EVALUATION OF ALEATORY RISK AND CORRELATION BETWEEN RISK LEVEL AND COSTS
IN ENEL DISTRIBUZIONE

Ugo Tramutoli, Riccardo Pirro, Antonio Cammarota
Enel Distribuzione - Italy
ugo.tramutoli@enel.it, riccardo.pirro@enel.it, antonio.cammarota@enel.it

INTRODUCTION

The intense development of the electricity market deregulation in Europe has produced a new scenario with a multiplicity of operators involved in the electric system activities. In this context, the operation of the electric network and the property of the plants could be entrusted to different companies. For this reason an evolution of the concept of safety is necessary and the introduction of risk management methodologies in the safety field can be useful.

Changing the approach to safety management is playing an important role for utilities so that, besides monitoring the injury phenomenon, they also have to consider, in safety field, efficiency and efficacy targets, as other business activities. Nowadays, risk management applied to safety field has to be considered as a profit centre and not just as a cost centre anymore. To this aim, for a company it is necessary to provide a safety management system that, not only analyzes and evaluates the risks and takes measures to prevent injuries, but also can individuate the best safety level at the lower total cost.

Every company has to invest in prevention and protection and to try to reduce the number and the severity of the accidents to improve its social reputation. For this reason, in order to minimize the safety costs, it is necessary to create a model able to represent these costs, related to the risk level associated to working activities.

In this context, the aim of the paper is to show how economic and quality benefits can be derived from a good application of safety aleatory risk management.

RISKS AND COSTS ANALYSIS

The risk management strategy here proposed is to shift the focus from mere risks evaluation to a safety management methodology, in order to:
- analyse and evaluate risks and carry out proportionate preventive and protective measures;
- correlate the fixed safety level to the safety costs.

In this paper risk identification, evaluation and management processes are defined with regard to typical power distribution networks operating activities. Advantages offered by the adoption of a safety management model, based on correlation between iso-risk curves and safety costs, will be presented.

Risk Evaluation

Evaluation and weighing of risks related to working activities are usually represented by mean of a matrix (damage vs. probability of occurrence). Even though this approach provides a proper risk weighing, it obviously does not allow to correlate risks weight to safety management costs. Therefore it is unsuitable for a correct planning of safety investments and for a reliable control of benefits and costs-to-profit ratio.

Iso-risk curves (extrapolated from damage vs. probability matrix) are defined by the following equation:

\[ \text{Risk} = \text{Probability} \times \text{Damage} = \text{Constant value} \quad (1) \]

A risk weighing diagram is represented in figure 1, showing Enel Distribuzione values from 1999 to 2003.

The severity rate \((Tg)\) and the frequency rate \((Tf)\) are defined as:

\[ T_g = \frac{D_a}{W_h} \cdot 1000 \quad (2) \]
\[ T_f = \frac{N_i}{W_h} \cdot 1000000 \quad (3) \]

where, fixed an observation period, \(D_a\) is the number of lost working days due to injuries, \(W_h\) is the number of working hours and \(N_i\) is the number of injuries.

Safety Costs

In this section we will propose a safety costs evaluation model whose result is a graph representing three curves. This graph can be merged to an appropriately modified version of the iso-risk diagram described above, as we will see further on.

Safety level \((Gs)\) is defined as:

\[ G_s = \frac{1000}{T_f} \quad (4) \]

and represents the thousands of working hours without any injury.

In order to quantify the costs that a company has to bear, with

\[ 0,0 \]
\[ 0,5 \]
\[ 1,0 \]
\[ 1,5 \]
\[ 2,0 \]
\[ 0 \]
\[ 10 \]
\[ 20 \]
\[ 30 \]
\[ 40 \]
\[ 50 \]
\[ 60 \]
\[ 0 \]
\[ 1,0 \]
\[ 1,5 \]
\[ 2,0 \]
\[ 2,5 \]

\[ \text{Tf} - \text{Frequency rate (1/10}^{6}\text{h)} \]

\[ \text{Tg} - \text{Severity rate (days/10}^{3}\text{h)} \]

Figure 1: Risks weighing diagram
regard to workers’ safety and health, two different classes of these costs can be identified:
CP (preventive costs) and CS (costs consequent to injuries or occupational diseases).
The total cost borne by the company can be evaluated with the following formula:
\[ CT = CS + CP \]  
(5)

The basic hypothesis of this model are:
- consequent costs (CS) decrease when company’s safety level grows;
- preventive costs (CP) increase when company’s safety level rises;
- the total cost curve decreases when company’s safety level grows, until it reaches it’s minimum point; beyond this point the curve starts to rise because of the increase of prevention costs.

According to previous hypothesis and representing the costs in € per working hour, the cost functions trends are represented in figure 2.

**Model Application in Enel Distribuzione**

We will now examine an application example, based on the data available in Enel Distribuzione S.p.A. referred to workmen only.

Merging the diagrams of iso-risk curves, appropriately modified, with safety cost curves, a new diagram is obtained, whose variables are risk and costs. This diagram not only allows to make up for accounting lacks, but also to plan investments in a more careful and precise way. In fact, by mean of this tool it is possible to get useful information for an accurate safety investments planning and for the definition of risk typologies on which focus our efforts.

Although in this case the priority is to have a set of actions in order to limit damages, the seek of an overall economic saving (a demand which may seem obvious) acquires a specific importance in this field.

In this context it is very important to have clear targets, consciously accepting residual risk (i.e. the part of risk that cannot be forecast) and, from this point of view, to look for an acceptable equilibrium between consequent costs and preventive costs.

The model allows also to estimate probable costs variations and to define monitoring and feedback tools which must be used in the management process in order to regulate investments on reachable improvement basis.

**Iso-risk Curves Determination**

We will modify iso-risk curves in order to make them representable as a function of safety grade. Representing the same curves as a function of safety level (Gs) instead of frequency rate (Tf), we will obtain a new diagram with straight lines instead of curves. Damage tolerance level, instead of growing from the bottom-left (green area) up to the top-right (red area), will grow from bottom-right to top-left. Therefore, we will obtain \( T_g = f(G_s) \).

The new iso-risk diagram has the shape of the one shown in figure 3.

Although the two diagrams represent, from both the qualitative and quantitative points of view, the same phenomenon, the second one has the following advantages:
- it is easier to be read and drawn, being made up of straight lines;
- on the abscissae axis the safety grade is represented, growing as the number of injuries decreases.

On the ordinates axis the severity rate is shown, which can be easily correlated to injury consequent costs by multiplying it by the equivalent unitary cost of one lost working day due to an injury.

The criteria used to choose iso-risk coefficients for tolerable risk limit (black line) and acceptable risk limit (green line) refer to INAIL (National Institute of Occupational Accidents Insurance) guidelines on evaluation of injuries. Practically, less than ten lost working days due to injury will be considered slight, more than thirty lost working days due to injury will be considered severe.

The drawing of figure 3 is divided in three zones by the two straight lines:
- green area: slight and tolerable risk;
- red area: severe and non-tolerable risks;
- yellow area: moderate risk area.

**Evaluation of Safety Costs in Enel Distribuzione**

Safety costs related to the operative working activities of Enel
Distribuzione from 1999 to 2003 can be obtained analysing general and industrial accounting databases. Preventive costs curve (CP) has been obtained considering the following parameters:
- CP1, safety structure costs;
- CP2, individual protection devices costs;
- CP3, safety training costs;
- CP4, safety document and emergency plan costs
- CP5, health control costs.
Consequent costs curve (CS) has been obtained taking into account the following parameters:
- CS1, lost working hours costs;
- CS2, interruption of working activities costs;
- CS3, legal costs;
- CS4, injury costs.
Even if insurance costs are relevant for Enel Distribuzione, they have not been included in the safety costs evaluation because they are not related to injuries number variation and they have no effects on safety level.

Costs Curves Determination

The preventive costs curve and the subsequent costs curve are determined by interpolation of real data. Even if the analysis can be extended to a larger period, only the years from 1999 to 2003 have been considered, because Enel structure deeply changed in last years. The curves in figure 4 are traced calculating the general equations described in the theoretical part of this paper using the actual data.

Each company is characterized by a certain position on the graph, given by the representation of severity rate and safety level. This position can be modified investing in prevention and/or protection. The prevention (for example training costs) influences injury frequency and has medium-long term effects. The protection (for example Individual Protection Devices costs) affects the severity and takes effect immediately. Investing only in prevention would increase the safety level by decreasing injury frequency, but would slightly reduce the severity rate. Consequently, the number of injuries would decrease but they would be as severe as to keep consequent costs roughly constant.

On the other side, by investing only in protection, injury frequency would remain constant while severity rate would obviously decrease. Of course, this is just a theoretical analysis because investments actually depend on company conditions; anyway, companies usually invest in both prevention and protection. As an example, it is useful to consider two hypothetical companies characterized by the same iso-risk and costs curves, but placed at opposite areas of the graph. The first one, called “A”, is situated at the left of the total cost curve minimum, nearby the black iso-risk straight line. This company has a very low safety level and its risks are placed by the limit of tolerability area. It would be good for this company to invest more for protection than for prevention first, and do the opposite later. In this way, short term costs would grow, but they would be balanced by a stronger successive costs decrease, with not only economic advantages. Furthermore, it is possible to quantify these investments, obtaining a forecast of consequent benefits. Of course this is just a theoretical evaluation because, being dynamic, the model can change through the years, although, as demonstrated by Enel Distribuzione data, it is tendentially a steady model. The opposite situation is represented by company “B”,

