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Risk analysis by threshold evaluation (RATE): a new approach to OHS in small and medium enterprises

Keywords

RATE, SME, OHS

Abstract

Traditional risk assessment methodologies have been thought for large enterprises and they are not easy to handle by small and medium enterprises (SMEs): that can hardly assign resources to safety analysis. However, occupational health and safety is even more important in SMEs since their core competencies are based on skilled manpower. Attempting to solve this problem, a new methodological approach was developed: RATE (Risk Analysis by Threshold Evaluation) is a "bottom up" method which allows safety analysts to follow a standard path, not much time-spending due to a semi-probabilistic approach and enabling identification of hidden risks. RATE perspective is centred on recognising risks for workers rather than machine ways of failure. It is aimed to help entrepreneurs to assess the capacity of their system to reach a desired safety level and to what extent safety measures can improve safety performance.

1. Introduction

In the last years big enterprises have become 'lean and mean' and thereby pushing the risk down to small and medium enterprises (SMEs), [4].Furthermore, SMEs and their aggregation into industrial districts represent a successful productive model for many countries such as Italy.Therefore, the interest in the work environment of small enterprises has grown rapidly, both politically and scientifically.

Many countries have launched programs to support small enterprises, and the EU gives high priority to improving the business conditions for work environment in SMEs [1]-[3].

The policy approach is based on the assumption that small enterprises have problems with the work environment in terms of higher risk and also in terms of controlling the risk. The higher risk has been pointed out by several authors, see for example [6],[7] and [9].

Notwithstanding this, major accidents continue to occur, with significant consequences for workers and their community, the environment and economy.

In Italy 927,998 accidents occurred in 2006 with an increasing trend for fatalities (+ 2%) with respect to the previous year [5].

Occupational health and safety is even more important in SMEs since their core competencies are based on skilled manpower. Absence due to accidents at work can have higher consequences in terms of productivity for a small enterprise than for a large one, where employees can be easily interchanged.

Traditional methods for safety analysis seem not to be effective in order to identify potential risks in SMEs. Their approach is mainly focused on facility availability, which becomes the key performance to be evaluated and provided. In addition, traditional methods have been thought for large enterprises, which have much more resources and time to spend in performing such analysis than SMEs.

For these reasons we decided to develop a new method which provides a safety analysis, specifically created for SME's. Occupational health and safety of manpower should become the centre of the analysis rather than machine failures.

The method should be easy to understand and apply, not much time consuming. Furthermore, it should allow to identify and evaluate "hidden" risks. We noticed, in fact, that most accidents happen because of incomplete understanding of possible risk sources.

The paper is organised as follows. We describe our approach in section 2, while the new method is fully analysed in section 3 and related subsections. Conclusions are provided in section 4.

2. RATE: a new approach for SMEs

Our approach is based on the assumption that the safety level provided to a SME derives from a deliberate choice of its entrepreneur. A system might be, in fact, considered "safe" as regards national OHS regulation, but not enough risk free for workers in the entrepreneur's opinion.

Therefore, he should be provided with a tool able to guide his decision concerning the capacity of his production system of matching those safety requirements established by himself. That is, he should be enable to answer the following questions:

- Are regulatory safety measures sufficient to provide my desired safety level?
- Can additional safety measures achieve my safety goal and in what extent?

The aim of the new methodology is to provide a global safety performance measure, which describes the capacity of the system to avoid injuries for workers. Such index is then compared to a threshold quantifying the desired safety level chosen by the entrepreneur.

Therefore, the Risk Analysis by Threshold Evaluation (RATE) method is proposed. RATE is based on comparison between calculated values and upper bounds, as commonly performed in civil engineering. To properly size a building structure, in fact, the following inequality is commonly used:

$$Stress < Resistance \qquad (1)$$

This concept has been adapted to safety analysis by relating the behaviour of the analysed system during its operations to a stress and the desired safety level described by the threshold to a resistance. Thus, the system will be considered as "safe" if the inequality (1) is satisfied, i.e. if the risk associated with its configuration is less than the value allowed by the safety level chosen by the entrepreneur.

