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COST BENEFIT ANALYSIS IN DESIGN FOR SAFETY

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1. Introduction

Since the beginning of 90's the European community has been committed to facing problems related to Machine Safety issuing new laws and standards aimed at reducing risks in workplaces. In spite of this new approach towards Machine Safety and huge technical and technological progress achieved in recent years, the number of accidents related to machine malfunctioning or an improper use of machines and safety devices continues to grow more and more every year.
The main reasons which cause such a conflict can be attributed to the following aspects:

1. the growing number of regulations have brought to manufacturers difficulties in decision making both regarding the choice of machines and safety devices, and regarding machine management (use, maintenance, modifications);
2. the fact that the complexity of mechanical systems is becoming deeper and deeper, so that both in the case of machine producers and users, an ever specific knowledge and skill is required.

Moreover, the evolution of market requirements and structure of the industrial world (mainly composed by small and medium sized companies) have contributed to producers' and manufacturers' growing costs, so that they have actually become a hindrance to the final pursuing of a proper level of Safety.
In particular, the link between safety and costs is indeed directly faced in the new review of the Directive "Safety of Machine", which takes into account the possibility that the *ERSs (Essential Health and Safety Requirements, Directive 98/37/EC, Annex I)* could not be achieved not only because of technical limits, but also because of economical constraints.
In such a context, the designer plays a fundamental role in order to find the optimal balance between safety and costs, finding optimal criteria in order to evaluate the maximum level to which the safety of machines could be increased, thus making it economically feasible and in compliance with laws.
The goal of the research carried out collaborating with the research department of Safety Technologies of the Italian Institute for Prevention and Safety, was to define a Methodical Design Approach aimed at the evaluation and improvement Safety of MSs with acceptable Costs, in accordance with the recent EC Directives.

2. Scientific Background

As shown by many Authors in the field [Ashford, Hallet, Hunter, Scheel 1999], the pursuance of the new regulations and laws in the matter of Machine Safety is a huge problem for companies both because it requires deep modifications of products' design and manufacturing processes, and because it needs additional costs which companies have to bear.

On the other hand, it is clear that by operating from the first stages of the machines' design and development, it is possible to increase the safety level of machines and at same time obtaining a reduction of costs related to the whole life cycle of the machine [Hundal, 1997; Hunter 1992, Wang et alia 1997].
The research work, begun in 2001, was based on the investigation of problems related to the reception of the new laws regarding Safety of Machines, not only collecting data on accidents on work, but also through a detailed inquiry which involved:

- Public Institutions (ISPESL, Italian Work Ministry, Italian Ministry for the Industry and Local Health Authorities).
- Machine Producers and Users (machine manufacturers, users, consulting and training Companies, etc.).

Summarizing the results of this first phase of the research [Fargnoli, Pighini 2003] the following main problems stand out:

1. most of the accidents are caused by the great confidence of skilled users and because of the lack of attention during maintenance or setup operations;
2. there are still a lot of former machines in relation to the new Directives, and most of them are not even updated according to the new Directives, mainly because of economic reasons;
3. the lack of "specific rules" related to the design, development and use of machines and safety devices, which can be used as guidelines both by manufacturers and designers, and by users, as well as by Authorities in charge of controlling and assessing compliance with the regulations;
4. an incorrect interpretation of the criteria for choosing safety devices (i.e. EN 954:1996), which often leads designers to evaluate and choose these systems in the wrong way, with the only effect of increasing the cost of machines;
5. the continuous development and improvement of technical standards ("harmonized standards"), which regard specific categories of machines and devices, as well as the more and more widespread use of safety management systems (often together with quality and/or environmental management systems) have significantly changed the role of designers and manufacturers, modifying their modus operandi as well as generating confusion in decision making stages.

The second stage of the research was focused on the analysis of the costs related to Safety, and in particular on the costs concerning the "lack of Safety", which have great influence on the company's budget, as well as on the whole economy of society.
Moreover, considering both the preventive costs and the costs following accidents, it is deemed that an increase of the costs related to Safety prevention leads to a reduction in accidents and consequently further costs. Such a reduction does not however follow a proportional law since, even simpler and cheaper measures can lead to a notable reduction in accidents, whereas more complex and expensive ones may only lead to insignificant reduction.

3. Methods

In spite of the high number of methods, techniques and rules developed in the field oriented to facing such a problem, all of them appear disconnected from each other and generally aimed at solving specific problems.
On the scientific basis of Methodical Design, the research performed has led to an integrated design procedure aimed at leading designers in coping with risks and increasing MSs safety level, and guaranteeing sustainable costs at the same time. Such an approach, shown in Figure 1, consists of a rational way of proceeding which leads to the identification and the assessment of the risks of a mechanical system (both the ones related to its structures, and the ones related to its use and maintenance), and allows designers to choose optimal solutions both from the technical point of view and the economical one. The developed approach provides for the use of Design methods and techniques within each one of its phases, as well as a bottom-up validation: in particular, it is based on

the application of both Risk Analysis and Costs Evaluation methods and techniques (e.g. FMEA, FTA, PHA, FCA, LCCA; SCRM, etc.) in a coordinated and systematic way.

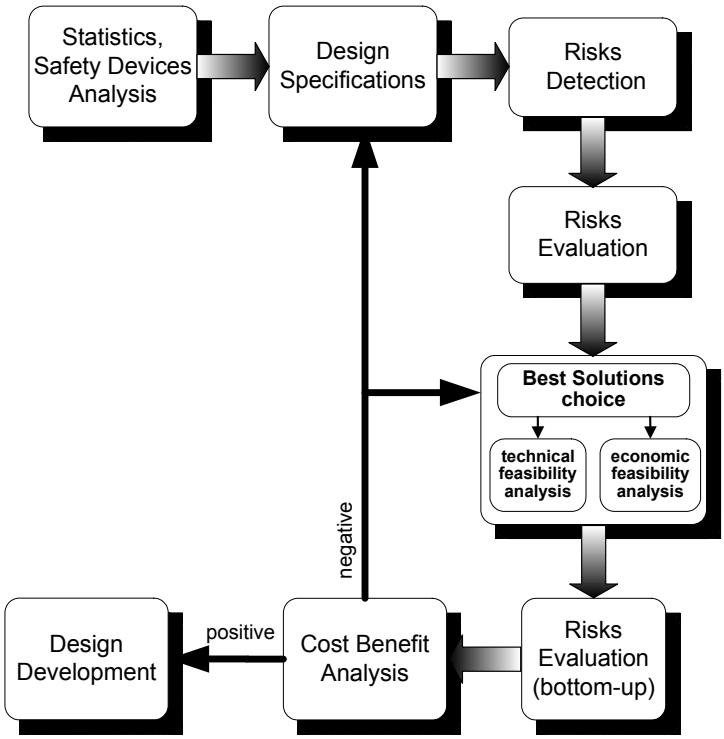

Figure 1. Cost/Benefit approach

In practice, the design methodology developed, consists of both a top-down and a bottom-up approach:

1. *Top Down*: in order to define and characterize single components of the product on the basis of the risks underlined as well as following both users and regulations requirements;
2. *Bottom-up*: in order to lead designers in choosing the best combination of the available solutions, among several suitable alternatives for each highlighted risk. Such an evaluation not only takes into account technical aspects and components costs, but also costs related to the use and maintenance phase of the machine, as well as costs related to the "lack of Safety".

In particular, the use of the Safety/Cost Ratio method (SCRM) [Fargnoli, Pighini 2003] allows us to evaluate technical performances, safety level and relative costs for each component/part of the mechanical system, from the early stages of the design activity and supplies useful information for the further application of both risk assessment and cost evaluation methods and techniques (i.e. FMEA, ISSA technique, ISO 1050, FCA, CBA, etc.). 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, in a coordinated and effective way so that the designer can make the right choice in each phase of the Design Activity. In Figure 2 an example of the use design methodology is shown.

4. Case Study

The result of the present study was the development of a methodical design approach 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. To verify the effectiveness of the study performed, such an approach has been applied to the redesign of a loading platform used in construction sites, in collaboration with both user and producer companies.

The re-design of such a Mechanical System represents a direct attempt to show how using this approach in the right way, it is possible to reach an adequate Safety level and at same time a considerable cost reduction, also considering the fact that the European standard concerning this kind of machine is very recent (EN 280:2001).

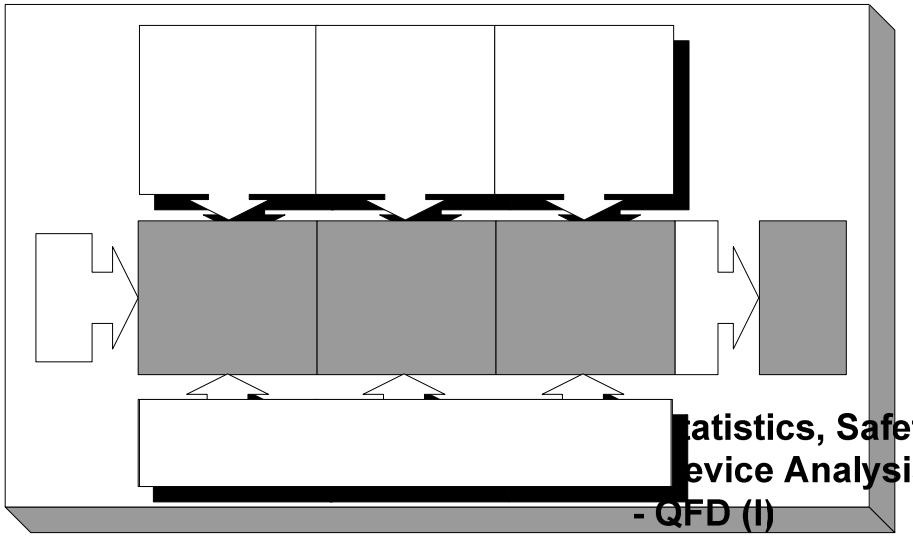

Figure 2. The Design Methodology

Moreover, the inquiry carried out in the first phase of the research showed construction sites as one of the work places which had the highest occurrence both of accidents and of non conformity with the regulations in the matter of Safety. In accordance with the above mentioned Procedure, in order to clarify the design task (first phase of the Design Process), all necessary data to understand and explain the problem were collected; in particular we considered customer requirements, standards, characteristics and typologies of the main existing similar machines: in order to establish a preliminary selection among all possible structural alternatives, on the basis of the information collected, we applied the first phase of the method Quality Function Deployment (QFD), as shown in Figure 3.

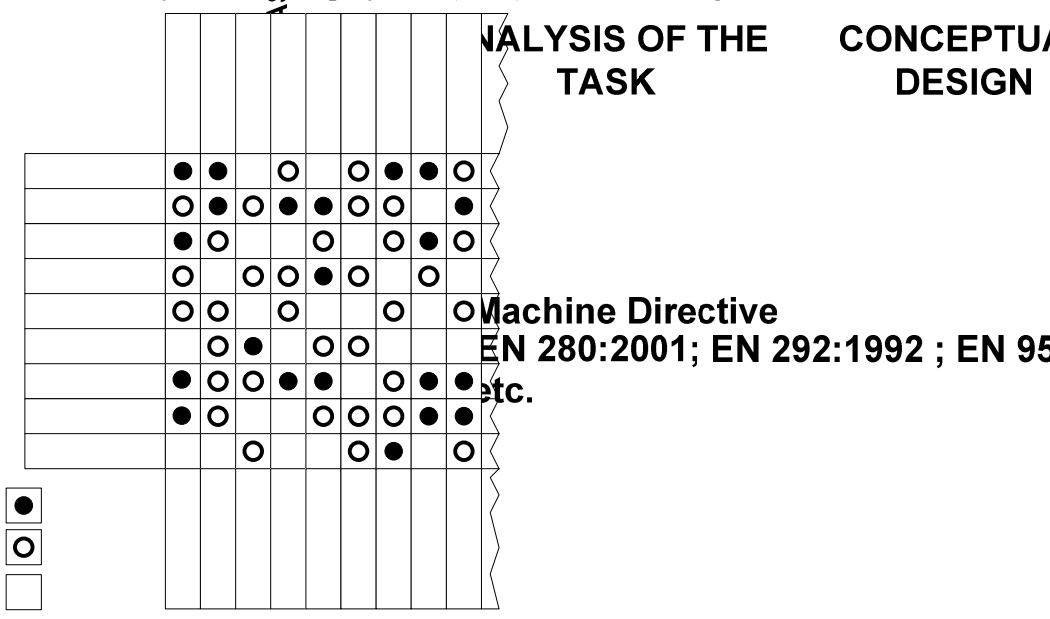

Figure 3. Quality Function Deployment (I)

The information collected, especially that related to customer requests and safety requirements, laid the basis to identify the first Design Specifications through the application of Preliminary Hazard Analysis (PHA) and the Safety/Cost Ratio Method (SCRM). During the second phase of the design

Process, the mechanical system starts to take on a more concrete shape and it was possible to apply various methods both for the Risk Assessment and Reliability evaluation, and for the costs evaluation:

- the Functional Cost Analysis has been helpful to determine which functions/characteristics influence costs the most;
- the FMEA has been applied in order to assess the safety and reliability level of the MS;
- the SCRM, has been applied again in order to choose the optimal one better among the several concepts developed.

