Collaboration on Safety in Dutch Chemical clusters (CONFIDENTIAL MATTERS REMOVED

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Executive Summary

This project aims to answer the question of how cross-plant safety can be improved in a general way, including the prevention of domino effects, as is needed by Article 9 of the European Seveso III legislation (Article 8 of the Dutch BRZO legislation). In the context of chemical industrial, a domino effect is defined as “A primary unwanted event propagates within an equipment (‘temporally’), or/and to nearby equipment (‘spatially’), sequentially or simultaneously, triggering one or more secondary unwanted events, in turn possibly triggering (higher-order) unwanted events, resulting in overall consequences more severe than those of the primary event” (G. Reniers & Cozzani, 2013). This project is part of the fourth road-map of the Safety Delta Netherlands (SDN) program and aims to make the Dutch chemical industry safer by looking at it from a cluster perspective. Examples of chemical clusters in the Netherlands are: Amsterdam, Delfzijl-Eemshaven or Rotterdam-Rijnmond.

The main research question is: **How do we improve collaboration between companies in a chemical cluster, in so that an overall safety gain is achieved?** In order to answer this question research is done in (1) the current state of collaboration in Dutch chemical industrial parks, (2) how does the conventional QRA work, (3) what are the main drivers and impediments to cross-company collaboration and (4) What are the solutions to promote drivers or remove impediments. The Research methodology includes a literature review on cross-company collaboration and twelve interviews of HSE- and TOP-managers of Dutch chemical companies.

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From the literature review and the interviews a list of the main drivers and impediments have been created. There are 10 drivers that drive cross-company collaboration on safety: (1) Economic benefits, (2) Reduction of safety and security risk, (3) Support of decision-making on the prevention of domino effects, (4) Improvement of efficiency in safety training, (5) Improvement of efficiency of safety management, (6) Improvement of safety inspection and maintenance of infrastructure, facilities and services that are related to domino effect prevention,

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Additionally ten impediments have been found that hamper collaboration on cluster safety: (1) Communication and information sharing impediment, (2) Knowledge gaps, (3) Mistrust among companies, (4) Collaboration costs, (5) Difference in interest, (6) Insufficient policy and legislation support, (7) Cluster risk identification and recognition gaps, (8) Confidential issues and restrictions from mother company,

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The conventional QRA framework is not build for cluster-wide safety and could be improved. The improved QRA includes a loop for additional analysis of installations that are affected by escalations of other installations. The analysis if an escalation is possible requires the knowledge of surrounding installations, also outside of companies' perimeters. Further analysis has to be performed on the (additional) risk of the affected installation. This means that the list of installations that require analysis grows when escalation happens towards an installation that was not on that list before. Additionally, the risk of installations already on the list can increase due to the additional escalation from other installations. Due to the loop, collaboration from the beginning would be more beneficial compared to each company performing their QRA individually.

Further research could be done in analysing the link between types of collaborations (sharing information, learning from each other, sharing facilities & equipment, etc.) and the drivers and impediments. This could be done via a questionnaire including questions that ask companies what their existing drivers and impediments are and to what degree a type of collaboration is present in their cluster. High correlation between a type of collaboration and a driver might imply a strong link, which could offer insight in which drivers to pursue to improve that type of collaboration. Similarly, a strong link between an impediment and a type of collaboration might imply that that impediment is hampering that type of collaboration to a larger extent. Another option could be the aim to create a platform where cluster safety can be discussed and where information can be shared. This platform could lead to increased cluster safety and a best practise. Lastly further research could be done in implementing the domino effect and cluster safety into the conventional QRA analysis.

Contents

Introduction

This project aims to answer the question of how cross-plant safety can be improved in a general way, including the prevention of domino effects, as is needed by Article 9 of the European Seveso III legislation (Article 8 of the Dutch BRZO legislation). In the context of chemical industrial, a domino effect is defined as "A primary unwanted event propagates within an equipment ('temporally'), or/and to nearby equipment ('spatially'), sequentially or simultaneously, triggering one or more secondary unwanted events, in turn possibly triggering (higher-order) unwanted events, resulting in overall consequences more severe than those of the primary event" (G. Reniers & Cozzani, 2013). This project is part of the fourth road-map of the Safety Delta Netherlands (SDN) program, which aims to make the Dutch (petro)chemical industry the safest in the world by 2030 by looking at safety from a cluster perspective.

A chemical cluster is defined by van Nunen et al. (2019) by its geographic demarcation, or more specific the possibility of direct effects between companies as a result of an incident (fire, explosions or toxic events). The chemical cluster is not defined by the level of cooperation between companies. Following this definition, there are six (petro)chemical clusters in the Netherlands:

- Amsterdam
- Delfzijl-Eemshaven
- Moerdijk
- Rotterdam-Rijnmond (with sub-cluster: Pernis, Botlek, Europoort, Maasvlakte)
- Sittard-Geleen (Chemelot)
- Zeeland (Terneuzen).

Within the domino effect regulations, companies can be domino receiver and/or domino causer. Being a domino effect causer, you are obligated to determine the area of effect of heat load, overpressure and fragmentation of high risk scenarios and share information with companies and citizens within those areas. Domino effect receivers have to determine if their installations might fail due to the received domino effect and adapt emergency plans, risk analysis, etc. accordingly (source).

Before 2022 only communication to BRZO (Besluit Risico's Zware Ongevallen) companies was obligatory, since 2022 not-BRZO companies also have to be informed about the domino effects. BRZO companies perform risky activities and have to prove that they control those risks. There are about 400 BRZO companies in the Netherlands. BRZO companies can either be "lage drempel (low threshold)" or "hoge drempel (high threshold)", depending on the nature and quantity of the chemicals used. The high threshold companies bare more risk, compared to the low threshold companies and have to abide by stricter regulations (source).

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1 Plan of Approach

1.1 Research Problem: Safety risk of cross-plant domino effects within chemical clusters

The Safety Delta Netherlands (SDN) program aims to make the Dutch (petro)chemical industry the safest in the world by 2030. SDN coordinates between the Dutch (petro)chemical industry and its chain partners, scientific institutions and the government. Partners from this collaborative network are working together in five roadmaps. Roadmap four focuses on maximizing safety in (petro) chemical clusters. In the context of this roadmap, the research groups from TU Delft and the University of Antwerp conducted a study in 2018-2019 to map out which parameters influence the safety of (petro) chemical clusters and to what extent these parameters are present in isolated (petro) chemical companies. A follow-up study (2020-2021) is currently being conducted to develop a user-friendly software tool for prioritizing the safety parameters that can yield the most safety gain for a chemical industrial park. To further ensure the safety of chemical clusters, the risk associated with external (cross-plant) domino effects (on escalation effects or knock-on effects) must be well managed. In the context of chemical industrial, a domino effect is defined as "A primary unwanted event propagates within an equipment ('temporally'), or/and to nearby equipment ('spatially'), sequentially or simultaneously, triggering one or more secondary unwanted events, in turn possibly triggering (higher-order) unwanted events, resulting in overall consequences more severe than those of the primary event" (G. Reniers & Cozzani, 2013). Since the 1990s, domino effects have drawn increasing attention of the authorities and the research community. Hemmatian et al. (2014) conducted a historical survey on 330 accidents related to domino effects in process/storage plants and hazardous material transportations. The risk of domino effects in the (petro)chemical industries must not be underestimated and neglected, due to their severe consequences, reflected by the number of deaths and injuries in the domino effect accidents occurred in the history, e.g., about 650 deaths and 6500 injuries in Mexico City explosion in 1984 (Pietersen, 1988), over 40 injuries in Buncefield accident in 2005 (Buncefield Major Incident Investigation Board, 2008), 78 deaths and 617 injuries in Jiangsu Tianjiayi accident in 2019 (UPI, 2019). In 2012, the "Seveso-III" Directive emphasized the importance of exchange information between chemical plants to prevent external domino effects in chemical clusters (Council Directive 2012/18/EU, 2012).

1.2 Research Objective and Tasks

This project aims to answer the question of how cross-plant safety can be improved in a general way, including the prevention of domino effects, as is needed by Article 9 of the European Seveso III legislation (Article 8 of the Dutch BRZO legislation).

This study can help to enhance chemical plants' understanding of how to better collaborate with neighbouring companies, in general, and in particular with regard to domino effects analysis and management. This study will also validate the applicability and practicability of the existing approaches and tools available for domino effect and risk analysis and identify potential improvements. This report will provide a better understanding of the current collaboration within chemical clusters, tools and approaches currently used and it will offer drivers and impediments to collaboration on safety with solutions to promote drivers or remove impediments.

In the end, the goal is to develop an instrument that can serve as a basis to establish a guideline or code of good practice for any chemical industrial area composed of minimum two plants, interested to stimulate collaboration and thereby improve cross-plant safety within the industrial parks. This report, however, will not include the creation of a software tool, but set a solid foundation to do so in following research.