The need of a user-friendly method easily adoptable by SMEs leads to simplify the amount of data required for a safety analysis. RATE overcomes the typical problem of data unavailability in SMEs by a semi-probabilistic approach similar to the civil engineering one. Here, evaluation of the forces stressing a building structure as far as the resistance offered by materials and section profiles is based not on actual values, but on statistical ones, which designers can derive from available tables.

3. Description of RATE method

To effectively describe the proposed method we introduce a simple illustrative example, already considered to explain other approaches [8].

A frying system is considered as follows: after frying in an electric device, an operator collects the product with a metal basket and puts it into a hopper reachable through a small stair. The product falls on a belt conveyor that transfer it to another unit not considered in this analysis. The conveyor has also the function to drop cooking oil and therefore it is provided with an oil collecting tank.

The process is shown in *Figure 1*.

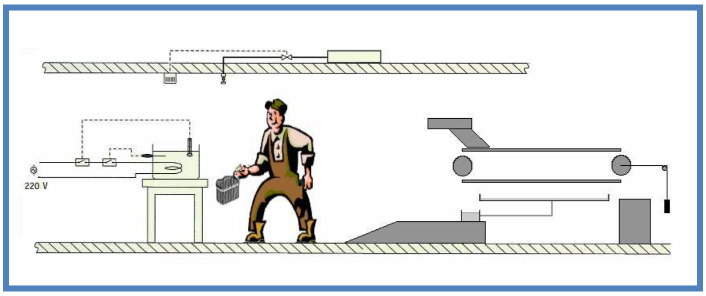

Figure 1. Process' scheme

3.1. System analysis

When applying RATE a system is analysed according to a functional logic.

Therefore, the following elements can be recognised.

A section is a portion of the process that can be considered independent from a logical or functional point of view. In the case of the frying facility (*Figure 1*) three sections can be identified: the frying section (where chips are fried), the handling section (where chips in the basket are moved by the operator to the hopper) and the dropping/transferring section (where chips are conveyed to the packaging area.

A component is, instead, a part of the system which can be physical, geometric or spatial as far as a process fluid or material, operator, etc. having an active role in the process.

About the frying facility, the first section, for example, consists of a frying device, frying oil, a thermostat and power wires.
At this stage any safety device the system has been provided with is not considered. Therefore, the high temperatures interlock and the sprinkler system of section 1 in Figure 1 should not be considered.
The system analysis for the frying facility leads to the block diagram in *Figure 2*.

