SSPC MODEL: CONCEPTUAL AND METHODOLOGICAL BASIS OF THE ALGORITHM SUPPORTING PRIORITIZATION OF INSPECTIONS AT INDUSTRIAL INSTALLATIONS SUBJECT TO INTEGRATED ENVIRONMENTAL AUTHORISATION (IEA)

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Abstract

Risk Assessments is a process based on objective assessment methods, characterizing the nature and magnitude of health risks to humans environmental and ecological receptors deriving from human activities.
According to the Directive 2010/75/EU the prioritization of industrial installation inspection has to be carried out through a "systematic environmental risk appraisal based -at least- *on a specified set of criteria".*
Therefore, in order to plan environmental inspections, ARPA Lombardia (an Italian Government Environmental Protection Agency) has developed a project for the implementation of a Risk Assessment method for the prioritization of inspections at industrial installations subject to integrated environmental authorization (IEA).
The primary focus of the method is on the innovative idea for a system linking each installation to a risk factor built in a n- dimensional vector space - the risk space - the components of which are independent of one another.
At present the risk space is a 3-dimensional vector space. For each installation the 3 components of the risk are the potential risk, the actual risk and the vulnerability; the latter component allows consideration of environmental, ecological and human health protection.
Thus each installation is characterized by its own risk index. As required by law the installations ranking is proposed as basis for ordinary inspections planning.
The method is operating satisfactorily and it has recently become the National Reference Standard method for IEA inspections.

Key words: SSPC, risk assessment, health risks, installations, IED inspection, Directive 2010/75/EU.

Introduction

Background

The adoption by the European Parliament and Council of the Directive 2010/75/EU [1] (IED[1] Directive) was a particularly important moment in the evolution of European regulations on the emission of pollutants produced by industrial installations.
The effects of this Directive are extremely important, specifically Article 23 specifies that systematic appraisal of the environmental risks shall be based on at least the following criteria:

[1] Industrial Emissions Directive

(a) the potential and actual impacts of the installations concerned on human health and the environment taking into account the levels and types of emissions, the sensitivity of the local environment and the risk of accidents;
(b) the record of compliance with permit conditions;
(c) the participation of the Operator in the Union Eco-Management and Audit Scheme (EMAS), pursuant to Regulation (EC) No 1221/2009[2].

The IMPEL Network [2] focussed from its beginning on improving inspection activities of its member countries. Milestones of these activities are the publication of "Minimum criteria for inspections" (1997-1999), the "IMPEL Reference Book for Environ-mental Inspection" (1999), the "Step by step guidance book for planning of environmental inspection" (2007) and the development of the IRAM methodology [3] as a risk assessment tool (2011).

Approach

This work paved the way for the development of a methodology supporting prioritization of inspections at industrial installations subject to integrated environmental authorization with the references contained in article 23 of the IED Directive.
Based on previous work within the IMPEL Network, the project proposed here has been developed by ARPA Lombardy, an Italian Regional Environmental Protection Agency.
The Project started in 2013, subsequently was tested by a group of Regional Environmental Agencies and ISPRA (National E.A.) in 2014, finally it was implemented in a programming language (VBA) at the end of 2015.
The SSPC Model (acronym SSPC - Sistema di Supporto alla Programmazione dei Controlli[3]) is therefore a development ensuing from IMPEL activities aimed at establishing a well-running system of prioritized inspections. A previous model was developed by Germany within the Do the Right Things (IRAM) Program. The SSPC model will be described in detail in the next chapter.

Materials and Methods

The *"Risk Space"*, a three dimensional vector space

A risk assessment model was developed, consisting in a multidimensional mathematical model able to provide in output the sorted list of installations according to a given set of rules and algorithms, taking into account the risk of accidents and the environmental impact of an installation, the vulnerability of the local environment as well as the operation performances and the environmental quality.
Each installation defines a vector placed in a n - dimensional coordinate system, the "risk space".

