A new evaluation methodology applied to the hazardous pipelines with the aim to determine a safety index supporting land-use planning strategies

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Abstract: - A new evaluation methodology applied to the hazardous pipelines with the aim to determine a safety index supporting land-use planning strategies has been implemented. This method take origin from a software instrument, designed on *ad hoc* basis, that has been developed to allow the storage of significant informations regarding existing pipelines, as well as the assessment of the spatial dimension in the pipelines risk evaluation. In particular, a database collecting basic information, such as pipe diameter, operating pressure, substance transported etc., has been realized in order to produce an inventory of the pipelines network existing in the Italian territory. A Geographical Information System (GIS) platform has been interfaced to this database to allow the storage of the geographical location of the pipelines and their visualization on a digitalized map of Italy. The software developed can represent, in combination with risk assessment considerations, an important tool supporting the decisional process concerning land use planning policies on the national territory.

Key-Words: - Hazardous pipelines, major accident hazards, land-use planning, Normalized Risk Index

1 Introduction

The environmental and land compatibility assessment of a productive site, where are present dangerous substances, should follow two main lines:

- Safety for surrounding population and infrastructures
- Protection from environmental damages

While there are evaluation criteria to define the existing risks in production plants and storehouses which can be considered *Major accident hazard* plants, right now, there are no criteria for pipelines. This work developed a specific tool, able to evaluate the environment and land compatibility of pipelines, homogeneous with the already existing criteria.

This evaluation tool is based on check-lists and table index systems, similar to those used for the risk analysis in warehouses containing LPG.

The logical criteria settled by current regulations for those storehouses foresees:

- Check-list evaluation to determinate danger level
- Classification (risk class) based over previous limit
- Determination of maximum damage distances
- Determination of land use categories admitted within the distances defined at previous point.

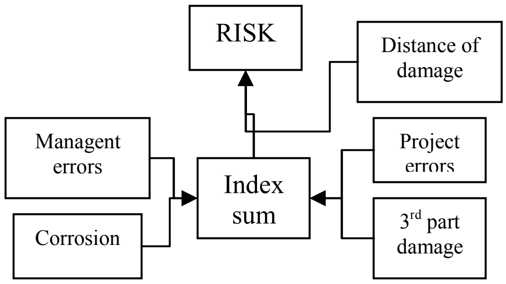
The risk class represents the probability that the warehouse can be the origin of hazardous events (Class 1=low risk, Class 4=high risk). The land use measures the incidence of human presence over the territory (Category A=high density area; Category E=rural area or low density area).

Accordingly to this logical scheme it was developed a methodology applicable for pipelines, fully overlayable to the ones existing for deposits, warehouses, production plants.

2 Pipelines risk assessment

A possible scheme, developed to define the risk index for a pipeline is shown in the following figure.

Fig.1 Risk evaluation flow-chart



The final score assigned to a specific pipeline, according to this method, is valuable as:

$$Risk = \frac{index\_sum}{impact\_scale\_factor} \quad (1)$$

Moreover all the indexes are described.

2.1 Third part damages

With the expression "3rd part damage" is indicated every kind of accident caused by people not directly involved with pipeline exercise. The relative index is based on the following list of risk factors and assigned percentage weight, obviously, the higher the damage, the higher the final score.

2.1.1 Minimum coverage depth

(0-20 pts. 20% of index)
As the minimum amount of soil or other material that covers the pipeline and protects it from potential damages.
The final score depends on covering material type (sand, gravel, etc.) and thickness.

2.1.2 Activity level

(0-20 pts. 20% of index)
It concerns the level of both human and natural activities (e.g. digging, construction, traffic, wildlife and vegetation etc.) over or around the pipeline trace.

2.1.3 Surface structures

(0-10 pts. 10% of index)
It refers to the fact that external parts of the pipeline are more exposed to potential damages.

2.1.4 Trace position

(0-15% pts. 15% of index)
It regards the fact that to avoid 3rd part damages, the localization of a sub-surface pipeline should be well known by workers around the pipeline.

2.1.5 Public education Programs

(0-15% pts. 15% of index)
Regards the role of the influence of public-dominion information to prevent damages.

2.1.6 Superficial trace conditions

(0-5% pts. 5% of index)
This index is based on the quality o recognition and their efficiency in base of pipeline tracing line and its accessibility.

2.1.7 Recognition frequency

(0-15% pts. 15% of index)
It concerns controls and monitoring activities of the pipeline, to avoid damages and other failures.

2.2 Corrosion index

The corrosion index regards the interaction between the pipeline and the atmosphere, the local sub-soil nature and the material carried in the pipeline. These factors are further sub-divided into sub-indexes.

