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Advanced Attractiveness Assessment of Process Facilities with respect to Malevolent External Attacks

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In the present contribution, a semi-quantitative methodology for the attractiveness assessment of industrial facilities as potential targets of malevolent external attacks is developed. The attractiveness is hereby proposed as a proxy to the likelihood of attack in order to support a security risk screening analysis. Technical and not technical factors are considered in order to adequately depict the motives and triggers which play a role in determining attractiveness. The plant hazard potential, determined through a simplified estimation of damages on population due to a major accident triggered by an attack, formed the objective basis of the evaluation. Then, the assessment was completed through the characterization of the “perceived” value of a potential target facility. To the purpose, a set of relevant factors that influence the targeting logic on the basis of strategic and geo-political considerations was identified; next, an analytic hierarchy process was adopted to prioritize the relevant factors and define a scoring system to evaluate overall plant attractiveness. The procedure for attractiveness assessment was exemplified through the analysis of case studies, which demonstrated the importance of not limiting plant attractiveness assessment to a consequence-based evaluation, stressing the importance of geo-political, ideological and strategic incentives.

1. Introduction

The analysis of all possible threats faced by the process industry shall include security threats (Nolan, 2008). The hazards posed by security threats to industrial installations, and in particular to chemical and petrochemical facilities, in terms of disruption of operations, destruction of property, injury or loss of life are somehow comparable to those coming from major accidents due to internal causes (Landucci et al., 2015). In fact, major accidents caused by external attacks may be triggered adopting military explosives (Salzano et al., 2013) or improvised explosive devices (Salzano et al., 2014). However, only after the World Trade Centre terrorist attacks on “9/11”, the security of sites where relevant quantities of hazardous chemicals are stored or processed became a matter of concern (Baybutt and Reddy, 2003) and thus started to be included in formal risk assessment (Bajpai and Gupta,2005). In USA, security-related legislation was enacted. The Department of Homeland Security (DHS) is required to analyze vulnerabilities and establish risk-based security performance standards for critical infrastructure and facilities; while facility owners and operators are required to prepare a Security Vulnerability Assessment (SVA) and a facility security plan, according to the prescriptions of the Chemical Facility Anti-Terrorism Standards (CFATS)(DHS, 2007).
In Europe, the concern with respect to intentional attacks against industrial facilities raised dramatically in 2015, following the attacks perpetrated in France against a production site of a chemical company and an oil refinery (ARIA Database, 2015). Although the “European Programme for Critical Infrastructure Protection (EPCIP)”, presented in the Council Directive 2008/114/EC (European Commission, 2008), has been established, no detailed guidelines are available for the security of chemical and process plants in the EU. Operators of the chemical and process industry may find guidance on the assessment and management of security issues referring to existing methodologies to Security Risk Assessment (e.g., see the methods developed by American Petroleum Institute (American Petroleum Institute, 2013), American Institute of Chemical Engineering (Center for Chemical Process Safety, 2003) and Sandia National Laboratories (Garcia, 2008)). Previous literature studies concerning security risks faced by the process industry (Reniers and

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Audenaert, 2013) were devoted to the evaluation of the severity of impacts due to external attacks on process plants (Störfallkommission, 2002) or to the analysis and characterization of the terroristic threat (Post, 2002;). However, a deeper investigation of the likelihood contributions to security risks is still lacking. In particular, literature methods do not systematically address attractiveness of process facilities accounting for the specificity of hazards. Moreover, the integration of this type of evaluation with aspects related to the social, economic and political contest is not yet available and would be beneficial for a more structured evaluation of process facilities attractiveness.
In the present contribution, the attractiveness of industrial facilities as potential targets is proposed as a proxy to the likelihood of attack in order to support a security risk screening analysis. A novel formulation of a previously presented method (Argenti et al., 2015) is herein presented to support the semi-quantitative attractiveness assessment. Besides technical considerations, non-technical factors are accounted for and weighted to more adequately depict the motives and triggers that play a role in determining attractiveness.