[2] Regulation (EC) No 1221/2009 of the European Parliament and of the Council of 25 November 2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS) (OJ L 342, 22.12.2009, p. 1)
[3] Inspections Programming Support System

Let $\mathcal{V}^n \subset \mathbb{R}^n$ be a vector space over the field $\mathbb{R}$, with $dim_{\mathbb{R}}(\mathcal{V}^n) = n$. We will call $\mathcal{V}^n$ the space of risk.
Let $\{x_1, \dots, x_n\}$ be the *n-pla* of coordinates of $\mathcal{V}^n$ in according to the basis $\mathcal{B} = (v_1, \dots, v_n)$; then each vector of the risk space is a linear combination ($\mathcal{LC}$) of the vectors of the basis $\mathcal{B}$:
$let\ \mathcal{B} = (v_1, \dots, v_n)$ and $v \in \mathcal{V}^n$ $then\ v = x_1\, v_1 + \cdots + x_n\, v_n$

At present we assume that the given risk space is a three dimensional space $\mathcal{V}^3 \subset \mathbb{R}^3$ over the field $\mathbb{R}$ and $dim_{\mathbb{R}}(\mathcal{V}^3) = 3$ where the basis is the orthonormal basis of versors related to Cartesian coordinate system $(\hat{\imath}, \hat{\jmath}, \widehat{k})$: $\bar{v} = v_x\hat{\imath} + v_y\hat{\jmath} + v_z\hat{k} \quad where\ \bar{v} = (v_x, v_y, v_z)$

With these axes any vector $\bar{v}$ in the risk space can be assigned three coordinates (*Figure 1*a) $\bar{v} = (v_x, v_y, v_z)$ defined as follows:

1. a coordinate of ”potential risk” concerning installation's potential to damage environment (v_x)
2. a coordinate of ”actual risk” concerning installation's actual impact on environment (v_y)
3. a coordinate of ”vulnerability” concerning the vulnerability of the surroundings (v_z)

So each installation is represented by a point in the risk space and is identified with its own x, y, z coordinates.

Once defined the risk vector in the space $\mathbb{R}^3$,its magnitude will be defined by vector length as follow (*Figure 1*b):