The proposed instrument (COSI) can be used by a (sub) cluster of companies. They include not only the BRZO companies from a cluster, but also risk-relevant companies, non-chemical companies (e.g., the railway company, the Brightlands campus of Chemelot), and other stakeholders that are part of the cluster, such as umbrella cluster bodies, port, local authorities, and so on. The implementation of the COSI instrument by a cluster or sub-cluster and other parties involved will initiate openness, transparency, dialogue, and collaboration. In that sense, the COSI instrument itself will also contribute to (safety) gains.

The research will consist out of a (1) literature review on collaboration, (2) Interviewing the participants, (3) Analysing interview results and (4) laying a foundation for the COSI instrument.

1.3 Research Methods

The following methods will be used to answer the question of how cross-plant safety can be improved:

(1) Step 1 – Carrying out literature review and subsequently interviewing the participants to identify drivers and impediments: This step identifies the drivers and impediments of cross-plant collaboration and of the implementation of QRA for domino effects in terms of i) data collection and communication/exchange, ii) scenario development, iii) quantitative risk assessment, and iv) risk management (e.g., exchange of information on HSE manager level, risk governance structure in clusters, risk-based approach to safety barrier design and operation). The literature study aims to obtain an up-to-date understanding of the existing research on cross-company collaboration on engineering risk management with a particular focus on domino effects in chemical process industries. The literature review will begin with the identification of keywords to formulate the search statement. This consists of the following procedure:

- Identify the keywords of the research topic (collaboration between companies)
- Identify similar terms or phrases that might also be used to describe these concepts
- Combine the search terms in a way that a database (e.g., WoS) can understand
- Apply truncation, parentheses, and phrase searching
- Develop a search statement.

Interview scripts (in Dutch) will be developed based on the results of the literature study. The following constitutes the primary aspects that the questionnaire aims to identify and then reach consensus on:

- Current level of collaboration within Dutch chemical clusters;
- Drivers and impediments of cross-plant collaboration;
- Difficulties encountered or foreseen for the implementation of QRA on domino effects;
- Potential solutions to enhance cross-plant collaboration for QRA on domino effects.

(2) Step 2 - Interviewing the participants to identify potential improvement: Interviews will now be used to get a clear understanding of the current level of collaboration within chemical clusters. Additionally, drivers and impediments are discussed and possible solutions to both. The interviews are semi-structured to find an optimum balance between sticking to the topic, but letting the interviewee do the talking.

(3) Step 3 - Analyzing interview results and dictate results following literature on collaboration dimensions and types of collaborations to (i) stimulate cross-plant collaboration and exchange of information, and (ii) for domino effects analysis and management within the conventional QRA framework: The results obtained from the previous steps will be summarised and used to elaborate an approach for cross-plant collaboration. The results will lead to a better understanding of (i) how people can collaborate across companies and (ii) how collaboration can be improved

1.4 Research Question(s)

The main research question is: **How do we improve collaboration between companies in a chemical cluster, in so that an overall safety gain is achieved?**

The following are the specific research sub-questions that this project investigates:

- Sub question 1: What is the current state of collaboration in chemical industrial parks in the Netherlands
- Sub question 2: How does the conventional QRA work?
- Sub question 3: What are the main drivers and impediments to cross-company collaboration?
- sub question 4: What are the solutions to promote drivers or remove impediments

With the above questions answered, this project will aid in developing a practical approach and instrument that guides chemical plants to collaborate, analyse and manage cross-plant safety, including the prevention of domino effects. The first sub-question is important as it will provide the current level of collaboration between companies in chemical parks. The second sub-question will analyse the current Quantitative Risk Assessment, as this can provide insight in how companies calculate risk and if neighbouring companies are taken into account. The third sub-question will provide a list of drivers and impediments to cross-company collaboration on safety. This is a starting point for improving collaboration. Lastly solution to the drivers and impediments are proposed to improve the collaboration.

1.5 Previous and connected research

This research is part of an ongoing investigation on the cross-plant domino effects within chemical clusters, lead by the Ministerie van Infrastructuur en Waterstaat, exercised by a TU Delft research team. I have joined this team as research assistant and I will aid in the literature review and interviews. From this research, my thesis will be created. This thesis and the ongoing research by the Ministerie will have similarities and although this report is self-contained, it is part of a bigger project.

1.6 Relevance to MOT programme

The master programme: Management of Technology provided courses on open networks and cross-company collaboration. The articles and lectures on shared/open networks were mostly to promote innovation, but has proven to also be valuable for improving safety. Another link is improving safety between companies through improved process management and a third weaker link is the management of engineers in leadership courses, with topics related to responsibility.

2 Literature review

This chapter contains the literature review on *2.2. Cross-company collaboration*, which aims to find the reasons why companies collaborate and what drivers and impediments exist. This literature review is more broad and aids to analyse the surroundings of the research. Next, we scope in to analyse *2.3. Cross-company SAFETY collaboration.* Specific types of existing forms of collaboration are discussed, including found drivers and impediments. Solutions to drivers and impediments can also be found here. *2.4. Collaboration dimensions* are discussed which offers terminology to explain the existing collaborations and lastly, the conventional QRA is analysed in *2.5. Conventional Quantitative Risk Assessment.*

2.1 Introduction

This literature review is conducted to obtain an up-to-date understanding of the existing research on cross-company collaboration on engineering risk management with a particular focus on domino effects in (petro)chemical process industries. The literature review consists of six steps/tasks.

1. Literature review on cross-company collaboration
2. Summarise drivers and impediments to cross-company collaboration
3. Literature review on safety-related cooperation
4. Summarise drivers and impediments to safety-related collaboration
5. Literature review on collaboration dimensions
6. Research in conventional Quantitative Risk assessment

Step 1 aims to investigate the current state of cross-company collaboration in industrial parks/clusters and step 2 identifies the main drivers and impediments to cross-company collaboration. This research offers a broad and general understanding on why companies collaborate. Then, the current forms/approaches of safety-related cooperation in (petro)chemical companies are investigated in step 3. Based on the results from step 1,2 and 3, the impediments and drivers concerning safety-related cooperation in (petro)chemical companies, including cooperation on domino effects analysis and management are summarised in step 4. The potential solutions to enhance cross-plant safety cooperation through promoting the drivers and eliminating the impediments are also suggested. In step 5 research is done in how to typify/describe a collaboration and lastly, in step 6 the conventional qualitative risk assessment is described and analysed on existing collaboration.

2.1.1 Limitations

Only English literature has been used during this literature review. This excludes Dutch literature, which might have had given a few articles with additional insight to the collaboration of Dutch companies.

2.2 Cross-company collaboration

This chapter will focus on literature of cross-company collaboration or also known as horizontal collaboration. This search will provide a general understanding of the literature available on cross-company collaboration and will aid in the following literature review that will solely focus on safety collaboration. This chapter will include a *2.2.1. Search Criteria* with the main topics found during the literature search. The drivers of cross-company collaboration can be found in *2.2.2. Drivers* and the impediments can be found in: *2.2.3. Impediments.*

2.2.1 Search Criteria

A search statement is created with keywords related to collaboration between companies. The keywords can be found in Table 1. The search resulted in 589 bibliographic papers. After selection, 202 publications were selected as the database. The search was conducted 29 July 2021, from the Web of Science (WoS). The WoS includes the following subscriptions:

- Science Citation Index Expanded (SCI-EXPANCED) - 1900-present
- Social Sciences Citation Index (SSCI) - 1900-present
- Arts & Humanities Citation Index (AHCI) - 1975-present
- Conference Proceedings Citation Index - Science (CPCI-S) - 1900-present
- Conference Proceedings Citation Index - Social Sciences & Humanities (CPCI-SSH) - 1900-present
- Book Citation Index - Science (BKCI-S) - 2005-present
- Book Citation Index - Social Sciences & Humanities (BKCI-SSH) - 2005-present
- Emerging Sources Citation Index (ESCI) - 2005-present
- Current Chemical Reactions (CCR-EXPANDED) - 1985-present
- Index Chemicus (IC) - 1993-present

Table 1: Keywords search criteria

Themes	Keywords
Collaboration	Cooperation
	Collaboration
	Assistance
	Sharing
	Joint learning
	Joint training
	Joint investment
Industrial area	Industrial park
	Industrial area
	Companies
	Industrial plants
	Clusters
	Chemical plants
Exclude	Government
	University
	Police

The literature selected is sorted in topics to understand the research status and main trends in this field. The main topics, related to collaboration of companies/clusters is found in Table 2.

Table 2: Topics of found literature

Topics	Occurrences
Knowledge sharing	34
Cooperation strategy	25
Supply chain collaboration	19
Sharing economy	14
Information sharing	12
Logistics cooperation	11
Sustainable development (includes environmental collaboration)	10
Organizational learning	9
Safety cooperation	8
Energy Sharing	4

Knowledge sharing

Knowledge sharing has the most occurrences, which means knowledge sharing is employed as a significant approach to enhance collaboration between companies. Examples are: Knowledge sharing and collaborative innovation in industry clusters (Connell et al., 2014), knowledge sharing and collaboration in business clusters (D. Li, 2009), and knowledge sharing and stakeholder alignment in solar energy clusters (Jaegersberg & Ure, 2011).