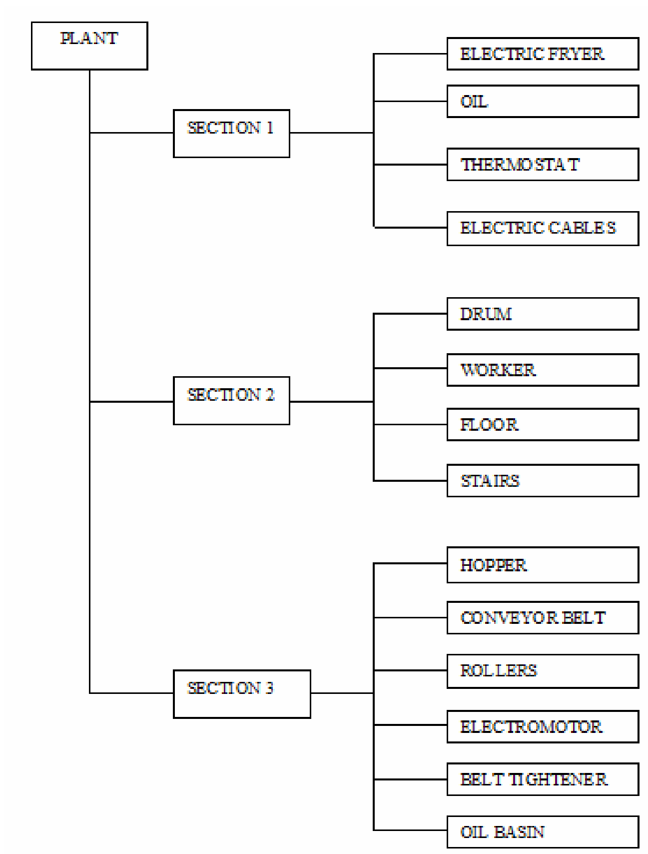

Figure 2. Example of plant schematization

3.2. The risk matrix

After splitting the analysed system into its sections and components, it is necessary to build the risk matrix, where risks arising from interaction of such elements are identified and coded.
A cell (i, i) in the risk matrix of a given section is filled only if component i represents a potential source of danger for the worker.
For example, the risk for a worker to be burned by ebullient oil is coded as 1 in the related cell of the triangular matrix representing the only frying section in Figure 3.
A cell (i, j) is filled if the interaction between the i-th and the j-th component of a given section may lead to a risk for the operator.
For example, the cell identified by the risk with code 3 in *Figure 3* represents the danger of fire due to the failure of the thermostat switch which doesn't stop the oil from boiling.

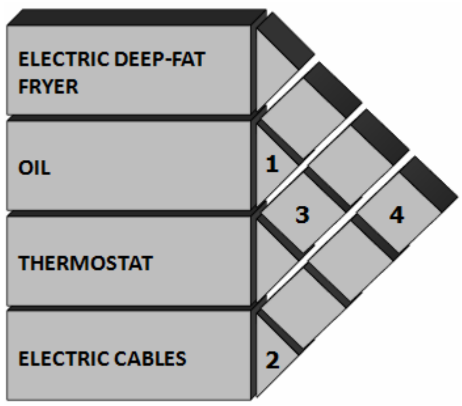

Figure 3. Filling in the risk matrix

We believe that risks to be considered are not only those from interaction of components belonging to the same section, but also those coming from the interactions between different sections.
To take into account this fact we decided to add the so called "mixed sections" to the more traditional key section analysis. Mixed sections have no physical meaning but take a very important role on hidden risk detection. About the frying facility, sections 1-2, 2-3 and 1-3 must be considered.
Let H and K any two sections, the cell (h, k) representing the interaction of component h of section H with component k of section K must be filled if it may be a danger for manpower.
Concerning the frying facility, for example, we identified the risk code 14 of electric shock for the operator. If the frying device is not insulated, in fact, it may transmit electric power to the basket and the latter to the worker.
Therefore, the operator can be the victim of an event that originated in Section 1 but invests him after propagating in Section 2.
After identifying all the cells of the matrix corresponding to possible risk sources the workers, each of them is linked to the description of the type of the expected damage for manpower as shown for example for Section 3 in *Table 2*.

3.3. Risk evaluation

Once identified all possible risk sources for workers (see *Table 1*), frequency and magnitude should be quantified in order to assign a value to every cell in the risk matrix.
Frequency of injuries is not commonly available or quickly evaluated for a small enterprise. Accident data eventually recorded might be not statistically significant due to the relative low number of occurrences.

Table 1. Risk matrix with codes

		Electric fryer	Oil	Thermostat	Electric cables	Drum	Worker	Floor	Stairs	Hopper	Conveyor belt	Rollers	Electromotor	Belt tightener	Oil tank
		Section 1				Section 2				Section 3					
Section 1	Electric fryer														
	Oil		1												
	Thermostat		3												
	Electric cables	4			2										
Section 2	Metallic basket	14	15												
	Worker														
	Floor						7	5							
	Stairs						8		6						
Section 3	Hopper		16							9					
	Conveyor belt		17								10				
	Rollers											11			
	Electromotor												12		
	Belt tightener													13	
	Oil tank		18				19								

Table 2. Description of risks for section 3

	Cod.	Risk description	Effect
Sec. 3	9	Sharp edged hopper	Wound
	10	Worker dragged by conveyor belt	Contusion
	11	Fingers crushed under roller pression	Loss of limb
	12	Overheated engine	Fire
	13	Fingers crushed under the weight that tensionates the belt	Fracture