2. Methodology for attractiveness assessment of industrial facilities

2.1 Overview

The present contribution illustrates a semi-quantitative methodology to assess the attractiveness of process facilities to malevolent external attack. The method was developed in order to have input data easy to gather, which could be derived from documents available to plant operators, in order to facilitate method application and to obtain a quick but exhaustive screening tool. The proposed methodology requires the calculation, for the industrial facility of interest, of an overall attractiveness index (I_A), defined as the product of a hazard-based index (I_H) and of a location-specific "induction index" (φ), as given by Eq(1). The induction index is obtained in turn summing 1 to the *F* index (see Eq(2)) that represents the contribution of geo-political, social and strategic factors in increasing the attractiveness of an industrial facility.

$$I_A = I_H \times \varphi \quad (1)$$

$$\varphi = 1 + F \quad (2)$$

The I_H index describes in a sound way the value of the installation in terms of major accidents and severe damages potential. The quantitative evaluation of I_H is performed accounting for both the process facility inherent hazard, based on the analysis of the hazardous material inventories, and the vulnerability of the area surrounding the facility under analysis that might be impacted by an accident triggered by an external attack. The evaluation procedure concerning the index I_H was extensively discussed in a previous work (Argenti et al., 2015), to which the reader is referred for further details; while the detailed description of the procedure to determine the value of index F is provided in Section 2.2. In order to rank the overall attractiveness index, I_A, calculated by Eq(1), three levels of attractiveness are defined (high, medium and low) on the basis of the overall index value. Table 1 reports the correspondence between the evaluated scores for I_H, I_A and the qualitative ranking levels.

Table 1: Qualitative ranking associated to hazard based attractiveness index I_H and overall attractiveness index I_A.

Index	Score Range	Qualitative ranking
	2 – 5	Low
I_H	5 – 8	Medium
	> 8	High
	2 – 5	Low
I_A	5 – 8	Medium
	> 8	High

2.2 Estimation of non-technical triggers (F index calculation)

Beside considering the destructive potential of a successful attack, threat agents may have other incentives to attack a facility. In fact, threat history in the area and other non-technical aspects have to be taken into account. Table 2 reports the different criteria accounted for in the evaluation of the overall attractiveness increase index F. The selection of the most relevant criteria was made through a screening of relevant literature (see references in Table 2). The scores to be attributed for the assumed states are given in Table 3.

Table 2: Definition of Non-technical aspects that increase attractiveness. Cited references (REF): A = (Bajpai and Gupta, 2005); B = (Ackermann et al., 2007); C = (Kys-Katos et al., 2011); D = (Pape, 2003).

ID	Definition	REF	ID	Definition	REF
S1	Company ownership	A	S6	Political instability	C
S2	Presence of third-party highly attractive targets	B	S7	Ease in weapons gathering	C
S3	Presence of chemicals that can be used as WMD	A	S8	Local aversion due to Company image and reputation	D
S4	Past threat history	A	S9	Aversion due to local stakeholders engagement and awareness of technology	D
S5	Terrorists/activists activity in the area	A	S10	Aversion due to economic/ environmental reason and/or interactions with cultural/religious heritage	D

Table 3: Scoring of Non-technical aspects that increase attractiveness (see Table 2 for ID definition).

Aspect ID	State	Description	Score (σ_i)
S_1	presence	Public ownership/ State participation in company management. Company may be seen as a symbol of state authority	1
	absence	Private ownership	0
S_2	presence	Presence of military targets, institution buildings, embassies, monuments of high symbolic value, critical infrastructure in the site proximity.	1
	absence	Absence of military targets, Institution buildings, embassies, monuments of high symbolic value, critical infrastructure in the site proximity.	0
S_3	presence	Chemicals which can be used as WMD are stored, handled, processed/, produced in significant quantities in the site.	1
	absence	Chemicals which can be used as WMD are NOT stored, handled, processed/, produced in significant quantities in the site.	0
S_4	presence	Similar facilities or facilities owned by the same Company object of past attacks	1
	absence	Similar facilities or facilities owned by the same Company never object of attacks	0
S_5	presence	Terrorists'/ activists' groups are active in the area	1
	absence	No terrorists'/ activists' groups are active in the area	0
S_6	low	A context of political stability and democracy exists. Governing authorities are legitimated and supported by populace.	0
	medium	Few opposition groups willing to mine government authority exist and may be blamed for violent actions. Existence of political factions.	0.5
	high	Political instability and internal conflicts exist. Social order control and maintenance is periodically disrupted.	1
S_7	low	Strict legislation concerning the transport, selling and detention of weapons of any nature. Effective and diffuse implementation of controls by police forces.	0
	medium	Legislation concerning the transport, selling and detention of weapons is present but control is not a priority.	0.5
	high	The transport, selling and detention of weapons is poorly ruled and uncontrolled. Third-party interests in favouring the weapons market.	1
S_8	low	Extremely positive reputation; Local community judges company beneficial	0
	medium	Company activities accepted by local community. Few/minor aversion motives	0.5
	high	Company reputation extremely negative. Existence of organized aversion groups.	1
S_9	low	High level of engagement of local stakeholders. Transparency and continuous information sharing to enhance community awareness of company activities.	0
	medium	Medium level of engagement of local stakeholders. Company activities are accepted by local community. Few aversion motives of minor importance.	0.5
	high	No engagement of local stakeholders, climate of suspicion and mistrust.	1
S_{10}	low	No interactions with cultural/historical, archeological, religious heritage. Absence of activists groups on the area/No evidence of aversion by activist groups.	0
	medium	No significant negative interactions with cultural/historical, archeological, religious heritage. Sporadic demonstrations of aversion by local activist groups.	0.5
	high	Negative interactions with cultural/historical, archeological, religious heritage.	1