Cooperation strategy
Another topic is using cooperation as a business strategy. Some examples are: evolutionary game analysis was employed to investigate enterprise's cooperation strategy in industrial clusters (Qiuying & Wenping, 2009), the cooperation business strategies of Slovak companies were studied by Holubčík & Soviar (2021), and the cooperation and competition behaviors of enterprises were researched to support evolutionary stable strategies of Chinese creative industrial clusters (J. S. Li & Yan, 2013).

Supply chain collaboration
The topic supply chain collaboration is an important topic on cluster collaboration and has its focus on cooperation between companies in the same supply chain. Examples are: The cooperation in supply chains of the furniture industry in Colombia (Lamadrid et al., 2018), the cooperation of advertising companies in social networks (Hafezalkotob et al., 2018), and supply chain collaboration of Brazilian companies to support strategic collaboration (Carvalho et al., 2020).

Sharing economy
A sharing economy is a socio-economic system built around the sharing of resources. The possibilities of the sharing economy from the point of view of chemical companies were researched by Tetrevova & Kolmasova (2021). The sharing economy strategy of creative clusters was studied by analyzing the resource sharing modes among the business starters and providing a reference on operational strategy-making to the later-comers in the future (Chang, 2016).

Information sharing
Information sharing is a big part of collaboration and has been investigated to support onsite works for chemical plants (Nakai et al., 2017). A collaboration-driven mode focused on the information sharing was proposed to support the sustainable development of smart industrial parks (Xiang & Yuan, 2019).

Logistics cooperation
Logistics cooperation between companies is also discussed. For example: The cooperation of incentives, development, and re-cooperation in Chinese small and medium-sized logistic companies (Newman & Zhao, 2008) and the cooperation between natural resource- and energy-intensive companies in reverse logistics operations by using evolutionary game analysis (Gu et al., 2019).

Sustainable development (includes environmental collaboration)
Another topic is the collaboration on sustainable development. The collaboration drivers for enhancing vertical and/or horizontal collaboration in the chemical industries were identified and a framework was proposed to increase collaborative arrangements within the chemical industry and contribute to more sustainable chemical industrial parks (G. Reniers et al., 2010).

Organisational learning and energy sharing
Organisational learning and energy sharing can enhance cooperation in clusters. The knowledge management and organisational learning within clusters were investigated by Steiner & Hartmann (2006). The factors that affect knowledge sharing and organisational learning qualities in pharmaceutical companies were studied (Kharabsheh et al., 2012) and energy sharing in industrial areas is an important approach to contribute to energy savings (Matsuda, 2008).

Safety cooperation

Last but not least, safety cooperation and cross-company safety is also discussed in previous literature. The importance of a multi-plant safety and security management system was stressed and an approach was proposed to classify chemical industrial clusters with regards to safety and security risks (Casciano et al., 2019). The game theoretic analysis of strategic cooperation on safety and security among chemical companies was proposed to improve cross-company safety and security management in a chemical industrial cluster (Pavlova & Reniers, 2011). A Finnish project on the safety in chemical industrial parks studied how safety and environmental issues can be best managed in multi-company chemical parks, and how the current legislation in Finland supports companies facing problems accentuated in or specific to industrial parks (Heikkilä et al., 2010). The drivers and partner collaboration characteristics within the Antwerp-Rotterdam chemical cluster were analyzed in a previous study and a cluster organisation framework was proposed and a scheme for continuously improving cluster and plant safety management via communication and cooperation at plant department level as well as at cluster level was suggested (G. Reniers, 2009; G. L. Reniers et al., 2009). A decision support software tool, called DomPrevPlanning, was proposed to prevent knock-on or domino accidents by making decisions on where to take safety and security measures in complex chemical surroundings (G. L. Reniers & Dullaert, 2008).

2.2.2 Drivers

All drivers per topic can be found in *A. Drivers per type of collaboration.* After summarising and removing redundancy, 7 categories/main drivers are left, and are presented in no specific order:

1. **Generate value for regions and job creation**: Generate value for targeted regions by growing economic development, diversify economies, and create jobs (Connell et al., 2014; Jaegersberg & Ure, 2011).
2. **Economic benefits**: The economic benefits or extra profit of cooperation obtained by sharing the temporarily unused assets, sharing resources, cost reduction, etc. (Chang, 2016; Hafezalkotob et al., 2018; G. Reniers, 2010; Tetrevova & Kolmasova, 2021; Xiang & Yuan, 2019; F. Xu et al., 2017).
3. **Market opportunities**: Improve companies' market position by getting into new markets, expanding market, protecting market share, fasting speed to market, etc. (Chang, 2016; F. Cruijssen, Cools, & Dullaert, 2007; F. Cruijssen, Dullaert, & Fleuren, 2007; Holubčík & Soviar, 2021; Lamadrid et al., 2018; G. Reniers et al., 2010).
4. **Products and services development**: Integrate activities of companies in a cluster or enhance specialisation to improve products or services, increases productivity, and complement goods and services (F. Cruijssen, Dullaert, & Fleuren, 2007; Holubčík & Soviar, 2021; G. Reniers, 2009).
5. **Stimulate technology and innovation**: Obtain technological competitive advantage and enhance innovation abilities through cooperation on developing technical standards and accessing superior technology (F. Cruijssen, Dullaert, & Fleuren, 2007; D. Li, 2009).
6. **Reduce safety and security risk and prevent accidents**: Prevent miscommunication and support operators make quick decisions to prevent the expansion of an accident and improve

efficiency in the reduction of safety and security risk, safety training, and safety management through cross-company collaboration (Casciano et al., 2019; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009).

7. **Reduce environmental impacts**: Mitigate environmental impacts of their operations, reduce associated costs and increase competitiveness through cross-company collaboration (Ahvenniemi et al., 2017; Trujillo-Gallego et al., 2021).

2.2.3 Impediments

All impediments per topic can be found in *B. Impediments per type of collaboration.* After summarising and removing redundancy, 11 categories/main impediments are left:

1. **Psychological and relationship impediments**: Psychological and relationship impediments include the mistrust among companies or participants, the difficulty in finding a trusted party/person to lead the cooperation, worrying about the fairness of benefits splitting, and the bad duration/quality of the experience that the participants have developed from working together (Connell et al., 2014; Quigley, 1996)
2. **Organisational impediments**: Organisational impediments include the difficulties in establishing a fair allocation of the shared workload/benefits, unequal bargaining positions (e.g. due to size difference), unclear division of authority, and disagreement over the domain of decisions caused by unreasonable management mode and arganizational structure (Connell et al., 2014; F. Cruijssen, Cools, & Dullaert, 2007; F. Cruijssen, Dullaert, & Fleuren, 2007; J. Cummings, 2003; J. L. Cummings & Teng, 2006).
3. **Negative influence from neighbouring companies**: In the networked environment, the decisions of other actors may affect others' operations in a negative way and the companies operating in a cluster are facing risks caused by the actions taken by the neighbouring companies. These risks are not always easy to identify and related decisions are not under the control of the company itself (Connell et al., 2014; J. Cummings, 2003; Heikkilä et al., 2010).
4. **Knowledge impediments**: Knowledge impediments refer to the gap between the companies or participants of the cooperation in terms of their knowledge bases (Connell et al., 2014; J. Cummings, 2003; J. L. Cummings & Teng, 2006).
5. **Communication impediments**: Communication impediments mean the difficulties in communication between companies/ participants of the cooperation caused by physical distance (such as companies are located in different time zones), the communication barriers associated with IT mediated services and communication facilities, and lack of face-to-face interaction. (Hafezalkotob et al., 2018; Jaegersberg & Ure, 2011; Lamadrid et al., 2018; Nakai et al., 2017).
6. **Cooperation costs**: Cooperation costs are impediments, which include high coordination costs due to differences in operating procedures, high indispensable information and communication technology (ICT) costs, etc. (F. Cruijssen, Dullaert, & Fleuren, 2007; Qiuying & Wenping, 2009).
7. **Difference in interests**: The difference in interests of companies/participants of the cooperation in an impediment, which can induce different epectations of cooperation,

opportunistic behavior, problems related to the management of cooperation and its setting, etc. (F. Cruijssen, Dullaert, & Fleuren, 2007; Holubčík & Soviar, 2021).

