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Development of an economic model for the allocation of preventive security measures against environmental and ecological terrorism in chemical facilities

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ABSTRACT

Several recent events raised the attention toward possible major accidents triggered by external acts of interference in industrial facilities. In particular, a growing concern is present with respect to the intentional release of dangerous substances resulting in environmental and eco-terroristic attacks. Therefore, optimal selection and allocation of preventive security measures is becoming more important for decision-makers. Despite the existence of economic models supporting the decision-making process, their applications within the chemical industry security context are relatively limited. This study describes a specific model for economic analysis and selection of physical security measures, with respect to potential environmental and eco-terroristic attacks in chemical facilities. An example of application to a relevant case study is presented to show the model capabilities. Site-specific analysis of the baseline physical security system performance allows comparing the costs of different security upgrades with the benefits related to either prospective or retrospective losses, meanwhile accounting the uncertainties related to the threat probability. Selection of the most profitable security measures within budget constraints and definition of economic indicators are the main outputs of the model, in order to support decision-making processes for allocation of security barriers.

1. Introduction

In the last years, chemical and process facilities have emerged as attractive targets for malevolent intentional actions, due to the potential consequences in terms of disruption of operations, destruction of property, environmental damages, health deterioration or loss of life (Bajpai and Gupta, 2007) with potential for cascading effects (Landucci et al., 2015). Two environmental security-related phenomena, named

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Table 1 – Definitions and comparison of enviro-terrorism and eco-terrorism in industrial facilities, adapted from Alpas et al. (2011).

	Enviro-terrorism	Eco-terrorism
Definition	Unlawful action or set of actions, committed by individuals or groups, leading to short or long term disruption of environmental resources and properties to deprive others of its use	Severe damage/disruption to property, rare threat and/or harm against people, and/or nonviolent activism caused by individuals or groups protesting because of perceived harm/destruction to the environment and/or nature
Examples	Sabotage or terroristic action w.r.t. industrial facilities containing large inventories of hazardous substances (e.g., chemical and process plants, nuclear installations, infrastructures involved in energy production) with the aim to trigger a major accident, with the worst environmental damages possible	Arson actions against housing/industrial developments, targeting companies using animals for tests, theft and trespassing; demonstrative actions (e.g., machinery and vehicles sabotage) in industrial facilities perceived as pollutant
Motivation	Political, religious, personal, economic, etc.	Ideological (i.e., "very radical environmentalism")
Targets	Environment	Assets (e.g., equipment), rarely people (e.g., managers)
Scale of the accident/consequences	Relevant environmental, health and assets losses, sometimes not confined within facility boundaries. The accident may cause the partial/complete interruption of operations for several hours/days and may contribute to the facility closedown. Severe environmental damages take place, generally requiring massive emergency intervention, causing health consequences to workers and, less often to the resident population (including injuries and/or casualties). Remediation costs and assets losses are relevant	Generally, the consequences consist on minor assets losses, confined within facility boundaries that might cause a short and/or partial interruption of operations

enviro-terrorism and eco-terrorism, emerged among security threats to tackle in chemical and process facilities and in hazardous material transportation routes worldwide. Enviro-terrorism and eco-terrorism are aimed at respectively triggering severe environmental damages and demonstrating radical environmentalism by means of unlawful set of actions within chemical facilities (Alpas et al., 2011). Comparison between the two has been reported in Table 1.

The importance of environmental losses in the context of security-related accidents has been highlighted by the results of an ARIA survey, regarding 850 malicious acts perpetrated within industrial facilities (mainly chemical industrial sites), in the period 1992–2015 (ARIA, 2015). Security-based accidents may be classified according to four main possible typologies of consequences: environmental, economic, social and human. For instance, the survey results highlight that 46% of security-based accidents resulted in severe environmental consequences (Fig. 1A), leading also to economic consequences. For instance, economic consequences include internal damages necessitating repair expenses and production losses, as well as damages to third parties operations and properties. Environmental damages include soil, air, surface and ground water pollution. Moreover, release of hazardous or polluting substances occurred in almost half of security-based accidents (Fig. 1B). However, as demonstrated by Fig. 1, security-based accidents are complex phenomena, not limited only to environmental and economic damages, wherein social consequences (e.g., installation of safety perimeters and personnel redundancies) and human consequences (e.g., casualties and morbidities) should be considered too. Therefore, an accurate monetary quantification of environmental damages within security-based accident losses, including intervention and remediation costs, may lead to a more realistic description of all the other accidents consequences.

Within this context, reducing chemical plant vulnerabilities towards enviro-terrorism and eco-terrorism acts makes the investigation of intentional risks a relevant topic. Economic analyses, such as cost-benefit and cost-effectiveness analyses, may offer rational criteria for the selection and allocation of security measures within the decision-making process, as demonstrated by the application to other domains, as aviation (Stewart and Mueller, 2013, 2011, 2008) and navy facilities (Cox, 2009; Dillon et al., 2009). Table 2 summarizes recent contributions regarding theoretical, methodological and applicative aspects of economic analyses within the safety and security domain, referred to chemical and process industry installations. The analysis of research gaps highlighted that, despite the potential of economic analyses in establishing competitive business advantage within chemical process safety and security (Reniers, 2014), previous contributions are referred mostly to the selection and allocation of safety measures with respect to unintentional major and occupational accidents (i.e., safety-based accidents). No specific complete economic models and applications are yet available addressing the selection and allocation of preventive security measures, within the chemical and process industry domain.

The present study addressed the development of a model for cost-benefit and cost-effectiveness analysis of preventive security measures, with respect to potential environmental and eco-terroristic attacks, called ECO-SECURE, specifically addressing chemical and process facilities. The ECO-SECURE approach, starting from the analysis of the baseline physical security system, allows proposing security upgrades and accounting both for the performance improvements and the costs derived from their implementation. The model also includes the evaluation of benefits, considering avoided losses for different pertinent hypothetical scenarios. Thus, ECO-SECURE enables the comparison among different security upgrades and guides the choice of those economically feasible. Moreover, it determines the combinations allowing the maximum profits, according to different assumptions regarding the likelihood of the attack. The ultimate aim of the model is allowing a more rational allocation of security measures and supporting the decision-making process, within the context of chemical industrial activities. The model is specifically tailored for security measures aimed at the prevention of security-related events, as illustrated in Section 2, even if also the adoption of safety measures may offer sound support in the prevention, control and mitigation of security-based accidents (Aven, 2007; Reniers, 2010). ECO-SECURE was applied to an illustrative case study, freely adapted from a possible security-related environmental disaster that took place in Italy.

2. Model description

2.1. *General layout of the model*

The ECO-SECURE model layout is shown in Fig. 2. Definition of the site-specific adversary sequence of actions and assessment of baseline physical protection system (PPS) performance need to be carried out before the model application. This preliminary step was defined as Module 0. Six steps are then required to complete the assessment: