacturing costs as well as the total life cycle cost.

Moreover, with the proper choice of Safety Devices, it was possible to achieve a considerable increase in Safety with a very little increase in costs.

The results achieved were considered very good: in fact the work carried out from a theoretical as well as a practical point of view, allowed us to improve Safety, Ergonomics, and Reliability of the mechanical system significantly; particularly, an original system for locking columns both in case of accidents, and during maintenance was designed.

Moreover, following such an approach, all Design stages have successfully satisfied Safety certification.

6.1 Further work

The developed methodology and approach have been considered positive so much so they will be applied both to a wood working machine and to a mowing machine, with the double aim to further validate SCRM, and to define some general safety guidelines useful both for machines manufacturers and users.

Acknowledgements

The study was carried out with the support of the Safety Technologies Department of the ISPESL (Italian Institute for Prevention and Safety) of Rome.

References

[1] Ashford, N.; Hallet, Hunter, Scheel , "A question of Costs and Benefits", Magazine of the European Agency for Safety and Health at Work, Office for Official Publications of the European Communities, Luxembourg, 1999.

[2] Birmingham, R.; Sen, P. et al. "Development of a design for safety procedure for search and rescue craft", Journal of Engineering Design, Vol. 11, No. 1, 2000.

[3] Euronormes:89/392/EC; 91/368/EC; 93/44/EC; 93/68/ EC; 83/391/EC; 86/654/EC; 89/655/EC; 89/656/EC; 90/296/EC; 90/270/EC; 90/394/EC; 90/676/EC; EN 1050/96; EN 291; EN 292:1992 ; EN 954:1996.

[4] European Commission, "Guide to the implementation of directives based on the New Approach and the Global Approach", Office for Official Publications of the European Communities, Luxembourg, 2000.

[5] Hundal, M.S., "Product Costing: A Comparison of Conventional and Activity-based Costing Methods", Journal of Engineering Design, Vol. 8, No. 1, 1997.

[6] Hunter, T.A. "Engineering Design for Safety", McGraw – Hill, New York, 1992.

[7] International Social Security Association (ISSA), "Assess your accident risk yourself: Risk evaluation at the workplace" International Section Machine and System Safety, Mannheim , 1998.

[8] Main, B.W. et al. "What Do Design Engineers Really Known about Safety", Mechanical Enginering, August 1992

[9] Pighini, U.; Fargnoli M.; Geraci, D.; "A Design Procedure for the Safety of Mechanical Systems", proceedings of ICED 01, Glasgow, 2001.

[10] Wang, J. & Ruxton,T. "A Review of Safety Analysis Methods Applied to the Design Process", Journal of Engineering Design, Vol. 8, No. 2, 1997.

Dr. Ing. Mario Fargnoli Chair of Machine Elements and Methodical Design Dept. of Mechanical and Aeronautical Engineering, University of Rome "La Sapienza", via Eudossiana 18 – I – 00184, Rome – Italy. Tel: 0039-06-44585236 Fax 0039-06-4881759 E-mail: mario.fargnoli@uniroma1.it