8. **Limited resources and facilities**: Limited resources and facilities influence the effectiveness and feasibility of cooperation, which may also be caused by the resources that cannot be integrated without ownership of the resources, undeveloped data platforms, and undeveloped public services (Newman & Zhao, 2008; Xiang & Yuan, 2019; Yuan et al., 2010).
9. **Policy and legislation impediments**: Insufficient policy support and lack of legislative suggestions on cross-company cooperation may induce the companies in an industrial park to have no or only a limited obligation to cooperate with each other. (He et al., 2018; Heikkilä et al., 2010; Kim et al., 2018; Y. Li et al., 2017; G. L. Reniers et al., 2009; Tiu & Cruz, 2017; Yuan et al., 2010).
10. **Confidential concern impediments**: On a strategic level, companies may be unwilling to cooperate due to confidentiality concerns (Pavlova & Reniers, 2011; G. Reniers, 2010; G. L. Reniers et al., 2009).
11. **Restrictions from the mother companies**: Sometimes, the mother companies leave little room for the companies to reach a common agreement specific for a certain industrial park. This can be the case when the mother company is situated abroad and has a different culture (Heikkilä et al., 2010; G. L. Reniers et al., 2009)

2.3 Cross-company SAFETY collaboration

In this sub-chapter only collaboration on the safety level will be discussed. We first discuss the safety parameters found by previous research (van Nunen et al., 2021), which will provide structure to this literature review. Next, the drivers for each safety parameters are researched and summarised / combined. These can be found in *2.3.2. Drivers of cross-company safety collaboration*, followed by solutions that promote those drivers in *2.3.3. Solutions to promote drivers*. Next, the Impediments will be discussed in *2.3.4. Impediments to cross-company safety collaboration*, followed by the solutions to combat those impediments in *2.3.5. Solutions to eliminate impediments*.

2.3.1 Types of collaboration (Safety Parameters)

There are 7 types of safety collaboration / safety parameters, companies can participate in, according to van Nunen et al. (2021). During the literature review, these safety parameters have provided guidance and no new safety parameters have been found.

1. **Sharing safety information**: Information can be shared on accident scenario's, non-regular work, QRA's, management systems, etc.
2. **Assessing & managing joint risk at the cluster level**: analysing joint risks between companies and how to manage those risks. Analyses can be done by e.g. discussing QRA's, Heat- & explosion-contours, radius of effect.
3. **Learning from each other**: learning from shared safety risks, each others' safety management practices, each others' safety policies, incidents or doing peer-to-peer safety

audits.
4. **Uniformity and standardisation of safety measures**: Standardising work procedures, standard level of safety knowledge and skills and uniform safety rules and standards (for contractors).
5. **The cluster as a collective**: Umbrella cluster coalition, joint budget for safety measures, joint communication to/with the local community.
6. **Sharing emergency equipment and facilities**: Joint investment in or sharing of technical equipment and facilities for emergency response, early warning system in event of calamities and uniform evacuation alarms
7. **Joint emergency response and crisis communication**: Shared fire department, joint emergency plan, cluster-wide emergency response team, joint evacuation and emergency response exercises, direct communication between cluster companies in the event of calamities, Joint communication to the local community in the event of calamities.

2.3.2 Drivers of cross-company safety collaboration

Below you will find container-terms for all the different drivers found, including the references that discussed them. They are not mentioned in a specific order

1. **Economic benefits**: The economic benefits of safety cooperation are obtained by sharing the assets and resources for safety and security purposes, thus potentially reducing costs (Chang, 2016; Heikkilä et al., 2010; Pavlova & Reniers, 2011; G. Reniers et al., 2010; Tetrevova & Kolmasova, 2021).
2. **Reduction of safety and security risks**: Improve efficiency in the reduction of safety and security risks through cross-company collaboration. The reduction and control of some risks need the participation of more than one company (Casciano et al., 2019; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009; G. L. Reniers et al., 2009; G. L. Reniers & Dullaert, 2008).
3. **Support of decision-making on the prevention of domino effects**: Cross-company safety collaboration aims to prevent miscommunication and support of decision-making on the prevention of expansion of an accident because a possible failure or accident situation may quickly affect the safety and the production of the other companies (Heikkilä et al., 2010; Nakai et al., 2017; G. Reniers et al., 2010).
4. **Improvement of efficiency in safety training**: Efficiency can be improved through shared safety training (Casciano et al., 2019; J. L. Cummings & Teng, 2006; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009).
5. **Improvement of efficiency in safety management**: Efficiency can be improved through shared safety management or sharing information on safety management (Casciano et al., 2019; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009; G. L. Reniers & Dullaert, 2008).
6. **Improvement of safety inspection and maintenance of infrastructure, facilities, and services that are related to domino effect prevention**: Companies have the common infrastructure, facilities, and services that require cooperation for maintaining and safety inspection (Heikkilä et al., 2010).

2.3.3 Solutions to promote drivers

Below you will find all the solutions to the previously discussed drivers, including all the references discussing the solutions

Economic Benefits
(Chang, 2016; Heikkilä et al., 2010; Pavlova & Reniers, 2011; G. Reniers et al., 2010; Tetrevova & Kolmasova, 2021)

- Save operating costs by sharing safety inspection facilities or teams (joint safety inspection).
- Save operating costs by joint emergency response, such as developing joint fire brigade.
- Joint procurement to reduce the purchase cost of safety facilities or technical systems.
- Save costs by sharing safety-related infrastructures and facilities, such as sharing emergency response facilities.

Reduction of safety and security risks
(Casciano et al., 2019; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009; G. L. Reniers et al., 2009; G. L. Reniers & Dullaert, 2008)

- Identification and assessment of joint risks.
- Promote the awareness of dealing with joint risks by bulletin boards and flyers.
- Joint investment and action on joint risk treatment.
- Developing cluster-level joint risk response team to coordinate above mentioned works.

Support of decision-maing on the prevention of domino effects
(Heikkilä et al., 2010; Nakai et al., 2017; G. Reniers et al., 2010)

- Promote information-sharing between field operators and safety managers, probably through communication equipment upgrade.
- Conducting safety training of field operators and safety managers targeting domino effects prevention, more specific training contents to deliver the knowledge of domino effects.

Improvement of efficiency in safety training
(Casciano et al., 2019; J. L. Cummings & Teng, 2006; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009)

- Set up a cross-company training centre with focus on domino effects.
- Facilitate group-based training activities between the cooperation parties through external expert guidance.
- Promote cluster safety consciousness and commitment amongst new employees by mandatory training sessions.
- Regular evaluation of safety training results by cross-company training center or external experts but not the individual companies.

Improvement of efficiency in safety management
(Casciano et al., 2019; Heikkilä et al., 2010; Nakai et al., 2017; Pavlova & Reniers, 2011; G. Reniers, 2009; G. L. Reniers & Dullaert, 2008)

- Tangible joint measures should be promoted such as fire protection service (fire brigade), emergency services, medical support infrastructure, shelters and safe havens, emergency operation centre, security services.
- Establish a joint emergency response plan targeting domino effects.
- Improve cluster and plant safety management via communication on safety deployment and accident scenarios at plant department level as well as at cluster level continuously.
- Enhance joint safety or cluster safety by developing a Cluster Safety Management System, which aims to minimise the likelihood of an accident, mitigate as conscientiously as possible potential consequences of accidents through emergency planning, land-use planning, and risk communication, and limit the eventually adverse consequences to health, the environment, and property in the event of an accident.

Improvement of safety inspection and maintenance of infrastructure, facilities, and services that are related to domino effect prevention
(Heikkilä et al., 2010)

- A joint safety inspection and maintaining program can be developed including inspection programs of machinery, corrosion control programs, work practices and maintenance procedures, training, design specs, long-term maintenance plan for periodic maintenance of critical equipment, and a control system for maintenance of critical safety devices.

2.3.4 Impediments to cross-company safety collaboration

Below you will find container-terms for all the different impediments found, including the references that discussed them. They are not mentioned in a specific order

1. **Communication and information sharing impediments**: Communication impediments mean that the companies do not communicate properly and are not sharing valuable information to prevent accidents, or share information too late (Connell et al., 2014; J. L. Cummings & Teng, 2006; Jaegersberg & Ure, 2011; Nakai et al., 2017).
2. **Knowledge gaps**: Not all companies are equally knowledgeable on risk prevention and domino effects. This makes understanding each other and communication difficult (J. L. Cummings & Teng, 2006; Heikkilä et al., 2010; G. Reniers, 2009).
3. **Mistrust among companies**: Mistrust among companies impedes safety cooperation. The mistrust can be related to the difficulties in establishing a fair allocation of the shared workload or due to historic events (Connell et al., 2014; Pavlova & Reniers, 2011; G. Reniers, 2010).
4. **Collaboration costs**: High coordinating and controlling costs due to safety cooperation (Pavlova & Reniers, 2011; G. Reniers, 2010).
5. **Difference in interest**: The difference in interest of the various stakeholders induces disagreements over the domain of safety-related decisions. Such as, the decisions of one company may affect others' operations in a negative way (Gómez et al., 2018; Heikkilä et al., 2010).
6. **Insufficient policy and legislation support**: Insufficient policy and legislation support on safety cooperation is when for example current policy regulations offer limited obligation

towards companies to cooperate (He et al., 2018; Heikkilä et al., 2010; Jaegersberg & Ure, 2011; Kim et al., 2018; Y. Li et al., 2017; G. L. Reniers et al., 2009; Tiu & Cruz, 2017; Yuan et al., 2010).

7. **Cluster risk identification and recognition gaps**: The companies operating in industrial parks are facing risks caused by hazards in neighbouring companies or the actions taken by the neighbouring companies but the safety & security risks are not recognized at cluster level. These risks are not always easy to identify and related decisions are not under the control of the company itself (Casciano et al., 2019; Heikkilä et al., 2010).
8. **Confidential issues and the restriction from the mother company**: The confidential issues and the restriction from mother companies sometimes leave little room for the companies to reach a common agreement (Heikkilä et al., 2010).

2.3.5 Solutions to eliminate impediments

Below you will find all the solutions to the previously discussed impediments, including all the references discussing the solutions

Communication and information-sharing impediments
(Connell et al., 2014; J. L. Cummings & Teng, 2006; Jaegersberg & Ure, 2011; Nakai et al., 2017)

- Evaluate the efficiency in sharing accident scenario information between field operators and control room operators.
- Document accidents, near-misses and incidents and communicate the lessons learned.
- Drafting a cluster database with relevant hazards information (at plant level) and ensure the database can be accessed by every plant.

Knowledge gaps
(J. L. Cummings & Teng, 2006; Heikkilä et al., 2010; G. Reniers, 2009)

- Developing the structure for knowledge transfer through 1) developing, communicating and reinforcing shared goals between the parties. 2) supporting joint development of rules of conduct between the parties. 3) putting in place administrative structures to support desired knowledge flows. 4) facilitating each party's appreciation for the other's operational and cultural situation. 5) assessing the knowledge-sharing capacities of the parties and develop plans through which to help them achieve compatible capacities

Mistrust among companies
(Connell et al., 2014; Pavlova & Reniers, 2011; G. Reniers, 2010)

- Trustworthiness is developed through repeated knowledge exchange and through involvement in networks.
- Processes need to be in place in order to assist the sharing of information, the mutual exchange of ideas and the building of trust.
- Ensure transparency between the cooperating parties in terms of communication and measurability of costs, benefits and risks.

Cooperation costs
(Pavlova & Reniers, 2011; G. Reniers, 2010)

- Industrial application of the external domino effects investment approach (based on game theory) might thus lead to lower investment costs and at the same time bring about a truly safer chemical cluster.
- Joint investments in the prevention of external domino effects can take place at a sufficiently low cost or when deliberate incentives are provided.
- The establishment of a Multi-Plant Council (MPC) helps to achieve full cooperation among players through establishing a subsidy system at minimum expense.

Difference in interest
(Gómez et al., 2018; Heikkilä et al., 2010)

- There is a strong need for common agreements between companies operating.

Insufficient policy and legislation support
(He et al., 2018; Heikkilä et al., 2010; Jaegersberg & Ure, 2011; Kim et al., 2018; Y. Li et al., 2017; G. L. Reniers et al., 2009; Tiu & Cruz, 2017; Yuan et al., 2010)

- The legislation should acknowledge industrial parks and their unique problems or give specific supports in contracting or other legal issues.
- Various contracts and commonly agreed guidelines are the key elements. It is also good to avoid assuming any issues to be self-evident and to write down limits of responsibility also in these issues.
- The safety policy should be clearly communicated to employees and relevant contractors in order to make them aware of their roles, responsibilities and accountabilities with respect to cluster safety.
- Cluster safety policy is best reviewed regularly and updated in the light of incident experience and any relevant changes in safety knowledge, technologies, laws and regulations.

Cluster risk identification and recognition gaps
(Casciano et al., 2019; Heikkilä et al., 2010)

- Industrial companies or authorities should change risk maps at industrial parks by involving risks caused by hazards in neighbouring companies or the actions taken by the neighbouring companies.
- Identify external risks related to dependability with other companies.

Confidential issues and the restriction of the mother company
(Heikkilä et al., 2010)

- Negotiation with the mother company when the agreement to be signed conflicts with the risk management principles from the mother company.

2.4 Collaboration dimensions

Collaboration typologies use several dimensions to typify horizontal inter-firm collaboration. Namely, nature, structure, integration level, scope, objectives, assets, intensity, the potential of flow consolidation and collaboration activities (Badraoui et al., 2021). In this chapter we will discuss typologies used to describe the collaborative structures of the companies/clusters that are interviewed. The collaboration dimensions will be used to discuss the current level of collaboration of the chemical clusters during the interviews.

2.4.1 Collaboration dimension: ’Decision level’

(F. C. A. M. Cruijssen et al., 2006; Verstrepen et al., 2009; Zinn & Parasuraman, 1997)

Zinn & Parasuraman (1997) introduce the dimensions scope (broad versus narrow) and intensity (high versus low) properly for the first time as a four-cell typology to describe logistics-based strategic alliances. The dimensions are presented for vertical collaboration but transition well to horizontal collaboration. Scope is defined by Zinn & Parasuraman as the range of services to be included in the alliance and Intensity is defined as the extent of direct involvement between partners.

F. C. A. M. Cruijssen et al. (2006) introduces the dimension: “decision level of a cooperation”, which aims to combine the scope and intensity dimensions. The decision level of a cooperation can either be operational, tactical or strategic. These levels determine the inter-organisational compatibility between partners. Verstrepen et al. (2009) follows a similar description. F. C. A. M. Cruijssen et al. (2006) Describes the levels as follows:

1. Operational cooperation: relates to the daily operations within the logistics companies or divisions. It is practical in nature and can be described as ‘joint execution’ or ‘sharing of operational information’.
2. Tactical cooperation: relates to achieving mid-term objectives and involves more intensive planning and investments. It can be described as ‘joint organizing’, ‘servicing markets together’ or ‘sharing logistics resources’.
3. Strategic cooperation: is aimed at achieving long-term company objectives. Strategic cooperation can be described as ‘joint learning’, ‘joint development of innovative concepts’ and ‘joint investments’.

In most cases, strategic cooperation can only be achieved with tactical cooperation being established and tactical cooperation can only be achieved with operational cooperation being established.

2.4.2 Collaboration dimension: 'Nature of the relationship/Competitiveness'

(Bengtsson & Kock, 1999; F. C. A. M. Cruijssen et al., 2006; Verstrepen et al., 2009)

With Horizontal cooperation it could be the case that parties sharing the same market, benefit in collaborating. This is called a competitive horizontal collaboration. When companies are situated in different markets/industries, it is referred to as non-competitive horizontal collaboration.

- Competitive
- Non-competitive

2.4.3 Collaboration dimension: 'Structure'

(Bakker et al., 2008; Cooper et al., 1997; Kampstra et al., 2006)

The structure refers to the structure of the collaboration. Who is in charge and managing the cooperation? Following this dimension, there are three types. The first type is a dyadic relationship where a direct relationship between members/employees is established. Employees from all partners work together. The second type is referred to as a channel integrator. The channel integrator is a single employee/member responsible for ensuring cooperation on behalf of all the partners. The third type is a third-party taking control over collaboration between the parties.

- Dyadic relationship
- Channel integrator
- Third-party organisation

2.4.4 Collaboration Dimension: 'Operations integration level'

(F. C. A. M. Cruijssen et al., 2006; Jagdev & Thoben, 2010; Kopela, 2017; Martin et al., 2018; T. Xu et al., 2005)

integration level determines the level of integrative cooperation. The dimension ranges from very little integration (avoidance alliance) to full integration (integrative alliance) and is commonly presented in 5 to 6 levels. An avoidance alliance is limited to non-core activities and the structural-intertwinement between parties is low. When the integration level between parties is high the collaboration encompasses both core and non-core activities and there is a high level of structural intertwinement.

1. Arm's length relationship [kampstra, badroui] / avoidance alliance [martin et al]

2. short-term coordination setting involving a limited number of activities with companies remaining relatively independent. [badroui] / non-committal alliance [martin et all]

3. Cooperation on more activities and over a longer period, with companies integrating part of their business planning. [badroui] / restrained multidisciplinary alliance [martin et al]

4. Commonly referred to as a strategic alliance, requires significant integration of operations and is materialized by a contractual agreement [badroui] / peripheral alliance / profound alliance [martin et al]

5. full integration [badroui] / integrative alliance [martin et al]

2.4.5 Collaboration dimension: Proactive or reactive collaboration

With reactive collaboration, firms collaborate on a practical, short-term level. The focus is on working out mitigation measures. Most of the communication is practical and the measures are as a reaction to a certain event. With Proactive collaboration, the goal is to develop preventive safety measures. Proactive collaboration requires planning and strategizing and actively aims to prevent, rather than mitigate.

2.5 Conventional Quantitative Risk Assessment

This chapter will analyse the conventional qualitative risk assessment performed by Dutch companies and will aid in understanding why companies not collaborate (enough). Later in the *5. Discussion & Recommendations* an improved joint-QRA is proposed, with the inclusion of domino effects.

2.5.1 History

The Quantitative Risk Assesment (QRA) is a tool, used by each chemical company to assess the risk associated with using, transporting and storing dangerous chemicals (Veiligheid, 2009). In the Netherlands the "coloured books" where published in 1999 which are still used globally as a valuable standard reference material in safety studies. They serve as how-to guidelines and are extensively used as a reference in the global safety community (link). The series consists out of:

- **Yellow book**: Methods for the calculation of Physical Effects Due to releases of hazardous materials (liquids and gases).
- **Green book**: Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials.
- **Purple book**: Guidelines for quantitative risk assessment (P.A.M. Uijt de Haag, 2005).
- **Red book**: Methods for determining and processing probabilities.

The purple book focuses on the QRA and the current QRA designed by RIVM (Rijksinstituut voor Volksgezondheid en milieu / National institute for public health and the environment) is based on this book. In the QRA the chances as well as effects of incidents are calculated and the results are distances, risk-contours / place-specific risks (PR) and level of societal risk / group risk (GR) (Veiligheid, 2009).

In 2005 the "Besluit externe veiligheid van inrichtingen" (BEVI) was introduced to create more uniformity on the calculations and results. In the BEVI the PR and GR are legally binding, the PR is universally set to 10^{-6} years and orientation values are presented for the GR. (Veiligheid, 2009). To aid in making the calculations more uniform, a software program (SOFETI-NL) was chosen as the main software tool to calculate the GR and PR.

Attached to the software is the manual: "Risicoberekingen BEVI", which is derived from the purple book, but more geared towards the use of SAFETI-NL. The manual is the central document for performing or assessing a QRA (Veiligheid, 2009).

2.5.2 Tasks of the QRA

In Figure 1 you can find the steps taken in the QRA and also the order in which they are done. First the installations are chosen that seem relevant for the external safety. For each installation, accident scenarios are analysed. The effects as well as the frequencies are calculated and they look at measures that reduce the chance of effect of the accident. Next, information about the population and surroundings, ignition sources and weather data are gathered. Which leads to all the valuables necessary to calculate the GR and PR.

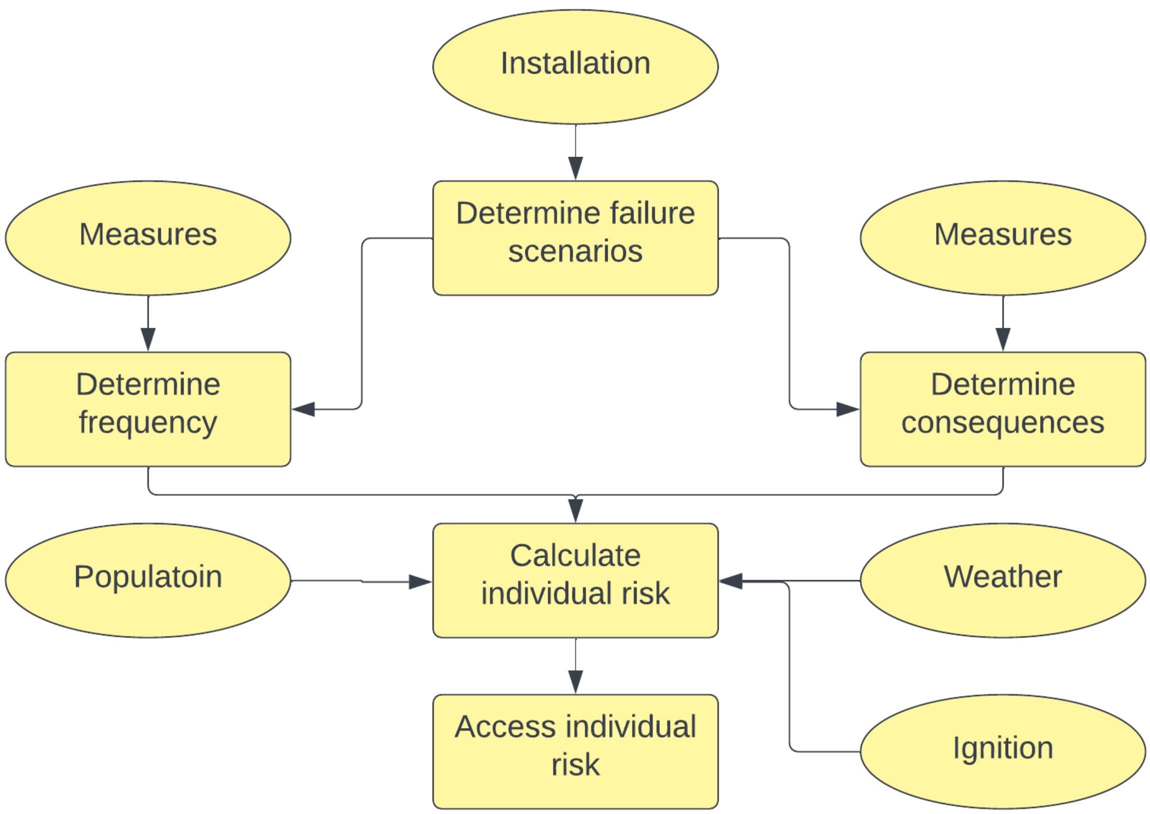

Figure 1: Individual taks that make out the QRA (Veiligheid, 2009)

2.5.3 Selection of relevant installations and scenarios

It is not necessary to do a QRA on every installation on the plant. Only when the effect of the released chemical causes deadly victims outside the boundaries of the company and if it meets the selection based on the amount of chemicals and the specific process circumstances. It is also not necessary to analyse every scenario. Only the scenario's that contribute to the PR and GR are included in the QRA. The scenarios are only taken into account if:

- The frequency of the scenario is bigger or equal to 10^{-9} year
- Lethal injury can happen outside company boundaries

When a Loss of Containnment (LOC) takes place, Safeti-NL calculates the emission and spread in the surroundings.

2.5.4 Additional information

The QRA also contains the repression measures, that aim to reduce the effects to the surroundings when an accident does occur. Examples are sprinklers, flow restrictors, embedding facilities, etc.

In order to understand the group risk, research has to be done in the surrounding population that is within the effect-radius.

Research has to be done in the ignition sources, within the company, but also outside of the company and aid in calculating the GR as well as the PR. After the release of hazardous gasses, direct or delayed ignition can take place and cause a torch, fireball or pool fire. The delayed ignition can take place when the gasses are carried by the wind to an ignition source outside of the company.

Only gas specific and location specific parameters have to be entered into Safeti-NL software, all other parameters are standardised for Dutch companies.

2.5.5 Report

In the end, the QRA report includes the selection process of the installations, list of scenarios and frequencies, names and amount of present gasses, substantiation of deviations for the manual, system responses, (source of) population data and the calculated results. The calculated results consist out of the risk contours, group risk, effect distances and the risk ranking report. The risk ranking report provides insight in which installations (largely) determine the risk.

2.6 BRZO legislation

Besides the QRA, additional regulations apply to BRZO (besluit Risico's Zware ongevallen) companies. BRZO companies perform risky activities and have to prove that they control those risks. There are about 400 BRZO companies in the Netherlands. BRZO companies can either be "lage drempel (low threshold)" or "hoge drempel (high threshold)", depending on the nature and quantity of the chemicals used. The high threshold companies bare more risk, compared to the low threshold companies and have to abide by stricter regulations (source)

The BRZO companies have to follow the European Seveso-III-Directive, which "aims at the prevention of major accidents involving dangerous substances. However, as accidents may nevertheless occur, it also aims at limiting the consequences of such accidents not only for human health but also for the environment" (source). The Directive follows a continuous improvement cycle found in Figure 2.

Figure 2: The Seveso Directive continuous improvement cycle (Veiligheid, 2009)

The main obligations of operators/companies are:

- Notification of all concerned establishments
- Deploying a major accident prevention policy
- Producing a safety report for upper-tier establishments
- Producing internal emergency plans for upper tier establishments
- Providing information in case of accidents

Only the Seveso legislation mentions the sharing of information with "concerned establishments". There is no mentioning of collaboration, learning from each other or shared practices. the BRZO law (source) mentions the necessity to share information to take into account the nature and consequences of a major accident, for the purposes of the major accident prevention policy, the safety management system and, if applicable, the internal emergency plan (article 8). Clusters can be appointed and they work together to communicate valuable information to the public and surrounding companies, with the purpose of drawing up their emergency response plans. Lastly, High treshold (hoge drempel) companies are obliged to share safety information with the

”Veiligheidsregio (safety region)” in order for the safety region to create external emergency plans for disaster management.

2.7 Concluding remarks

The conventional QRA does not mention anything related to sharing of information or collaborating with neighbouring companies. The BRZO legislation does mention the obligation to share contours, but no solid structure for collaboration is in place.

3 Interviews

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4 Results

From the literature review and interviews the safety parameters, ten drivers and ten impediments to cross-company collaboration on safety were found. Additionally, we found many solutions to promote drivers, or solve impediments.

Types of collaboration / Safety parameters

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Drivers of cross-company SAFETY collaboration

The drivers below are the main drivers found during literature review and interviews. These drivers promote cross-company collaboration on safety and are not mentioned in a specific order. Economic Benefits (D1) are obtained by sharing assets and resources for safety and security purposes, thus potentially reducing costs. Reduction of safety and security risks (D2) is a driver that improves efficiency in the reduction of safety and security risks, because some reductions need the participation of more than one company. Support of decision-making on the prevention of domino-effects (D3) reduces the chance and effect of a domino-effect through cross-company collaboration. Improve efficiency in safety training (D4) is about shared exercises to reduce off-time and learning from others' safety exercises. Improve efficiency in safety management (D5) can be improved through shared safety management, learning from each other and sharing information on safety practices. Improve safety inspection and maintenance of infrastructure, facilities and services that are related to domino effect prevention (D6) is about the benefits of shared inspection and maintenance. Adjacency (D7) is a driver that drives collaboration because the collaboration companies are situated close to each other. Communication happens more often and more informal. Connection/relatedness (D8) is driving collaboration because the companies are more related, e.g. chain connection or industry connection. Informal communication (D9) improves collaboration by removing the barrier of asking questions, getting into contact with each other. Peer Pressure (D10) is a driver that improves collaboration by expecting other companies to participate. An umbrella association and centralised responsibility brings companies/people together.

D1: Economic benefits
D2: Reduction of safety and security risk
D3: Support of decision-making on the prevention of domino effects
D4: Improvement of efficiency in safety training
D5: Improvement of efficiency of safety management
D6: Improvement of safety inspection and maintenance of infrastructure, facilities and services that are related to domino effect prevention

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Impediments to cross-company SAFETY collaboration

The impediments below are the main impediments found during literature review and interviews. These impediments hamper cross-company collaboration on safety and are not mentioned in a specific order. The communication and information sharing impediment (I1) means that the companies do not communicate properly and are not sharing valuable information to prevent accidents. Knowledge gaps (I2) is about neighbouring companies that are not equally knowledgeable on risk prevention and domino effects. Mistrust among companies (I3) impedes safety cooperation and is usually present due to historic events. Collaboration costs (I4) hampers collaboration due to high additional costs to maintain and organise collaboration. An example of Difference in interest (I5) is that certain safety measures effect one company more than the other. Insufficient policy and legislation support (I6) is when for example current policy regulations offer limited obligation towards companies to cooperate. Cluster risk identification and recognition gaps (I7) is an impediment that hampers collaboration because certain risks identified by certain companies, are not identified by the cluster as a whole. Confidential issues and restriction from the mother company (I8) encompasses all restrictions proposed by confidential agreements or by the mother company. Changing positions/roles (I9) is an impediment mentioned during interviews. Changing positions within a company make collaboration difficult, due to e.g. not being able to build a relationship, or not having the right contact information. Juridical/legal impediments (I10) apply When fines or sanctions make communication difficult. Due to liability, documents are checked by lawyers before information is send out. This hampers informal communication and collaboration.

I1: Communication and information sharing impediments
I2: Knowledge gaps
I3: Mistrust among companies
I4: Collaboration costs
I5: Difference in interest
I6: Insufficient policy and legislation support
I7: Cluster risk identification and recognition gaps
I8: Confidential issues and restrictions from mother company

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The link between drivers and impediments

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Solutions to promote drivers
Below you will find all the solutions to promote each driver.

D1: - Joint safety inspection
- Joint emergency response
- Joint Procurement
- Joint infrastructure & facilities

D2: - Identification & assessment of joint risks
- Promote awareness of dealing with joint risks by bulletin boards and flyers
- Joint investment & action on joint risk treatment
- Develop cluster level joint risk response team

D3: - Promote information sharing between field operators and safety managers (e.g. communication upgrade)
- Safety training specific on domino effects

D4: - Set-up cross-company training centre
- Facilitate group based training activities, through external expert guidance
- Mandatory training sessions
- Regular evaluation of safety training by external party

D5: - Promote tangible joint measures (e.g. fire brigade, emergency services, medical support infrastructure, shelters, emergency operation centre, security services
- Establish joint ER plan targeting domino effects
- Improve cluster & plant safety management via communication on safety deployment and accident scenarios at plant department level & cluster level, continuously
- Enhance cluster safety by developing a cluster safety management system

D6: - Joint safety inspection and maintaining program

Solutions to solve impediments

I1: - Evaluate efficiency in sharing accident scenario information between field operators and control room operators
- Document accidents, near-misses and incidents and communicate the lessons learned
- Drafting a cluster database with relevant hazards information

I2: - Developing the structure for knowledge transfer

I3: - Trustworthiness is developed through repeated knowledge exchange and through involvement in networks
- Processes need to be in place in order to assist the sharing of information, the mutual exchange of ideas and the building of trust
- Ensure transparency between the cooperating parties in terms of communication and measurably of costs, benefits and risks

I4: - Industrial application of the external domino effects investment approach
- Joint investments in the prevention of external domino effects
- The establishment of a Multi-plant council (MPC)

I5: - Common agreements between companies operating

I6: - The legislation should acknowledge industrial parks and their unique problems
- Create various contracts and commonly agreed guidelines, avoid assuming any issues to be self-evident and write down limits to responsibility
- Safety policy should be clearly communicated to employees & contractors
- Cluster safety policy is best reviewed regularly

I7: - Industrial companies or authorities should change risk maps at industrial parks by involving risks caused by hazards in neighbouring companies
- Identify external risks related to dependability with other companies

I8: Negotiation with the mother company when the agreement to be signed conflicts with the risk management principles from the mother company

5 Discussion & Recommendations

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6 Conclusion

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A Drivers per type of collaboration

Types of collaboration	Drivers	Sector/companies	Organizational OR Operational	Reference
Knowledge sharing	New areas of economic development Diversify economies and job creation Enhance competitiveness of small-medium enterprises (SMEs) Build or revitalize certain targeted regions	industry clusters	organizational	(Connell et al., 2014)
Knowledge sharing	Influence clusters' development and innovation and maybe provide each organization with a competitive advantage	business clusters	organizational	(D. Li, 2009)
Knowledge sharing	Generate value for regions, particularly through the opportunities it may present for small regional enterprises as vehicles for growth and job creation	solar energy clusters	organizational	(Jaegersberg & Ure, 2011)
Cooperation strategy	The company is able to face multiple challenges of the current global environment	business companies	organizational	(Holubčík & Soviar, 2021)
Supply chain collaboration	Reduce cost or access new markets	furniture industry	organizational	(Lamadrid et al., 2018)
Supply chain collaboration	Extra profit of cooperation	advertising companies	organizational	(Hafezalkotob et al., 2018)
supply chain collaboration	Operating improvements that maximize efficiency and improve the competitive position of the entire supply chain	shippers, logistics service providers (LSPs) and carriers	organizational and operational	(Gentry, 1996); (Carvalho et al., 2020)
Logistics collaboration	Cost reduction Learning and internalization of tacit, collective, and embedded knowledge and skills More skilled (or more efficient use of) labor force Complementary goods and services Ability to comply to strict customer requirements/improved service Specialization Penetrating new markets New product development/R&D Serving larger clients Protecting market share Faster speed to market Developing technical standards Overcoming legal/regulatory barriers Accessing superior technology Enhancing public image	horizontal cooperation in transport and logistics	organizational and operational	(F. Cruijssen, Cools, & Dullaert, 2007)
Logistics collaboration	Horizontal cooperation increases the company's productivity for core activities, e.g. decrease in empty hauling, better usage of storage facilities etc. Horizontal cooperation reduces the costs of non-core activities, e.g. organizing safety trainings, joint fuel facilities, etc. Horizontal cooperation reduces purchasing costs, e.g. vehicles, onboard computers, fuel etc. LSPs (Logistics Service Providers) can specialize while at the same time broadening their services	horizontal cooperation in transport and logistics	organizational and operational	(F. Cruijssen, Dullaert, & Fleuren, 2007)

	LSPs can offer better quality of service ' at lower costs, e.g. in terms of speed, frequency of deliveries, geographical coverage, reliability of delivery times etc.			
	Horizontal cooperation enables individual LSPs to tender with large shippers on larger contracts			
	Horizontal cooperation helps to protect the company's market share			
Sharing economy	The economic, environmental, and social benefits of developing business models based on sharing the temporarily unused assets	chemical companies	organizational	(Tetrevova & Kolmasova, 2021)
Sharing economy	Improve marketing and promote their businesses by cutting costs, sharing experience, integrating advantages or horizontal alliances	creative clusters	organizational	(Chang, 2016)
Information sharing	Prevent miscommunication and support operators make quick decisions to prevent the expansion of an accident; safety training	chemical plants	operational	(Nakai et al., 2017)
Information sharing	Facilitate efficient waste utilization, resource-sharing, and economic growth	smart industrial parks	organizational	(Xiang & Yuan, 2019); (F. Xu et al., 2017)
Information sharing	Mitigate environmental impacts and reduce associated costs	smart industrial parks	organizational	(Ahvenniemi et al., 2017)
Sustainable development	Financial opportunities: a potential for cost reduction	chemical industrial parks	organizational and operational	(G. Reniers et al., 2010)
	Service level enabled through collaboration: integrating activities in the supply chain through partnerships can often lead to service improvements for customers.			
	Market position: collaboration can enhance companies' competitive position or market power, provide entry into new markets and access to technology and innovation to stimulate product development.			
	Return on collaboration investments: By achieving profit stability or growth in the collaborative agreement, a relationship is strengthened, often leading to long-term commitments, reduced variability in sales, and joint use of assets.			
Environmental collaboration	Reduce the environmental impact of their operations and increase the competitiveness	manufacturing companies	organizational	(Trujillo-Gallego et al., 2021)
Safety cooperation	Improve efficiency in the reduction of safety and security risk	industrial clusters	organizational and operational	(Casciano et al., 2019); (Pavlova & Reniers, 2011)
Safety cooperation	Companies have common infrastructure, facilities and services that require cooperation for maintaining and development.	industrial parks	organizational	(Heikkilä et al., 2010)
	The companies are located so close to each other that possible failure or accident situations may quickly affect the safety and the production of the other companies.			
Safety cooperation	Domino accident risk/knock-on risk reduction	chemical clusters	organizational and operational	(G. Reniers, 2009); (G. L. Reniers & Dullaert, 2008)
Safety cooperation	Financial opportunities	chemical clusters	organizational	(G. L. Reniers et al., 2009)
	Service level offered			
	Internal stakeholder support and commitment			
	Necessary investments for collaboration			

Table 4: Drivers per topic

B Impediments per type of collaboration

Types of collaboration	Impediments	Sector/companies	Organizational OR Operational	Reference
Knowledge sharing	Distrust; Processes need to be in place in order to assist the sharing of information, the mutual exchange of ideas, and the building of trust	Industry clusters	Organizational and operational	(Connell et al., 2014); (Quigley, 1996)
Knowledge sharing	Organisational distance: parties in strategic alliances/networks share knowledge more effectively with members than outsiders as networks enhance denseness of social ties, creating more opportunities to share knowledge, experience and develop trust; Physical distance: when the other party is physically distant and/or located in a different time zone, there are difficulties with communication making knowledge sharing arduous; Institutional distance: refers to the degree of congruity between the institutional environments facing the two parties; Knowledge distance: refers to the size of the gap between the source and the recipient in terms of their knowledge bases; Relationship distance: refers to duration/quality of the experience that the source and the recipient have developed from working together	Industry clusters	Organizational	(J. Cummings, 2003); (J. L. Cummings & Teng, 2006); (Connell et al., 2014)
Knowledge sharing	Communication barriers associated with IT mediated services; Communication barriers between SMEs and policymakers; Difficulties at the interface between SMEs and Universities/R&D Institutions (Barriers to research collaboration)	Solar energy clusters	Organizational	(Jaegersberg & Ure, 2011)
Cooperation strategy	Trust among enterprises; Cooperation cost	Industrial clusters	Organizational	(Shen & Wang, 2009)
Cooperation strategy	Problems related to the cooperation relationship; Problems related to specific activities on cooperation; Problems related to the expectations and real results of a cooperation; Problems related to management, goals of cooperation, its setting, etc.; Specific problems from the environment of the studied companies	Business companies	Organizational and operational	(Holubcik & Soviar, 2021)
Supply chain collaboration	Mistrust among companies; Worry about the fairness of benefits splitting; Lack of face-to-face interaction	Furniture industry; advertising companies	Organizational	(Lamadrid et al., 2018); (Hafezalkotob et al., 2018)
Supply chain collaboration	Different companies have different levels of commitment to indicators of collaboration such as shared projects, involvement of top management, knowledge of partners, joint actions and joint improvement processes	Shippers, logistics service providers (LSPs) and carriers	Organizational and operational	(Carvalho et al., 2021); (Oliveira et al., 2018)

Logistics cooperation	Resources cannot be integrated without ownership of the resources caused by irregular organizational structure	Logistic companies	Organizational and operational	(Zhao & Wang, 2008)
Logistics collaboration	Difference in interests, opportunistic behaviour Difficulty in finding partners with whom to cooperate Difficulty in finding a trusted party/person to lead the cooperation Difficulty to distinguish oneself towards customers High coordination costs due to differences in operating procedures Risk of losing clientele to competitors/ partners Difficulty in determining the (monetary) benefits Difficulty in establishing a fair allocation of the shared workload Difficulty in establishing a fair allocation of the benefits Disagreement over the domain of decisions Unequal bargaining positions (e.g., due to size differences) High indispensable ICT costs High additional coordinating and controlling costs ICT Loss of control	Horizontal cooperation in transport and logistics	Organizational and operational	(Cruijssen, Dullaert, et al., 2007)
Logistics collaboration	It is hard to find commensurable LSPs (Logistics Service Providers) with whom it is possible to cooperate for (non-)core activities It is hard to find a reliable party that can coordinate the cooperation in such a way that all participants are satisfied It is hard for the partners to determine the benefits or operational savings due to horizontal cooperation beforehand Partners find it hard to ensure a fair allocation of the shared workload in advance A fair allocation of benefits to all the partners is essential for a successful cooperation When an LSP cooperates with commensurable companies, it becomes harder to distinguish itself Over time smaller companies in the partnership may lose clients or get pushed out of the market completely When benefits cannot be shared in a perceived fair way, the larger players will always benefit most Cooperation is greatly hampered by the required indispensable ICT investments	Horizontal cooperation in transport and logistics	Organizational and operational	(Cruijssen, Cools, et al., 2007)
Information sharing	Miscommunication for working	Chemical plants	Operational	(Nakai et al., 2017)
Information sharing	Inappropriate cooperation requirements and management means	Smart industrial parks	Organizational	(Xiang & Yuan, 2019); (Gómez et al., 2018)
Environmental infrastructure sharing	Limited resources, complex production processes, dynamic environmental conditions, and various stakeholders	Smart industrial parks	Organizational	(Xiang & Yuan, 2019); (Yuan et al., 2010)
Sustainable development	Unreasonable industrial structures Undeveloped industrial symbiosis networks Infrastructure shortage Serious environmental pollution Low economic benefits Unreasonable management mode Large amount of fresh water usage	Smart industrial parks	Organizational and operational	(Xiang & Yuan, 2019); (Spekkink, 2015); (Y. Li et al., 2017); (Yuan et al., 2010); (He et al., 2018); (Tiu & Cruz, 2017); (Kim et al., 2018)

	Land shortage			
	Undeveloped public services such as education and medical care			
	High energy consumption			
	Insufficient policy support			
	Defective overall planning			
	Insufficient public participation			
	Lack of talent			
	Undeveloped data platforms			
Safety cooperation	Safety & Security are not recognized at cluster level. There is no exchange of information and lack of trust between companies.	Industrial clusters	Organizational and operational	(Casciano et al., 2019)
	Emergency response programs are only available at plant level.			
	Physical connections between plants are almost completely absent. No synergy is considered.			
Safety cooperation	On a strategic level, firms are unwilling to cooperate due to trust and confidentiality concerns.	Chemical clusters	Organizational and operational	(Pavlova & Reniers, 2011); (Genserik Reniers, 2010)
Safety cooperation	In the networked environment, the decisions of other actors may affect others' operations in a negative way.	Industrial parks	Organizational and operational	(Heikkila et al., 2010)
	Companies operating in industrial parks are facing risks caused by the actions taken by the neighbouring companies in the park. These risks are not always easy to identify and related decisions are not under the control of the company itself.			
	The possible operational linkages are not taken into account in the legislation.			
	The companies in an industrial park have no or only a limited legal obligation to cooperate with each other.			
	The various mother companies dictate the risk management principles of the individual companies at the industrial park and sometimes leave little room for the companies to reach a common agreement specific for a certain industrial park.			
Safety cooperation	The complex nature of external domino effects and the involvement of different plants make it very difficult to obtain all the necessary confidential information to assess multi-plant events.	Chemical clusters	Organizational and operational	(G. L. L. Reniers et al., 2009)
	The industry should be convinced of the need to enhance external domino prevention cooperation			
	Legislative suggestions on swapping domino effects information lack			

Table 6: Impediments per topic