In order to provide the entrepreneur with an effective instrument for benchmarking too, data coming from all SMEs of the same industrial sector should be considered.
For this reason frequency data used by RATE are taken from reports published by governmental agencies; for Italy we adopted data coming from the annual INAIL (National Institute for Insurance against Work Injuries) report. This choice allows to base the analysis on actual and immediately available data, which are also periodically updated by national agencies.
Estimated frequencies are so aligned with current behaviour of each industrial sector, involving any performance improvement due to new technologies or practices exploitation.
Risk data have been standardized to obtain the iso-risk curve with risk value equal to one.
Since data analysis highlighted how injuries causing serious effects happen more frequently than injuries with high severity, we decided to define magnitude as the inverse of the frequency values in order to reach a constant risk value of one. This choice was also driven by the fact that it is hard to establish if it is better for a worker being exposed to small injuries very often rather than becoming a victim of a serious accident once in his life. We want to focus instead on the ability of preventing dangerous events, independently from their nature.
Concerning the Italian case, INAIL agency classify data into three subsets: temporary injury, permanent injury and death. Risk values were obtained as described in the following *Table 3*.

Table 3. Evaluation of workers' potential accidents

INJURY	*Temporary* %	Risk	*Permanent* %	Risk	*Death* %	Risk	*MEAN* Risk	Coefficient
Wound	21,17%	2,117	0,48%	0,963	0,01%	0,429	1,1696	**1,15**
Contusion	29,29%	2,929	0,77%	1,541	0,03%	1,705	2,0587	**2,00**
Dislocation	26,81%	2,681	0,81%	1,626	0,00%	0,035	1,4474	**1,45**
Fracture	9,65%	0,965	2,93%	5,856	0,09%	4,548	3,7896	**3,80**
Amputation	0,38%	0,038	0,20%	0,397	0,00%	0,087	0,1743	**0,15**
Pathogen agents	0,08%	0,008	0,00%	0,006	0,00%	0,017	0,0103	**0,01**
Other agents (heat, etc.)	2,53%	0,253	0,07%	0,141	0,02%	1,076	0,4901	**0,50**
Foreign body	2,33%	0,233	0,03%	0,053	0,00%	0,044	0,1099	**0,10**
Strain (hernia, etc.)	1,52%	0,152	0,03%	0,070	0,00%	0,044	0,0885	**0,10**
Undetermined	0,66%	0,066	0,06%	0,116	0,02%	1,172	0,4514	**0,50**
Mean value		**0,944**		**1,077**		**0,916**	0,979	**1**

Every risk code previously associated with a cell of the risk matrix (*Table 1*) is then replaced with the respective risk value, as shown in *Figure 4* for section 3.

		Section 3					
		Hopper	Conveyor belt	Rollers	Electromotor	Belt tightener	Oil basin
Section 3	Hopper	1,15					
	Conveyor belt		2,00				
	Rollers			0,15			
	Electromotor				0,50		
	Belt tightener					3,80	
	Oil basin						

Figure 4. Risk matrix for section 3

3.4. The risk index

After identifying risks related to the interaction of system components, it's now necessary to obtain a global performance measure to be compared with a threshold value.
We introduce the Risk Index (RI) for the i-th section of the analysed system as follows:

$$RI_i = CF_i \cdot R_i + \sum_{i \neq j} (\psi_j \cdot CF_j \cdot R_j) \qquad (2)$$

where:
R_i = risk of the i-th section of the system;
CF_i = concurrent factor for section i;
Ψ_i = system concurrent factor for the i-th section.

For a given section, the risk R_i is calculated as the sum of the related risk values in the cells of the risk matrix.
For example, for section 3 (see *Figure 4*), we have:

$$R_3 = 1,15 + 2,00 + 0,15 + 0,50 + 3,80 = 7,60 \qquad (3)$$

Results concerning our case system are shown in the second column of *Table 4*.
In a section with a lot of risk sources, we must consider the possibility that more risks may coexist at the same time. This fact is considered by the introduction of the section concurrent factor CF.
The CF is calculated as the ratio between the number of cells identified as risk sources and the total number of cells of the same section.
For section 3 we have:

$$CF_3 = 5/21 = 0,2381 \qquad (4)$$

CFs for the other sections of our case are shown in the third column of *Table 4*.
The system concurrent factor Ψ represents the same concept of CF at a system level.
It's calculated as the ratio between the number of filled cells of a section and the total number of cells in the risk matrix.
For section 3 we have:

$$\psi_3 = 5/105 = 0,048 \qquad (5)$$

Results concerning the other sections of our case system are shown in the fourth column of *Table 4.*