Final Graph and Conclusions

In next step, the modified iso-risk diagram and the safety costs curves are merged and the points listed in table 1, which represent Enel Distribuzione, are drawn on the same graph:

<table>
<thead>
<tr>
<th>TABLE 1 – Safety levels and severity rates in Enel Distribuzione</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Gs</td>
</tr>
<tr>
<td>Tg</td>
</tr>
</tbody>
</table>

Obviously, the ordinates of the iso-risk diagram have been modified (expressing them in € per working hour) so that they coincide with the ordinates of the costs diagram. The final graph obtained is represented in figure 5. This graph is a very useful tool for safety management: in fact, it merges both risk management analysis and economic evaluation in an efficient way.
characterized by a high safety level and, we suppose, the same severity rate. The safety condition of this company is much better than the other one, but its expenditure for both prevention and protection are much higher. On investment capabilities basis, company “B” can choose between two different strategies. It can improve its position investing in protection, striving to further reduce injuries severity rate and also improving its social reputation. On the other side, it can limit prevention investments, reducing its costs, because protection costs have already been borne and are contributing in keeping constant present severity rate.

Enel Distribuzione position during the years between 1999 and 2003, will be presented. In these years safety level has constantly increased, and severity rate has shown a strong decreasing trend, leading the company in a more than acceptable risk area.

The model presented allows to forecast the cost increase which has to be borne to obtain a further improvement in terms of risk, or to estimate the expected worsening of the risk itself due to safety investments reduction.

By mean of this model, it is therefore possible to have a safety investments management tool at our disposal. Once the target position is fixed on the graph, being the model dynamic, it will provide a useful control and monitoring task, as long as it is kept updated, just like other management tools as, for example, budget.

The standard reference period will be set by the company safety manager; anyway, being safety investments effective in the mid-term, three months period can be considered as the minimum sensible one.

One more consideration can be done about insurance and transfer expenses. While company “A” needs insurance cover for its lack of safety investments, company “B” could turn to self-insurance.

The model also confirms insurance companies strategy that stimulates, by mean of price reduction, those companies who substantially respect law limits and, most of all, show an improvement of their safety status\(^1\).

Throughout final graph analysis it is possible to focus investments towards a specific risk category, particularly the most profitable.

In fact, supposing to invest in prevention by mean of training courses, it would be better to focus these courses on risks with a lower safety level which guarantee the shortest term return, instead of risks with a higher level of safety.

Similarly, protection investments will be addressed towards higher severity risks producing a short term return.

An additional advantage of this model is the opportunity to quantify those investments and choose the most appropriate tool to evaluate their profitability.

ANNEX

Parametric analysis requires the choice of those functions which may better represent our model.

Costs functions are described by the following equations:

\[
C_p(x) = K_p \cdot x^\alpha
\]  
\[
C_s(x) = K_s \cdot x^{-\beta}
\]

where \(x\) is \(G_s\) and \(K_p, K_s, \alpha\) and \(\beta\) are positive constant values.

The minimum total cost is obtained with a safety level \(G_{sm}\) which can fluctuate in a ±25% \(G_{se}\) wide range, where \(G_{se}\) is the equilibrium point of \(CS\) and \(CP\) (abscissa of \(CS\) and \(CP\) curves interception). Looking at the graph it can be easily observed that the minimum of the total costs curve is flat.

The equilibrium point is given by the following equation:

\[
X_e = \alpha + \beta \frac{K_s}{K_p} \sqrt{\frac{K_s}{K_p}}
\]  

while the minimum point of total costs curve is:

\[
X_m = \alpha + \beta \frac{K_s}{K_p} \frac{\beta}{\alpha} = \alpha + \beta \frac{K_s}{K_p} \cdot X_e
\]

The ratio between \(X_e\) and \(X_m\) is independent from \(K_p\) e \(K_s\) and is a function of \(\alpha\) and \(\beta\) only.

Moreover, if \(\beta < \alpha\) then \(X_m < X_e\), if \(\beta = \alpha\) then \(X_m = X_e\) else \(X_m > X_e\).

The values of these parameters in Enel Distribuzione are listed below:

\[
\alpha = 2.07, \beta = 0.57, K_p = 2.31 \cdot 10^4 e K_s = 3.90.
\]

REFERENCES

[10] Enel, Procedura per l’archiviazione e la gestione dei dati sugli infortuni SIL (sistema di gestione della Sicurezza e dell’Igiene sul Lavoro).

\(^1\) see as an example INAIL (National Institute of Occupational Accidents Insurance) incentives in compliance with Italian Law D.L. 38/2000.