2.2.1 External corrosion

(0-10 pts. 10%)
Due to chemical exchange between the atmosphere and the pipeline construction material. It's sub-divided in:

1. weathering 50%
2. atmosphere type 20%
3. presence of covering 30%

2.2.2 Internal corrosion

(0-20 pts. 20%)
It regards losses or damages to the internal structure, due to chemical reactions between product and construction material. More frequently it's caused by impurities and the pipeline construction material. It's sub-divided in:

1. product spec. 50%
2. prevention measures 50%

2.2.3 Sub-soil corrosion

(0-70 pts. 70%)
The most common damage is the galvanic corrosion, anyway this sub-index still ranks among the most difficult ones to be properly evaluated. It's commonly sub-divided in three sub-factors:

1. Sub-surface environment (0-20 pts.)

- soil corrosion (0-15)

- mechanical corrosion (0-5)

2. Cathodic protection (0-25 pts.)
   - efficiency (0-15 pts.)
   - interference (0-10 pts.)
3. Coating (0-25 pts.)
   - adequacy (0-10 pts.)
   - status (0-15 pts.)

2.3 Design index

The risk connected to the desing phase can be divided in the sub factors described in the following sub-sections.

2.3.1 Safety factor

(0-35 pts. 35%)
It consists in the evaluation of the difference between the foreseen and the real performances of the pipeline under operative conditions. It's considered the overall resistance of the pipeline under the different exercise stress factors.

2.3.2 Metal fatigue

(0-15 pts. 15%)
It regards the possibility of stress rupture, typical of metals, caused by cycles of repeated stresses, in the case of pipelines, due to variation of inner pressure.

2.3.3 Water hammer

(0-10 pts. 10%)
The index of risk considers as hazardous event the reaching of a pressure 10% higher than Maximum Allowable Operating Pressure (MAOP).

2.3.4 Integrity testing

(0-25 pts. 25%)
It refers to integrity conditions of the pipeline, it's based on two main factors: Pressure test and In-line inspections.

2.3.5 Terrain movements

(0-15 pts. 15%)
It evaluates the incoming damages due to ground movements caused by slides, earthquakes, etc.

2.4 Bad operations

This index evaluates damages that can be caused by mistakes made by trained personnel during the project, construction, managing and maintenance phases. The index is sub-divided in the risk factors described in the following sub-sections.

2.4.1 Design

(0-30 pts.)
It is divided in several sub-factors:

- danger identification
- MAOP: design MAOP takeover
- safety systems
- materials selection
- controls.

2.4.2 Construction

(0-20 pts.)
The final score is based on the following factors:

- inspections
- materials
- covering junction points
- pipe-laying
- coating.

2.4.3 Management

(0-35 pts.)
This factor regards the risks that may raise in cause of bad management. The main factors are:

- procedures
- SCADA (Supervisory Control And Data Acquisition) systems
- drug tests for workers
- safety programs
- controls, maps, records
- training
- mechanical prevention.

2.4.4 Maintenance

(0-15 pts.)
It considers the level of maintenance of the pipeline, considering these main aspects:

- documentation
- scheduled maintenance
- procedures

3 Index method

The risk evaluation, according to the indexes over described, has been simplified by the use of an MS Excel spreadsheet.
In this form, the risk index of a pipeline varies from 0 to 400 points, the "normalized index" from 0 to 100.
The higher values correspond to higher levels of technical and managing skills, as shown in the following table.

Table 1

Normalized risk index values	Technical and managing Skills	Pipeline class

0-25	Poor	4
26-50	Average	3
51-75	Good	2
76-100	Excellent	1

4 Experimental method testing on a full-scale pipeline

The method has been validated by the application on a full-scale pipeline. The selected pipeline is the Ferrera Erbognone-Cremona pipeline, managed by Praoil Oledotti Italiani S.p.A. (ENI Group).
It carries crude oil from Ferrera Erbognone general storehouse to Tamoil refinery in Cremona.

4.1 Main characters

This pipeline starts at Ferrera Erbognone site, and goes almost directly eastward crossing administrative counties of Pavia, Milan, Lodi, Bergamo and Cremona.
In the surface, the pipeline is signaled by yellow signs, it crosses rivers, the Pavia-Cremona railway and several roads and highways. It is made by two pipes:

- Ferrera-Bertonico: inner diameter 550 mm (22"), external diam. 558,0 mm. Length: 82,6 km.
- Bertonico-Cremona: inner diameter 650 mm (26"), external diam. 660,40 mm. Length: 31,2 km.