$$|\bar{v}| = \sqrt{\sum_{i=1}^{3} (v_i)^2} \quad where\ \ 1,2,3{=}x,y,z$$

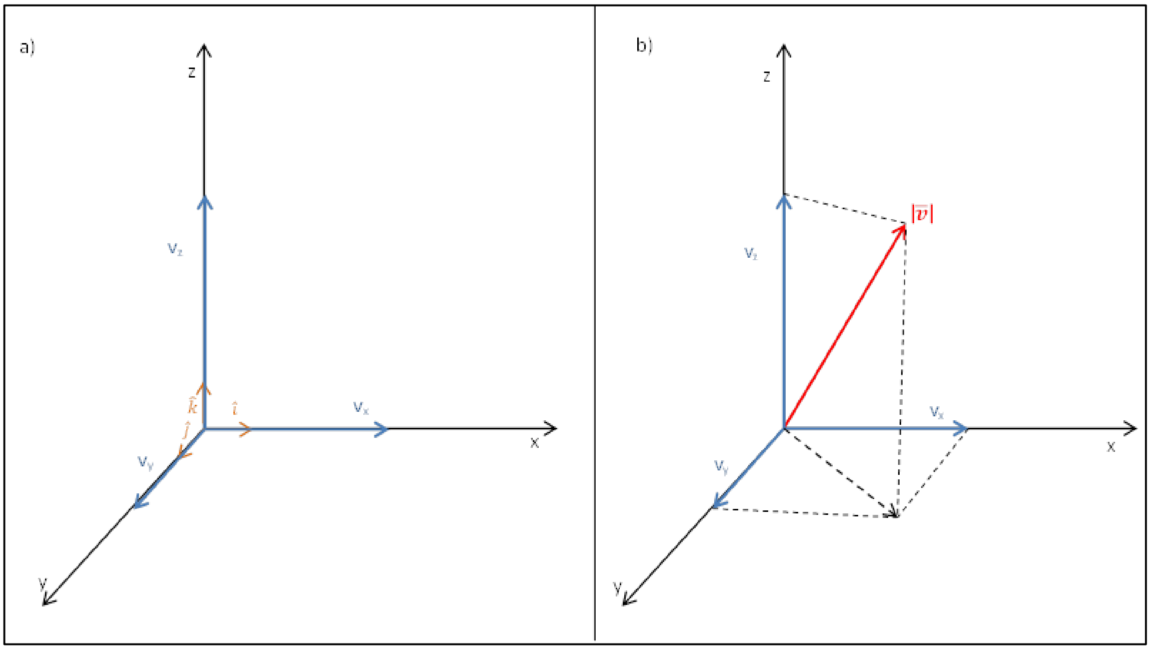

Figure 1: a) the risk space $\mathcal{V}^3$ and the related three coordinates of the $\bar{v}$ vector – b) the magnitude of the risk vector $|\bar{v}|$

The SSPC Model

The sequence of basis operations of the SSPC algorithm model development is displayed in *Figure 2*.