During the third phase some general characteristics such as materials and dimensions were defined in order to attain a further detailed design; moreover, in order to increase the safety level and verify the the results achieved in the second phase, both the techniques ISSA and ISO 1050 have been applied (in table 1 the most important risks are summarized).

Table 1. Main Risks related to the use of the platform

Main Risks
Overturning
Crushing
Sliding, slipping down
Involuntary start up
Vibrations – Noise
Incorrect use

Then, a Life Cycle Cost Analysis was carried out, taking into account costs related to the management of the machine during its whole life (main results are shown in table 2). In Figure 5 the general lay out of the mechanical system developed is shown. Furthermore, on the basis of the obtained results we used the Cost Benefit Analysis (CBA) in order to verify the evaluation of the economical feasibility of the project: in particular, considering an interest rate of 6%, we found out that the break even point is reached after 9 years of use of the machine. Such a result particularly fits the real tendency of the users of the loading platforms, since they often use this kind of machine for more than 10 years.

Table 2. Costs evaluation and main results

Costs (per year)	***Value (€)***
Ownership cost	**2452**
Use costs	**20124**
Maintenance costs	**350**
Main Results after the redesign	
Mechanical System Price	**+ 10%**
Occurrence of accidents	**- 25%**
Occurrence of Failures/Malfunctioning	**- 15%**

5. Results & Conclusions

Even though the present research work, begun in 2001, has already led to good results both from a theoretical and a practical point of view, it requires further studies because of the vastness of topics involved and the great variety of machines and safety devices present on the market nowadays.

This design approach surely represents an useful design tool 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; as well as being seen as a criterion which can be assimilated by workers as a guideline and a useful operative tool in being in compliance with current regulations and standards in the matter of Safety.

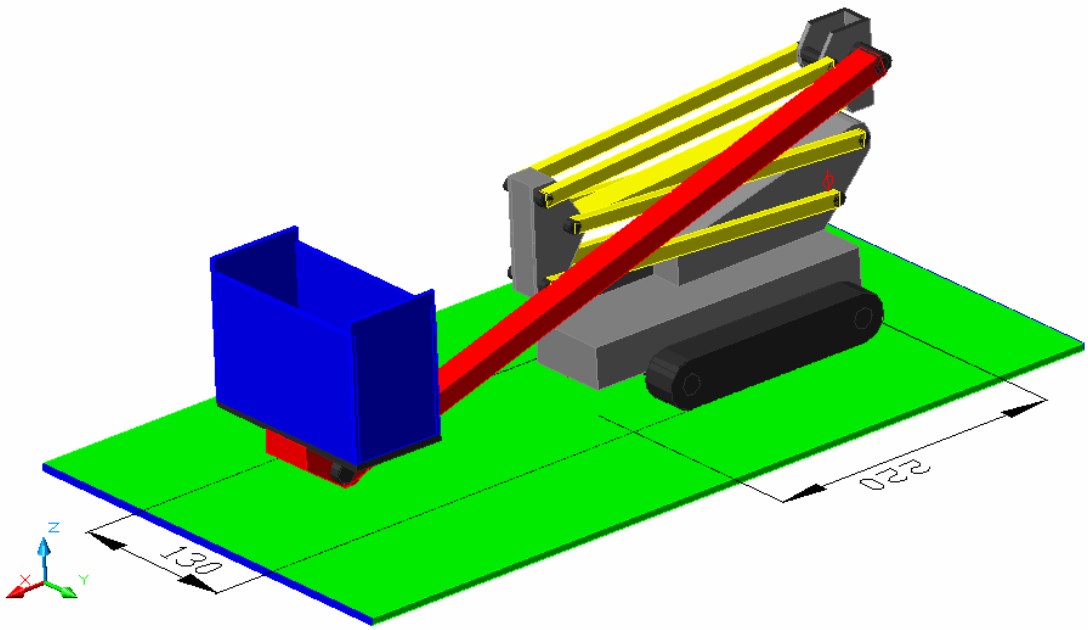

Figure 4. General Layout of the MS

Acknowledgement

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