There are two cut-off valves in Praoil site (one manual, one remotely controlled) and 25 cut-off valves along the pipeline (15 manual).
The pipeline is 1,5 meter below ground level (measured from upper pipe generatrix). It's coated by bitumen reinforced coating. The cathodic protection is supplied by 7 PPC (cathodic protection points) stations. The pipeline is electrically sectioned by insulating joints.
Crossing sections (railroads, roads, rivers) are protected by steel and/or concrete reinforcements.
The pumping station, located inside the Praoil site, consists of three groups of booster pumps that aspire the product from tanks and send it to pressure group. Tree groups of pressure pumps carry the crude oil inside the pipeline with an average flow rate of 1365 m^3/h.
A regulation valve provides a constant inner pressure lower than the MAOP (45 bar).

4.2 Experimental application

The application of the method by the spreadsheet gave, for normalized risk index, the final score of 75,75 on 100. Despite of age (35 years) the pipeline is in class 1 (the best). In the following table 2 are reported the four indexes used for the evaluation.

Table 2 Pipeline normalized risk index

Index	Value	Class
3rd part damage	74	2
Corrosion risk	82	1
Project risk	69	2
Bad operation	78	1
Overall average	77,75	1

As shown in Table 2, the worst value is for project risk (69/100) mainly due to the fact that the pipeline was projected in the early '70s. Corrosion index and operation indexes are very high, as a direct confirmation of an excellent level of management.

5 Maximum damage distances

The next step, after defining the pipeline class (based on the evaluated risk), is the calculation of maximum damage distances.
This distance, following pipeline spilling, is function of:

- product flammability
- product toxic properties (IDHL and LD_{50})
- diameter of spilling hole
- delay in remediation actions
- cut-off time
- pipeline length between two valves
- physic state of released product
- direction of outflow
- pool dimension
- evaporation rate (from pool)
- local orography.

The Maximum distances can be calculated in function of these parameters and are generally expressed as the distance within fires and explosions are possible, as natural consequences of an accidental spillage of dangerous substance.
The following table presents the dangerous effects considered by Italian law that regards major accident hazards site plans.
It is considered to be applicable to pipelines too.

Table 3 Possible effects

Scenario	High lethal effects	Limited lethal effects	Irreversible injuries	Reversible injuries	Domino effect
Fire	12,5 kw/m^2	7 kw/m^2	5 kw/m^2	3 kw/m^2	12,5 kw/m^2

BLEVE/Fireball	Fireball radius	350 kj/ m^2	200 kj/ m^2	125 kj/ m^2	200-800 m
Flash-fire	LFL	½ LFL			
VCE	0,3 bar (0,6 bar outdoor)	0,14 bar	0,07 bar	0,03 bar	0,3 bar
Toxic release	LC_{50}		IDLH		

5.1 Quantitative evaluation of usual damage distances

The simulation was made by software ALHOA ver. 5.4 developed by FEMA and NOAA. Several simulations have been created, in the following sub-sections the most important are reported.

5.1.1 Methane pipeline

This simulation considers a pipeline with the following characteristics:

- operating pressure: 34 bar
- distance between two valves: 10 km
- product: methane (gaseous)
- event type: guillotine break
- scenario: fire

The simulation evaluated the different heat radiation distances in base of the pipeline diameter variations. The final result (Table 4) shows the incidence of pipeline diameter on the damage area extension. Tree levels were considered: 10, 5 and 2 kw/m^2, corresponding to lethal area, 2nd degree burnings and pain; consequent to an exposure time of one minute.

Table 4 Damage distances and pipeline diameters

Diameter (")	10kW/m^2 (m)	5kW/m^2 (m)	2kW/m^2 (m)
4	17	24	38
6	27	40	63
8	39	56	89
10	51	74	116
12	64	92	144
16	90	130	204
20	118	169	266

5.1.2 Ammonia pipeline

In this other simulation is considered a pipeline with the following characteristics:

- operating pressure: 34 bar
- distance between two valves: 10 km
- product: ammonia (gaseous)
- event type: guillotine break
- scenario: atmospheric diffusion of toxic substance

The simulation considered the worst atmospheric conditions about diffusion that is high stability (Pasquill class F) and wind speed =2 m/s. The evaluated damage distance is the one where the IDLH concentration is reached.

Damage distances are referred to different pipeline diameters.

Table 5 IDLH distances

Diameter (")	Distance (m) IDLH concentration
2	300
4	700
6	1.200
8	2.000

Also in this scenario, the influence of pipeline diameter influences strongly the final effect.