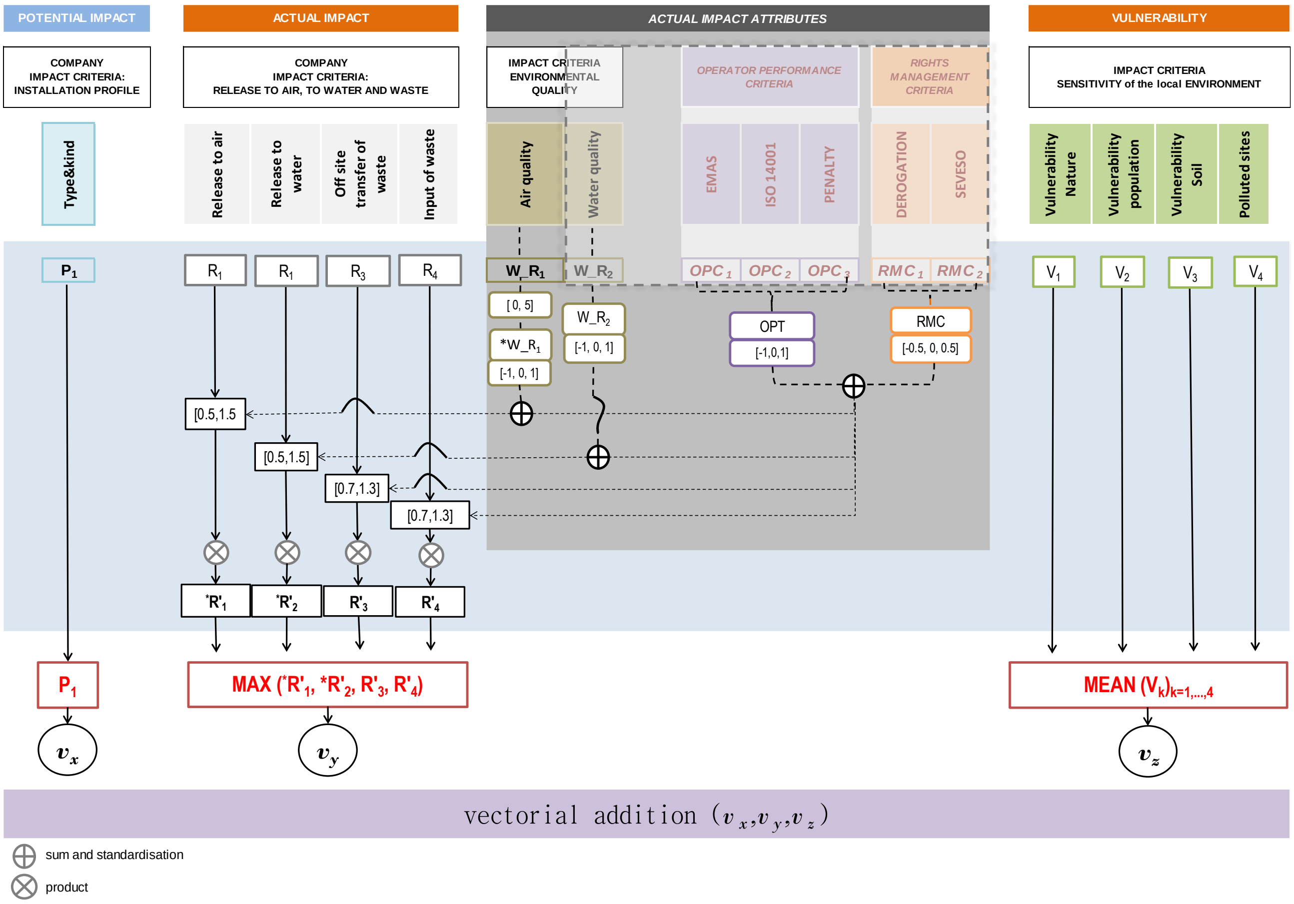

Figure 2: SSPC algorithms scheme

As can be seen, the three coordinates of the vector v_x *(potential impact)*, v_y *(actual impact)*, v_z*(vulnerability)* depend on n_i variables:

- **1** variable as a function of the potential impact: $v_x = f(P_1)$

  where:

  P1 = kind of installation; it characterises the complexity of plant and production cycle, the potential environmental danger deriving from use of substances in normal operation (not by accident)

- **4** variables as functions of the actual impact: $v_y = f(R_1, R_2, R_3, R_4)$

  where:

  R_1 = emission to air

  R_2 = emission to water

  R_3 = off-site transfer of waste

  R_4 = input of waste

  In addition, two parameters, OPT (**O**perator **P**erformance **T**erm) and RMC (**R**ights **M**anagement **C**riteria), apply to all R_i variables, where:

- OPT ($\boldsymbol{O}peration\ \boldsymbol{P}erformance\ \boldsymbol{T}erm$) a parameter indicating the operator performances
- RMC ($\boldsymbol{R}ights\ \boldsymbol{M}anagement\ \boldsymbol{C}riteria$) a parameter indicating the operator management system (EMAS, ISO 14000, etc.)

The first two variables R_1 and R_2 depend on two supplementary parameters $^*W\_R_1$ e W_R_2; where:

- $^*W\_R_1$ a parameter indicating the air quality in the area surrounding the installation; it's combined with R_1

- W_R_2 a parameter indicating the quality of surface water in the area surrounding the installation; it's combined with R_2

- **4** variables as functions of land vulnerability into the surrounding area of installation (radius = 2 km): $v_z = f(V_1, V_2, V_3, V_4)$

  where:

  V_1 = nature protection areas [4]

  V_2 = population density (inh/km^2)

  V_3 = soil vulnerability as an overlapping of hydrogeological vulnerability and aquifer protective capacity

  V_4 = contaminated sites

Conceptual and methodological basis of the algorithm

Ranges of parameters and variables described above are the following:

$P_1 \equiv \{1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5\} \in \mathrm{R}^+$

$R_i \in [0,5] \in \mathbb{N} \qquad i = 1, \dots, 4$

$V_i \in [0,5] \in \mathbb{N} \qquad i = 1, \dots, 4$

$^*W\_R_1 \in [0,5] \in \mathbb{N}$

$W\_R_2 \in [-1,1] \in \mathbb{Z}$

$OPT \equiv \{-1,1\} \in \mathbb{Z}$

$RMC \equiv \{-0.5, 0, 0.5\} \in \mathbb{R}$

As displayed in *Figure 2*, the 4 variables connected with the actual impact depend on attributes to actual impact ($^*W\_R_1$, W_R_2, OPT, RMC), according to the rules referred to in the previous subparagraph.

Parameters W_R_2, OPT and RMC enter the algorithm already processed, while the range of $^*W\_R_1$, equal to $[0,5] \in \mathbb{N}$, is redefined as follows:

$0 < {}^*W\_R_1 \leq 1 \quad \rightarrow -1$

$1 < {}^*W\_R_1 \leq 3 \quad \rightarrow \ \ 0$

$3 < {}^*W\_R_1 \leq 5 \quad \rightarrow +1$

the new range is:

$W\_R_1 \in [-1,1] \in \mathbb{Z}$

After that, the four parameters (W_R_1, W_R_2 OPT RMC) are algebraically added; achieved ranges of allowed values are listed below:

1)

$$n = \left(W_{R_j} + OPT + RMC\right) \in N \equiv \{-2.5, -2.0, -1.5, -1.0, -0.5, 0, 0.5, 1.0, 1.5, 2.0, 2.5\}$$

