



ELSEVIER

Contents lists available at SciVerse ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

A multi-attribute Systemic Risk Index for comparing and prioritizing chemical industrial areas

G.L.L. Reniers^{a,b,*}, K. Sørensen^a, W. Dullaert^{a,c,d}^a Faculty of Applied Economic Sciences, Research Groups ARGoSS and ANT/OR, University of Antwerp, Prinsstraat 13, 2000 Antwerp, Belgium^b Center for Corporate Sustainability (CEDON), HUB, KULeuven, Stormstraat 2, 1000 Brussels, Belgium^c Institute for Transport and Maritime Management Antwerp (ITMMA), Keizerstraat 64, 2000 Antwerp, Belgium^d Antwerp Maritime Academy, Noordkasteel Oost 6, 2030 Antwerp, Belgium

ARTICLE INFO

Article history:

Received 26 March 2011
 Received in revised form
 16 September 2011
 Accepted 9 October 2011
 Available online 17 October 2011

Keywords:

Systemic risks
 Network analysis
 Prevention management
 Chemical cluster
 Safety and security risk index
 Supply chain risk index
 Risk index
 Borda rule

ABSTRACT

Measures taken to decrease interdependent risks within chemical industrial areas should be based on quantitative data from a holistic (cluster-based) point of view. Therefore, this paper examines the typology of networks representing industrial areas to formulate recommendations to more effectively protect a chemical cluster against existing systemic risks. Chemical industrial areas are modeled as two distinct complex networks and are prioritized by computing two sub-indices with respect to existing systemic safety and security risks (using Domino Danger Units) and supply chain risks (using units from an ordinal expert scale). Subsequently, a Systemic Risk Index for the industrial area is determined employing the Borda algorithm, whereby the systemic risk index considers both a safety and security network risk index and a supply chain network risk index. The developed method allows decreasing systemic risks within chemical industrial areas from a holistic (inter-organizational and/or inter-cluster) perspective. An illustrative example is given.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

The concept of 'systemic risk' is well known in the financial world where it is connoted with risks, which are common to an entire financial market and not to any individual entity thereof. Systemic risks also exist within the chemical industry. Although the nature of systemic risks (w.r.t. causes, prevention, etc.) is very different in the financial and the chemical sector, the potential consequences are in both cases devastating, both from a social as well as an economic point of view.

In the (petro)chemical industry, economies of scope, environmental factors, social motives and legal requirements often force companies to 'cluster'. Therefore, chemical plants are most often physically located in groups and are rarely located separately. These clusters of chemical plants consist of atmospheric, cryogenic and pressurized storage tanks, large numbers of production installation equipment, and numerous pipelines for the transportation of chemicals and petrochemicals.

Clearly, such chemical industrial areas are characterized by reciprocal danger between equipment and infrastructures being part of the areas. As such, within chemical clusters intangible interdependencies between equipment and infrastructures may exist from a safety and security point of view. Every chemical installation represents a hazard depending on the amount of substances present, the physical and toxic properties of the substances and the specific process conditions. Hence, such installations present – to a greater or lesser extent – a danger to their environment (and thus to the other installations in the neighborhood). Besides losses of lives, both short and long term disruptions from accidents in the chemical industry have led to significant economic losses and environmental damage [1]. One type of accident particularly interesting in this regard is an escalating accident or a so-called domino effect, whereby one accident at one installation triggers another accident either at the same installation (temporal domino effect) or at another installation in the vicinity (spatial domino effect), leading to a major devastating accident. The reader interested in domino effects and domino accident prevention is referred to [2–4].

It is obvious that also strong tangible supply chain interdependencies do exist between the installations (and companies) composing a chemical industrial area. Supply chain interdependence is

* Corresponding author at: University of Antwerp, Faculty of Applied Economic Sciences, Research Groups ARGoSS and ANT/OR, Prinsstraat 13, 2000 Antwerp, Belgium. Tel.: +32 3 220 41 82.

E-mail address: genserik.reniers@ua.ac.be (G.L.L. Reniers).

not limited to a single industrial area. Natural disasters such as the 1999 Taiwanese earthquake, 2005 hurricane Katrina, 2010 Icelandic volcano eruptions, but also large company accidents (2001 fire in the Phillips semiconductor plant in New Mexico, 2005 Buncefield oil storage depot disaster in the UK, 2010 explosion and sinking of the BP-operated oil rig 'Deepwater Horizon' 50 miles off the US-Louisiana coast, 2011 Japanese earthquake-tsunami disaster, etc.) have illustrated the cascading effects of major disruptions along the supply chain. Different risk events in the supply chain are linked to each other in complex patterns with one risk leading to another, or influencing the outcome of other risks [5] and are therefore intrinsic to supply chain management.

Although most companies tend to develop plans to protect against high frequency, low impact risks in their supply chains and tend to ignore high impact, low likelihood risks [6], disaster and disruption management have received increased attention during the last decade, both from a safety and security and from a supply chain point of view, respectively. Examples of this increased attention can be found in [7–9].

This paper builds upon recent research on domino accident prevention to construct a multi-attribute index for managing safety and security and supply chain related systemic risks. Section 2 provides an overview of current literature. Current safety indices used in safety management in the chemical and process industries are discussed together with state-of-the-art research on supply chain risk management. Compatible network representations are built in Section 3, whereas safety and security-, and supply chain indices for measuring systemic risks are constructed in Section 4. In the Section afterwards, both indices are forged into one user-friendly so-called Systemic Risk Index for comparing and managing systemic risks in chemical industrial areas. An illustrative example is given in Section 6. Section 7 briefly discusses the usefulness of our approach. The conclusions of this article are formulated in Section 8.

2. Literature review

2.1. Safety and security management literature

Many safety indices have been developed for a number of different purposes in chemical industrial settings. They are extensively used for ranking various chemical installations based on the hazards these installations represent, possibly leading to accident scenarios such as fire, explosions, BLEVE, toxic releases, etc. Well-known examples are the Dow fire and explosion index F&EI [10,11], Dow chemical exposure index CEI [12] and the Mond fire, explosion and toxicity index [13,14]. Other examples include the Accident Hazard Index, which was developed by Khan and Abbasi [15] for the rapid assessment of potential damage caused by accidents in the chemical industry. In 2001, a Safety Weighted Hazard Index was proposed by Khan et al. [16] in which the impact of safety measures on the values of hazard indices was taken into account, leading to a more accurate relative ranking of chemical installations. A predictive safety index based on regular observations of unsafe acts and conditions was developed by Chen and Yang [17] to indicate safety performance in the process industries. Rahman et al. [18] present an overview of inherent safety indices used in process concept evaluation and the authors discuss the pros and the cons of the Prototype Index of Inherent Safety, the Inherent Safety Index, the *i*-Safe index, the I2SI index, INSET ISHE performance indices developed in the INSIDE project, and the EHS method. In 2006, a so-called PROCESO index was proposed by Maroño et al. [19] for evaluating operational safety. Al-Sharrah et al. [20] used accident databases to calculate a safety risk index composed of four terms: frequency of accidents,

hazardous effect of the chemical, inventory of the chemical released, and size of the plant. This index can be used for comparing safety risks within a model for petrochemical planning. Leong and Shariff [21] developed an inherent safety index module to assess inherent safety levels during the preliminary design stage. In 2008, Tugnoli et al. [22,23] elaborated a domino hazard index, providing a reference for the analysis of industrial area layout performance.

Our academic journal review of reported safety indices clearly indicates that indices are evolving from calculations where only single installation information is taken into account towards index computations where multiple installations information is ever more employed. However, to the best of the authors' knowledge, none of the developed safety indices so far can be used to evaluate and to compare entire chemical industrial areas and none of them incorporate safety and security, as well as supply chain systemic risks into the index computation algorithm.

2.2. Supply chain management literature

There is a wide acknowledgment of risks in the supply chain management literature, which distinguishes between supply, demand, operational and security risks. Building upon the existing literature and the grounded theory applied to in-depth interviews with senior supply chain executives, Manuj and Mentzer [5] define supply risk as *the distribution of outcomes related to adverse events in the inbound supply that effect a firm's ability to meet customer demand (both in quality and quantity) within anticipated costs and time, or which would cause threats to customer life and safety*. Along the same lines, operations risks relates to the *events that affect the company's internal ability to produce goods and services, quality and timeliness of production and/or profitability* [24]. Demand risk is the *distribution of outcomes related to adverse events in the outbound flows that affect the likelihood of customers placing order with the focal form, and/or variance in the volume and assortment desired by the customer* [25]. The different risk events in the supply chain are linked to each other in complex patterns, with one risk leading to another or influencing the outcome of other risks [5]. Supply chain risk management addresses these issues as reflected in its definition in the well-known SCOR model "the systematic identification, assessment and mitigation of potential disruptions in logistics networks with the objective to reduce their negative impact on the logistics network's performance." [26].

Kleindorfer and Saad [27] distinguish between risks arising from coordinating supply and demand (low impact, high frequency risks) and risks arising from disruptions to normal activities (high impact, low frequency risks).

To be able to optimize systems under uncertainty resulting from the first type of risks, a wide variety of Operations Research approaches such as stochastic programming (recourse models, robust stochastic programming, and probabilistic models), fuzzy programming (flexible and possibilistic programming), stochastic dynamic programming, and robust optimization have been developed (see [28] for a recent application).

Traditional Operations Research approaches seem less suited to handle high impact, low frequency risks. For this type of risks, Kleindorfer and Saad [27] offer a conceptual framework (SAM—Specifying risks, Assessment and Mitigation) that (i) identifies the underlying hazard giving rise to a risk, (ii) quantifies the risks using a risk assessment process that identifies pathways by which the risks may be triggered, (iii) provides guidelines to make assessment and mitigation actions meet the needs of the decision environment. For their SAM approach, Kleindorfer and Saad [27] formulate a set of 10 principles to be simultaneously implemented in an integrated way in industrial practice in order to avoid or

Download English Version:

<https://daneshyari.com/en/article/803283>

Download Persian Version:

<https://daneshyari.com/article/803283>

[Daneshyari.com](https://daneshyari.com)