5.1.3 Gasoline pipeline

The third simulation regards two different hazardous events. The pipeline has the following characteristics:

- operating pressure: 20 bar
- distance between two valves: 10 km
- product: gasoline (pentane)
- event type 1: guillotine break
- event type 2: pipeline hole (diameter 1/10 of pipeline diameter)
- scenario: gasoline diffusion on the ground

The conditions that can improve the diffusion are a plain and obstacle-less terrain and an elevate atmospheric stability (Pasquill class F, u=2 m/s). The evaluated damage distance is the one where the LEL concentration is reached.

Table 6 Results for Event 1

Variable	Pipeline diameter (")			
	2	4	6	8
Diameter (m)	0,05	0,10	0,15	0,20
Section (m^2)	0,00196	0,00785	0,01766	0,03140
Exhale coeff	0,6	0,6	0,6	0,6
Height (m)	200	200	200	200
Speed (m/s)	62,6418	62,6418	62,6418	62,6418
Flow rate (m^3/s)	0,0737	0,2950	0,6638	1,1801

The next step is the calculation of the distance where is reached a concentration equal to the gasoline LEL.

Table 7 LEL Distances

LEL	Pipeline diameter (")			
	2	4	6	8
Distance (m)	410	840	1200	1500

Once considered the outgoing of gasoline, the hazardous event to be considered is an explosion, caused by the firing of the flammable cloud in partially-confined volume. Even in this case, the different distances are function of pipeline diameter.

Table 8 Damage distances

Damage/distance (m)	Pipeline diameter (“)			
	2	4	6	8
Serious injuries	420	870	1.200	1.500
Glass cracking	510	1.000	1.500	1.900

Table 9 Results for Event 2

LEL	Pipeline diameter (“)			
	2	4	6	8
Distance (m)	115	250	390	530

Once considered the outgoing of gasoline, the hazardous event to be considered is an explosion, caused by the firing of the flammable vapours in partially-confined volume. Even in this case, the different distances are function of pipeline diameter.

Table 10 Damage distances

Damage/distance (m)	Pipeline diameter (“)			
	2	4	6	8
Serious injuries	115	250	400	540
Glass cracking	150	320	490	650

The simulations indicate that, considering the worst surrounding conditions, the typical damage distance for accident caused by pipelines is about some hundreds of meters. Only in extreme situations the risk area can reach at about 2 km.

6 Land compatibility definition criteria

As already done with the evaluations made in order to define the level of danger in storehouse, the last step of the project is the definition of suitable criteria to define land compatibility.
The following sections report the different categories used to classify the Italian territory.

6.1 Land categories

Italian regulations define 6 main classes (A-F) on the base of several parameters, such as land use, density, limitations (constraints), etc. divided as follows.

6.1.1 Category A

- areas classified as mainly residential (edification index > 4,5 m^3/m^2)
- places with high concentration of low mobility people, as Hospitals, schools, etc. (more than 25 beds in case of hospitals or more of 100 inhabitants)
- outdoor places subject to relevant crowding as markets, or others commercial destinations (more than 500 people)
- areas dedicated to show, sport, cultural and religious activities, with more than 5.000 places and monthly utilization
- areas of particular natural and environmental value
- protected areas
- areas with landscape and environmental goods.

6.1.2 Category B

- areas classified as mainly residential (edification index within 4,5 and 1,5 m^3/m^2)
- places with high concentration of low mobility people, as Hospitals, schools, etc. (till 25 beds in case of hospitals or 100 inhabitants)
- outdoor places subject to relevant crowding as markets, or others commercial destinations (less than 500 people)
- indoor places subject to relevant crowding as markets, or others commercial destinations (less than 500 people)
- places subject to relevant crowdings, as public shows places, with short periods of danger exposure (more than 100 people if indoor, more than 1.000 if outdoor) and cinemas
- areas of particular naturalistic and environmental value.

6.1.3 Category C

- areas classified as mainly residential (edification index within 1,5 and 1 m^3/m^2)
- indoor places subject to relevant crowding as markets, universities or others commercial destinations (less than 500 people)
- places subject to relevant crowdings, as public shows places, with short periods of danger exposure (more than 100 people if indoor, more than 1.000 if outdoor) and cinemas
- railway stations and other transport network (1000 passengers/day)
- highways and runabout highways
- airports

6.1.4 Category D

- areas classified as residential (edification index within 1 and 0,5 m^3/m^2)
- places subject to relevant crowdings, with maximum monthly frequency as fairs, markets, cemeteries, etc.
- high density roads

6.1.5 Category E

- areas classified also as residential (edification index lower than 0,5 m^3/m^2)
- industrial, agricultural, zootechnical settlements

6.1.6 Category F

- areas not used, without buildings and structures and where is not foreseen the presence of people.