It is worth to remark that the problem complexity may not exclude a cross-influence among aspects considered in the present study, which was however neglected for the sake of method simplicity.
The overall attractiveness increase index F is calculated as a weighted sum of the arbitrarily chosen scores adopting the weights reported in Table 4, according to Eq(3):

$$F = \sum_{i=1}^{m} w_i \times \sigma_i; \quad \sum_{i=1}^{m} w_i = 1 \tag{3}$$

Table 4: Criteria weights applied in the calculation of index F.

Parameter	Definition	Value
w_1	Weight associated to aspect S1	0.0324
w_2	Weight associated to aspect S2	0.1445
w_3	Weight associated to aspect S3	0.1445
w_4	Weight associated to aspect S4	0.1692
w_5	Weight associated to aspect S5	0.1445
w_6	Weight associated to aspect S6	0.0819
w_7	Weight associated to aspect S7	0.0653
w_8	Weight associated to aspect S8	0.0726
w_9	Weight associated to aspect S9	0.0726
w_{10}	Weight associated to aspect S10	0.0726
CI	Consistency index	0.0136
RI	Random Index	1.51

The different degree of influence that incentives may have on adversaries' targeting logic was accounted for with the relative weights w_i. In order to limit the subjectivity in the computation of the criteria weights, the technique of Analytic Hierarchy Process (AHP) was applied through the pairwise comparisons method (Saaty, 1988). In the specific case, the pairwise comparison matrix was built with a Saaty scale, which allowed converting from qualitative evaluations of the relative importance between two criteria to numbers that range from 1/9 to 9. By applying the AHP, the relative weights were calculated as the normalized values of the principal eigenvector of the pairwise comparison matrix; principal eigenvector elements are reported Table 4.
As it can be noticed from Table 4, the highest relative importance in increasing the perceived value of a facility, and thus attractiveness, was assigned to the existence of past history of malevolent acts against the facility under analysis. Then the facility proximity to strategic targets, the storage and handling of WMD precursors and the confirmed presence of terrorists/activists cells in the area were considered as secondary aspects. Given the proposed scheme of scores and weights, the location-specific "induction index" (φ) spans over the range 1 to 2.
The consistency index (CI) of the pairwise comparison matrix (see Table 4) was computed according to the rules described in (Saaty, 1988) and it was verified that CI is one order of magnitude lower than the Random Index (RI, see Table 4), i.e. the consistency index when the entries of the pairwise comparison matrix are completely random. When this condition is met, the inconsistencies are tolerable, and a reliable result is expected from the AHP (Saaty, 1988).

3. Definition of case studies

The methodology for attractiveness assessment was applied to a set of four installations, already defined and analysed in a previous study. Installation A and C are located in a harbour area in Italy and consist in a petroleum products tank farm and an offshore LNG regasification terminal respectively. Installation B is a petroleum products depot, located in the suburbs of a major city in Libya. Installation D is an onshore LNG regasification terminal, situated in an industrial area in UK. Different locations and geo-political contexts were selected to provide diversified conditions to be captured in the evaluation of index φ according to the method proposed in Section 2.2. For an extended discussion on considered facilities and on I_H index calculation, the reader is referred to (Argenti et al., 2015).

4. Results and discussion

Table 5 summarizes the results of the application of the presented methodology to the selected case studies.
Figure 1 illustrates the results of attractiveness assessment, in terms of overall attractiveness index I_A, conducted according to the method described in (Argenti et al., 2015) and according to its improved version

presented herein. It is worth remarking that the differences are only to be attributed to the novel calculation method proposed for the index φ, since no modification were made to change the value of index I_H.

Table 5: Results of attractiveness assessment for the case-studies

Parameter	Installation A	Installation B	Installation C	Installation D
I_H	4	5	6	7
φ	0.07	0.82	0.29	0.07
F	1.07	1.82	1.29	1.07
I_A	4.28	9.10	7.75	7.48
Overall attractiveness level	Low	High	Medium	Medium

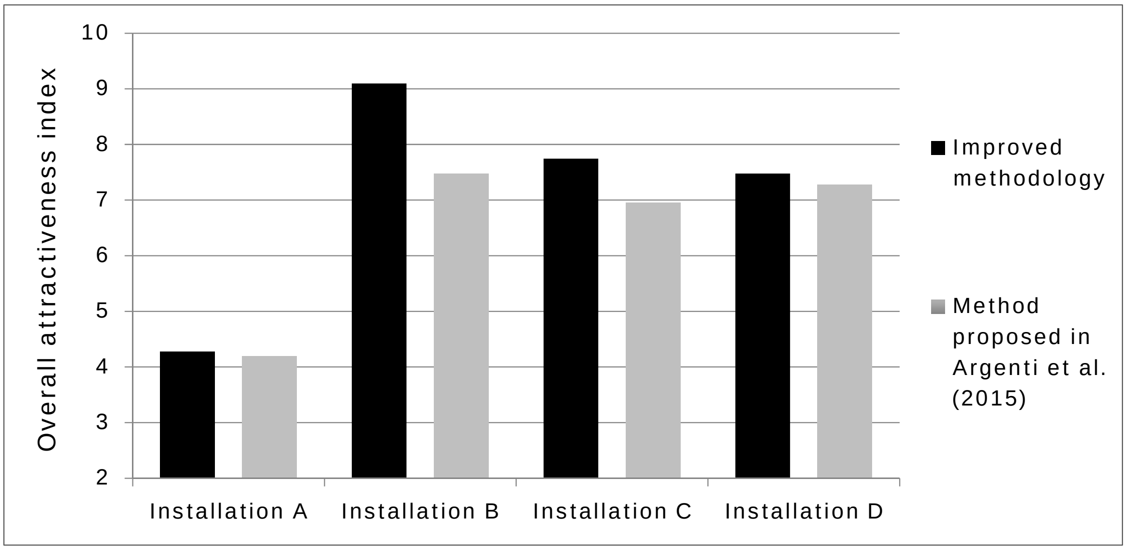

Figure 1: Results of attractiveness assessment for the considered installations according to the upgraded method described in the present contribution (black bar) and that proposed in (Argenti et al., 2015) (grey bar).

Figure 1, depicting an increase in the estimated level of attractiveness for Installation B and Installation C, shows the improved capability of capturing socio-political aspects, as well as ideological and strategic incentives to an attack, which play a significant role in determining industrial facilities attractiveness as targets. On the other hand, considering the graphs shown in Figure 1 and the qualitative ranking presented in Table 1, it can be evidenced that no differences in the overall qualitative level of attractiveness are obtained except from the case of Installation B. In fact, for installation B (petroleum product depot located in Libya), the level of attractiveness is estimated as “high”, rather than “medium”, through the application of the upgraded φ calculation method (see Section 2). The different result is due to the facts that, in the novel formulation, the aspect related to the history of attacks against similar facilities has been introduced and that the presence of active terroristic cells have a greater impact on the final value of the index φ.
Therefore, the method proposed herein tends to produce more conservative attractiveness estimates for facilities located in high-risk geo-political areas with respect to the method described in (Argenti et al., 2015) and has the advantage of explicitly taking into account the previous occurrence of attacks against facilities similar to that under analysis.

5. Conclusions

In the present study, a semi-quantitative methodology for the assessment of industrial facilities attractiveness with respect to malicious acts of interference was presented. The methodology considers two main aspects as targeting incentives. The first is related to the plant hazard potential, i.e. the potential of causing severe damage to population in case of successful attack leading to a major accident in the facility. The second aspect is the perceived value that a target may have for a specific threat, which is estimated considering social aspects, strategic considerations, geo-political context etc. An analytic hierarchy process was adopted to rank the importance of identified non-technical factors through the calculation of relative weights, whose consistency have been verified, and a scoring system was defined to support overall plant attractiveness evaluation. This allowed to reduce, although not to fully resolve, the arbitrariness issue that arises from expert judgement-based assessments. The procedure for attractiveness assessment was exemplified through the analysis of case studies and the results were compared against those obtained from the application of a previous method (Argenti et al., 2015). In particular, the improved procedure to the calculation of index φ, besides being more rigorous and consistent, showed to provide more conservative attractiveness estimates for facilities located in high-risk geo-political areas, thus making the novel formulation preferable in light of the increasing concern and the credibility of external attacks against process plants.

Finally, it is crucial to highlight that the developed methodology may contribute to analyze only a limited part of a complex Security Risk Assessment (API, 2013). Nevertheless, determining the attractiveness of a process plant is aimed at supporting a preliminary screening to prioritize resources (CCPS, 2003) and to determine further assessment needs in relation on the credibility of attacks to a given process facility in a particular context.

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