Table 4. Risk index and related coefficients for each section of the fast food facility

Section	R_i	CF_i	Ψ_i	RI_i
1	2,00	0,4000	0,0381	1,136
2	15,20	0,4000	0,0381	6,215
3	7,60	0,2381	0,0476	2,089
1-2	1,00	0,1250	0,0190	0,489
1-3	4,80	0,1250	0,0286	0,564
2-3	3,80	0,0417	0,0095	0,828

3.5. The threshold value

RATE method involves three different comparisons with a threshold value, which should represent the desired safety level.
The first comparison is performed between the RIs of the system without any safety measures and the threshold. The aim is to make the entrepreneur, but also the worker, aware of the most dangerous sections of the system and the types of risk a worker can be exposed to.
The second comparison is performed between the threshold and the RIs of the system when installed safety measures are taken into account. This leads the entrepreneur to understand the importance of system safety measures in terms of risk reduction. This awareness should be achieved both by entrepreneurs, who are responsible of their introduction, and workers, who should put them into operation day by day (e.g. PPE). Undervaluation of risks and, consequently, the inappropriate implementation of safety measures (e.g. not wearing a helmet) is, in fact, one of the major risks for occupational health and safety.
The introduction of additional safety measures, not specified as compulsory by laws, is a totally free entrepreneurial decision and should be evaluated in terms of expected benefits for workers and enterprises versus costs.
Therefore, the third comparison with the threshold value is aimed at enabling the entrepreneur to evaluate the contribute of every safety in reducing section risks and improving the system safety level.
Now it's important to define a threshold value, corresponding to system resistance, to be compared with the RIs (stresses) calculated as shown in *Table 4.*

Since data obtained from governmental agencies are related to operative plants, they refer to a mean scenario, encompassing best performance enterprises as far as the worst ones. Thereby we defined the threshold value as a reduced percentage of the iso-1-risk curve determined as previously described in paragraph 3.3.
Such percentage expresses the safety level that the entrepreneur desires to reach. For instance, in our example we decided to fix an arbitrary low value, corresponding to a percentage of 50%, i.e. we want the section risk for the analyzed process to be lower than the national half mean value.
In this way the threshold value is dynamically re-determined at every RATE implementation, because of its dependency on statistical data yearly revised.
Furthermore, threshold concept is associated with continuous performance improvement (kaizen). The use of updated data coming from governmental agencies forces application of best practices. In fact we can assume that the number of injuries and their severity will reduce year by year, because of advanced safety solutions due to technology innovation. As a direct consequence the entrepreneur, to keep its system under the threshold value, must yearly reduce the RIs.
A progressive improvement on safety performances is so induced by RATE at every application.

3.6. Comparison with the threshold value

Comparing section RIs without any safety measures applied to the threshold value, we can expect that few sections or no section at all present lower risk index, as we can see in black columns in *Figure 5* for the fast food example.
When safety elements are introduced, RIs must be recalculated in order to take into account the related risk reduction. In particular, safety measures act reducing the section risk R_i by a safety factor (SF) as follows:
-100% for safety measures which fully erase the problem (e.g. for the fast food facility, stairs can be replaced by a ramp);
-80% for safety measures which are automatically activated (e.g. a sprinkler system);
-50% for safety measures which are put into operations by workers (e.g. PPE).
RIs are redefined as follows:

$$RI_i = CF_i \cdot (R_i - SF \cdot R_i) + \sum_{i \neq j} (\psi_j \cdot CF_j \cdot (R_j - SF \cdot R_j)) \qquad (6)$$

For section number 3, the only safety measure installed is the "sprinkler system" that lowers risk 12 (see *Table 2*) to the 80% of its initial value.
So the section risk moves from the initial value of 7,60 to:

$$R_3 = 1{,}15 + 2{,}00 + 0{,}15 + 0{,}10 + 3{,}80 = 7{,}20 \qquad (7)$$

Results for the fast food facility, when already installed safety devices are considered (i.e. high temperature interlock and sprinkler system), are shown in grey columns in *Figure 5*.

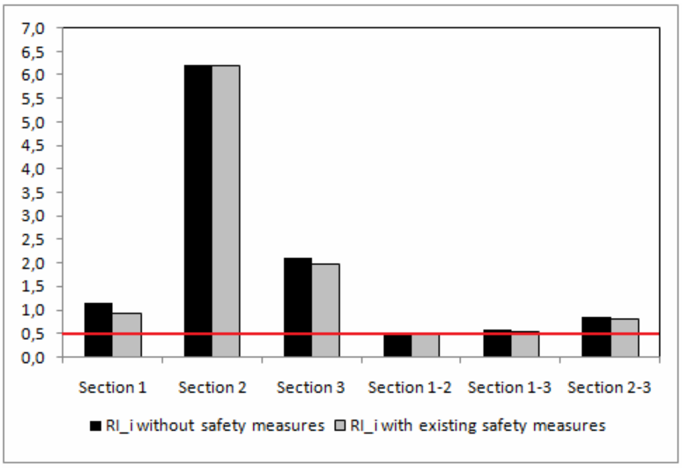

Figure 5. Comparison of RIs value with the threshold for the fast food facility

As it can be seen from *Figure 5*, existent safety measures aren't sufficient to match the entreprenuerial goal, because they don't reduce all system RIs under the threshold value.
So we can suppose that an entreprenuer could consider the hypotesis of installing addictional safety measures.
For the fast food facility, the addictional safety measures that could be introduced are: PPE, a residual current operated circuit breaker, a non slip floor material, a stair's parapect, an oil drops' retainer, a protection against the hopper sharpen edges, a protection for the conveyor belt and a displacement of the oil tank.
R_i and, consequently, RI_i of every system section i must be re-calculated.
Results for the fast food facility are shown in *Figure 6.*
From the comparison with the previous configurations we notice that there's a huge risk reduction for every section that brings the RIs under the threshold value.
For this case we can say that additional safety measures are effective and make the system "safe" in entrepreneur's opinion.
The entrepreneur can now compare these benefits with investments related to the additional safety measures considered.

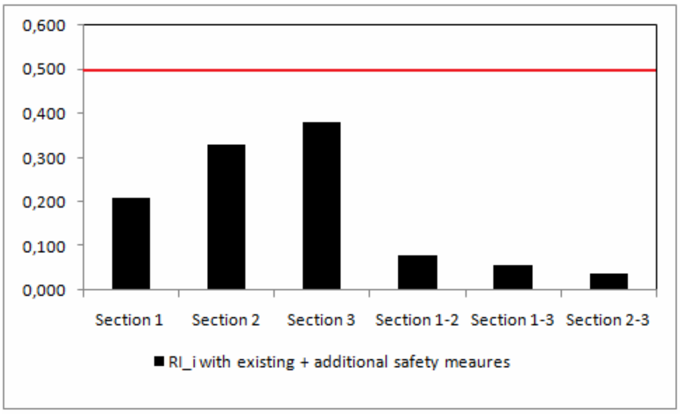

Figure 6. RIs with existing + additional safeties vs threshold

4. Conclusions

The RATE method appears able to fit particular needs of small and medium enterprises.

It is simple to apply and it's based on available and continually updated data, thus requiring few resources to be dedicated to.

RATE doesn't focus on system availability but mainly on OHS of manpower that is a precious and hardly replaceable resource for a SME.

The risk matrix gives a quick and comprehensive graphic representation of system safety status. In addition, it helps detecting potential risk sources, especially the "hidden risks".

The RATE application isn't excessively time consuming and this enables its use even for the design phase. It can be adopted to show the contractor that the pre-arranged safety level has been reached.

The RATE method is now being tested with the co-operation of some North-Eastern Italy small and medium sized enterprises.

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