$j = 1{,}2$

2)

$$m = (OPT + RMC\ ) \in M \equiv \{-1.5, -1.0, -0.5, 0, 0.5, 1.0, 1.5\}$$

$M \subset N$

Values *n* and *m* will change initial values of R_j

To avoid negative values, the following standardization operations are to be carried out:

$$t = \left(\frac{5+n}{5}\right) \quad , \qquad s = \left(\frac{5+m}{5}\right)$$

where:

5 is the maximum value of the range of variables R_j

t and *s* are the values of standardized parameters

The new achieved ranges of allowed values are listed below:

$t \in T \equiv \{0.0, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5\}$

$s \in S \equiv \{\ 0.0, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3\}$

$S \subset T$

Then the variables of actual impact are multiplied by standardized parameters as follows:

$^{*}R_j' = R_j\ \times\ t\ =\ {}^{*}R_j'\ , R_j \in [0, 5]\ \in \mathbb{N}\quad , \qquad t \in T \quad , \qquad j = 1, 2$

$R_k' =\ R_k\ \times s\ =\ R_k' \quad , R_k\ [0, 5]\ \in \mathbb{N}\quad , \qquad s \in S \quad , \qquad k = 3, 4$

So ranges of the 4 variables are redefined as follows:

$R_1, R_2, R_3, R_4 \ \rightarrow\ {}^{*}R'_1,\ {}^{*}R'_2,\ R_3',\ R_4'$

$^{*}R_j' \quad [0, 7.5]\ \in \mathrm{R}^{+}$

$j = 1, 2$

$R_k' \quad [0, 6.5]\ \in \mathrm{R}^{+}$

$k = 3{,}4$

The new ranges of allowed values are listed below (*Table 1*)

values of each possible outcome of R

values of each possible outcome of N	0	1	2	3	4	5
-2.50	0.0	0.5	1.0	1.5	2.0	2.5
-2.00	0.0	0.6	1.2	1.8	2.4	3.0
-1.50	0.0	0.7	1.4	2.1	2.8	3.5
-1.00	0.0	0.8	1.6	2.4	3.2	4.0
-0.50	0.0	0.9	1.8	2.7	3.6	4.5
0.00	0.0	1.0	2.0	3.0	4.0	5.0
0.50	0.0	1.1	2.2	3.3	4.4	5.5
1.00	0.0	1.2	2.4	3.6	4.8	6.0
1.50	0.0	1.3	2.6	3.9	5.2	6.5
2.00	0.0	1.4	2.8	4.2	5.6	7.0
2.50	0.0	1.5	3.0	4.5	6.0	7.5

Table 1: matrix of the values of each possible outcome

Were then introduced two kinds of weighting factors to ensure the influence over the decision making procedures related to policies: the Specific and the General Weighting Factor.

Here it is possible to multiply each variable by the Specific Weighting Factor:

P_1, $*R'_1$, $*R'_2$, R'_3 , R'_4, V_1, V_2, V_3, $V_4 \rightarrow P_{1W}$, $*R'_{1W}$, $*R'_{2W}$, R'_{3W}, R'_{4W}, V_{1W}, V_{2W}, V_{3W}, V_{4W}

Then the 4 variables of real impact and the vulnerability ones are grouped separately to obtain two different statistics quantities, corresponding to two of the three components of the risk vector:

$max_{j,k}\left({}^{*}R'_j, R'_k\right) \qquad j = 1{,}2 \quad k = 2{,}3$

$average\ \ (V_i) \qquad\qquad i = 1,..4$

Three new components of the risk vector are now so defined:

P_{1W}

$max_{j,k}\left({}^{*}R'_j, R'_k\right)$

$average\ \ (V_i)$

There now exists a further possibility to multiply each of the three variables listed above, by the General Weighting Factor.

The three output terms from the algorithm P, R and V are finally added vectorially.

$$A_j = \sqrt{{P_j}^2 + {R_j}^2 + {V_j}^2}$$

The result is the ***vector length*** $\boldsymbol{A_j}$ defining for each installation *j* the position on the risk scale.