6.2 Land compatibility

The evaluate compatibility between pipeline class and effects category can be summarized as reported in the following tables:

Table 11 new pipelines

Pipeline class	Effect category			
	High lethality	Lethality start	Irreversible injuries	Reversible injuries
I	EF	DEF	CDEF	ABCDEF
II	F	EF	DEF	BCDEF
III	F	F	EF	CDEF

Table 12 existing pipelines

Pipeline class	Effect category			
	High lethality	Lethality start	Irreversible injuries	Reversible injuries
I	DEF	CDEF	BCDEF	ABCDEF
II	EF	DEF	CDEF	BCDEF
III	F	EF	DEF	CDEF
IV	F	F	EF	DEF

6.3 Ferrera-Cremona Pipeline

After applying this classification to the Ferrera-Cremona Pipeline, reminding the value of normalized index (75,75) and the damage distance for different hazardous scenarios, the specific land compatibility can be reported in table X.

Table 13 Ferrera Erbognone - Cremona pipeline

Pipeline class	Effect category			
	High lethality (50m)	Lethality start (70m)	Irreversible injuries (90)	Reversible injuries (120m)
I	DEF	CDEF	BCDEF	ABCDEF

At the end of the evaluation process, the forbidden distances should be the following:

- class A 90 m
- class B 70 m
- class C 50 m.

For those about the environment risk caused by accidental spill of dangerous substances, the Italian regulations (DM 9-5-01) defines the vulnerable environmental compartments as follows:

- landscape and surrounding nature
- natural protected areas
- surficial water resources
- deep water resources
- land use

The vulnerability of those elements has to be evaluated compartment by compartment, on the base of the supposed accident. The evaluation must consider:

- the specific environmental damage
- the social and environmental relevance of damaged compartment
- the possibility of remediation actions.

During the realization of new pipelines the Authorities should consider the local context and all those factors that may negatively influence accident scenarios.
In the land planning phase, all the situation that may produce a bigger damage, must be attentively evaluated.
The environmental damage may be defined, by pipeline manager, on the base of quality and quantity of spilled product and on the possibility to reduce the impacts to surrounding context. Generally there can be two main damages: the "significant damage" and the "serious damage". The difference between the former and the latter is due to the duration of remediation activities. If they probably last not more than two years from the accident date, it's possible to talk about "significant damage", otherwise there is a "serious damage".
In order to evaluate land compatibility, the serious damage is to be considered as "not compatible".

7 Technical and managing parameters to improve safety

The cooperation with Italian biggest pipeline managing Company (Praoil Oleodotti Italiani S.p.A.) allowed to determinate two classes of technical and managing parameters suitable to improve the safety conditions. These parameters are:

- Project parameters
- Managing parameters (inspection and maintenance)

7.1 Project parameters

During project phase, the parameters to be highly considered are:

1. design pressure/operating pressure: this ratio gives the mechanic resistance index of the considered pipeline
2. materials and protecting covers
3. pipeline trance and its clear and visible signaling, preferably far from human activities and thought safe hydrogeologic conditions
4. river crossing protection: by double reinforced tube
5. number and position of cut-off valves, <in order to reduce the volume of the damaged part of the pipeline
6. definition of maximum allowable surge pressure relatively with MAOP.

7.2 Managing parameters

During the following managing phases, the parameters to be highly considered are:

1. frequency of pipeline aerial monitoring
2. frequency of pipeline land monitoring
3. frequency of cleaning pig inspection
4. remind everyone the presence of the pipeline, especially to whom who work nearby
5. periodical mass-balance and level control in the in/out tanks. It allows to check out spills
6. control and proper maintenance of cathodic protection system.

8 Conclusion

The evaluation method, develop in this research work, demonstrated to be scientifically strong, defendable, and aligned with the current Italian regulations.

Those regulations, D.Lgs. 238/05, L.R. 19/01 derive from European regulations, for this reason the work group is willing to think that this method may be applicable, with few and small modifications, even in other European Countries.

Right now the work group is checking this method I on other Italian pipelines, thanks to the strong cooperation with Praoil S.p.A.

References:

01. Muhlbauer, *Pipeline Risk Management*, Elsevier, 2006

02. AA.VV., *The orange book-Management of Risk, Principles and concepts*, HM Treasury, 2004

03. Torretta V., *Sicurezza e analisi di rischio di incidenti rilevanti*, Sistemi Editoriali, 2006

04. Gagliardi R.V., Torretta V., Bello G.C., An integrated software system supporting land-use planning strategies for hazardous pipelines, to be presented at *12th International Symposium Prevention and safety promotion in the process industries*, Edinburgh, Scotland, 2007.