Since various configurations can produce equivalent results there is an imperative paradigm under which the model run:

1. *if* vector length is equal *then go to* R_Σ and order ascending
2. *if* vector length is equal *and* R_Σ is equal *then go to* V_Σ and order ascending
3. *if* vector length is equal *and* R_Σ is equal *and* V_Σ is equal *then go to* P and order ascending
4. *if* vector length is equal *and* R_Σ is equal *and* V_Σ is equal *and* P is equal *then go to* last inspection date and order ascending

where:

$$R_\Sigma = \sum_{i=1}^{4} R_i$$

$$V_\Sigma = \sum_{i=1}^{4} V_i$$

Conclusions

A risk assessment model was developed as a multidimensional mathematical model able to provide the sorted list of installations according to a given set of rules and algorithms as an output, taking into account the risk of accidents and the environmental impact of an installation, the vulnerability of the local environment as well as the operation performances and the environmental quality.

Each installation defines a vector in a *3* - dimensional coordinate system, the “risk space”, where the risk of an installation is the vector length resulting from the vector addition of the three components: the potential impact, the actual impact and the vulnerability of the environment.

Calculations were adjusted by terms taking into account water and air quality where the installation is located and terms considering the operator performances and the management system.

Through this technique each installation is characterised by its own risk value. And so what you can do with that is to plot the risk curve of installations using the installations as the ordinates and the corresponding vector length value as the abscissae as shown in the example below (*Figure 3*).

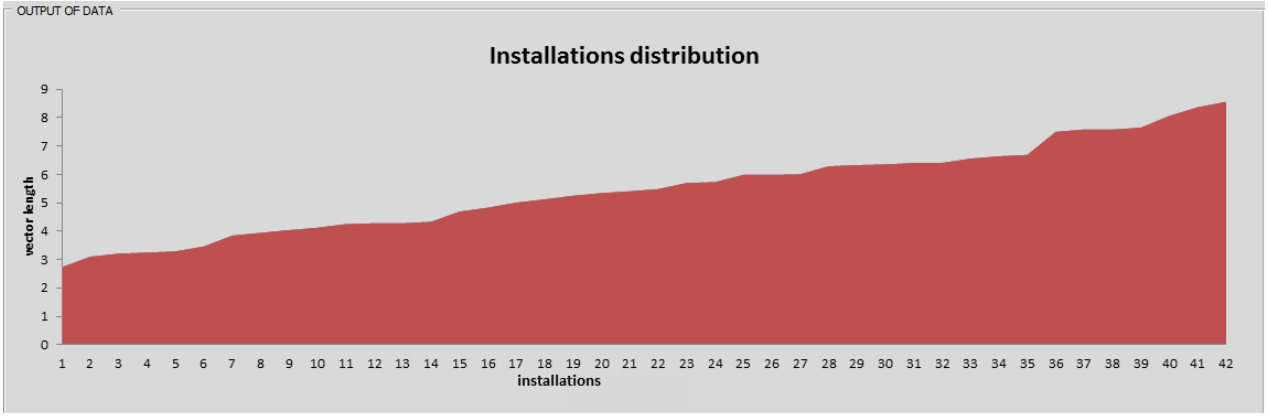

Figure 3: an example of the risk curve of installations

The ranking of the installations is proposed as the basis for programming ordinary controls required by law.

There are significant strengths in the system, such as a high degree of flexibility in the choice of risk factors to be entered. In addition, the implementation of risk factors is possible

without losing structural integrity of the model.

Key factor of its strength is also the impartiality of the model, resulting from use of the same system of indicators and factors for each installation.

Furthermore, it should be noted that the model could be a powerful self-assessment tool.

References

[1] Directive 2010/75/UE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

[2] IMPEL (European Union Network for the Implementation and Enforcement of Environmental Law) www.impel.eu

[3] IRAM Environmental inspections of industrial installations in accordance with the IED – Drawing up of IRAM related inspection programs (http://impel.eu/projects/environmental-inspections-of-industrial-installations-in-accordance-with-the-industrial-emissions-directive-ied-drawing-up-of-iram-related-inspection-programmes/)

[4] Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds

COUNCIL DIRECTIVE 92 /43 /EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora