

Database analyses and transport corridors

Parallel lines for accident research

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Abstract

'New' infrastructures are generally constructed to resolve existing congestion problems. Increasing scarcity of land-availability in combination with more stringent environmental zoning restrain possibilities for developing new infrastructures. To this end, intentions to develop large-scale infrastructures are nowadays almost synonym with clustering these large-scale infrastructures with already existing line infrastructures, called transportation corridors. However, induced by clustering various authors already warned for unexpected interactions affecting safety levels. These warnings concerned both 'new' accident causes and 'increased' accident consequences.

In this paper we focus on accident consequences. To find out whether or not clustering increases accident consequences, a database search is conducted. TNO's hazardous materials database FACTS is searched for consequences of transport corridor accidents, called domino-effects that are compared to consequences of similar accidents (the corridor aspect excepted).

This database analyses revealed that pressure is put on safety when transport corridors are developed. In addition it showed that accident database analyses provide for elementary accident data for use in a transport safety assessment and subsequently in safety management systems. To realize improvements and to learn from past performances, these accidents should be archived and analyzed. Therefore, accident databases play an essential role in this context.

1. Introduction

New infrastructures are generally constructed to resolve existing problems of congestion. However, increasing scarcity of land-availability in combination with more

stringent environmental zoning constraints restrain possibilities for developing additional infrastructures. To this end, intentions to develop large-scale infrastructures are nowadays almost synonym with ‘clustering’ these large scale infrastructures with already existing infrastructures. As a result, zones emerge that contain several parallel-aligned line infrastructures, called transport corridors. Once expanding infrastructure seems unavoidable environmentalists stress the positive effects of clustering line infrastructures. Safety analysts however, warn for unknown risks. Till now, less is known about safety aspects transport corridors. In this paper, we will present a database analysis that gives insights in ways clustering line infrastructures into transport corridors affects safety. In section 2, main spatial aspects of transport corridors are presented followed by describing related articulated safety criticisms. The articulated safety criticisms are analyzed using real-life accident data. In section 3, the accident database analysis is briefly described, selected accident data are presented and subsequently analyzed. In section 4, the most essential conclusions from this research are presented.

2. Transport corridors

Clustering line infrastructures implies that additional line infrastructures are developed close and parallel to already existing line infrastructures. Transport corridors are zones in which clustered line infrastructures handle main traffic and transport flows and in which other infrastructures for human activities are concentrated [Bovy and Sanders, 1997; Willems, 1996; Sottiaux, Journet and Philippe, 1994; Joachim, 1987; Weir and Eng, 1963]. It seems, as transport corridors become the solution thought of by policymakers for expanding infrastructure thereby simultaneously protecting environmental qualities. Authorities voluntarily adopt clustering because clustering concentrates or even reduces negative environmental impacts such as noise, smell, fragmentation of areas, land-use, vibrations, and visual nuisance [Sottiaux, Journet and Philippe, 1994]. Other authorities of countries such as Austria and Switzerland are forced to cluster infrastructures because of various topographical constraints including mountains, rivers and valleys. In this case authorities of mountainous countries are forced to cluster infrastructures. Regardless the reasons for clustering, transport corridors can be described using five spatial aspects, namely [after Willems, 1996]:

- kind of infrastructure; the transport modality that facilitates traffic/transport flows,
- mutual distance; the distance between parallel running infrastructures,
- longitudinal distance; the length over which clustered infrastructures run parallel,
- method; infrastructures could be clustered in two ways, coordinated or mixed. Coordinated means that no single part of an infrastructure is within the boundaries of another infrastructure. Mixed stands for the opposite which means some parts of a infrastructure are within the boundaries of another infrastructure,
- arrangement; arrangement refers to the position of infrastructures with respect to each other or the environment.

Using a front-view, the spatial aspects of transport corridors, except for the longitudinal aspect, can be visualized as shown in figure 1 below. Figure 1 concerns an example of a corridor near a residential area including a highway and a railway.

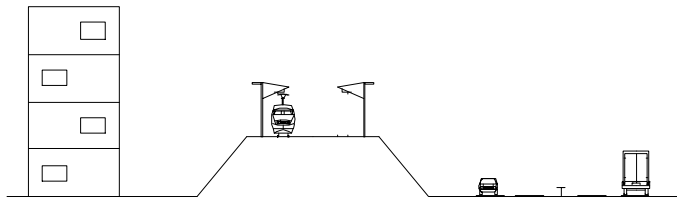


Figure 1: Example of a highway/railway corridor.

During the past years scientists, emergency response workers and public decision-makers have been intensively discussing safety aspects of transport corridors by. In The Netherlands, with respect to freight railway Betuweroute, Thissen [1993] concludes that from a scientific point of view, relevant safety aspects of transport corridors have still been under exposed, and that additional thinking and analysis on these aspects is necessary. He states that in large-scale systems there is more going on, then just the simple summation of single common aspects. He argues that mainports, transfer facilities and transport corridors have their intrinsic characteristics such as increase in scale, complexity, tight connections within logistical chains, complex decision making processes, spatial concentration and clustering infrastructures. Safety consequences of large scale infrastructure developments could result in dilemmas, such as conflicts with environmental aspects, ‘mutual interferences’ caused by vicinity of various infrastructures and criticality of capacity and accessibility of emergency response organizations after calamities occurred [Thissen, 1993]. In respect to French Train au Grande Vitesse that is for substantial length clustered with French National Highway 1, Pronost [1992] addressed the safety concern induced by its large-scale and complexity. From an emergency response point of view, Gorinchem’s fire commander De Grunt mentioned the lack of attention in risk analysis to ‘domino-effects’ (i.e. accidents propagation) as a result of clustering the Betuweroute with other major infrastructures [Orsel, 1993]. From a public decision makers point of view articulated criticisms concerned the insufficient safety information to decide upon transport corridor alternatives resulting from transportation risk analysis. Two Dutch integral impact assessments concerning transport corridors concluded that prioritizing corridor alternatives based upon accompanying risk levels is impossible [De Graaf and Rosmuller, 1996]. Recapitulating we could say that transport corridors seems to result in large scale and complex systems in which unexpected mechanisms may cause serious contributions putting safety under pressure. However, insights based upon empirical evidence in such unexpected mechanisms are absent yet.

3. Transportation accident search and analysis

As a guide to examine safety impacts of clustering, Kaplan and Garrick’s triplet conception of risk consisting accident scenarios, accident frequencies and accident consequences is used [1981]. In this paper we will focus on accident scenarios and consequences. Insights in accident frequencies and accident causes as a result of

clustering line infrastructures are presented in Rosmuller and Willems [1999]. Basically our research approach for analyzing accident consequences consists three activities.

Firstly, we search for transportation accidents in which clustered line infrastructures play a part. The according accident scenarios and consequences are briefly described. Clustering related accident consequences are sub-divided into:

- Domino-effects; accidents on line infrastructure A may lead to consequences on parallel line infrastructures B or C.
- Synergism; the simultaneous occurrences of two or more accidents may have an impacts that exceeds the sum of the impact of the individual accidents.

Secondly, we search for transport accidents that have a similar accident scenario as the clustering related transport accident, except for the clustered line infrastructure aspect. Again we will briefly describe accident consequences of the selected accidents.

Thirdly, the accident consequences of the clustered and according similar accident scenarios are compared. The accident search is restricted to national highways, railways, pipelines and waterways. This implies that airways, electricity and information lines are excluded from the research just as local streets, distribution pipelines and ditches. In addition the search is restricted to world's most extensive database on hazardous material accidents, FACTS. FACTS is developed and maintained by the department of Industrial Safety of TNO (Dutch Organization for Applied Scientific Research) [FACTS, 1999].

Step 1: clustered transportation accidents

To select transportation accidents containing domino-effects three types of transportation accidents were distinguished. Firstly, we distinguished 'single mode transportation accidents' in which only one (single) line infrastructure is involved. Secondly, we distinguished 'multi-modal transportation accidents' in which several line infrastructures are involved. Thirdly, we distinguished 'clustering related transportation accidents' which are accidents involving clustered line infrastructures. To find domino-effects firstly single mode transportation accident are selected. Out of these single mode accidents, multi-modal transportation accidents are filtered. Out of these multi-modal accidents, clustering related transportation accidents are filtered that are analyzed for identifying domino-effects. Figure 2 illustrates this procedure.

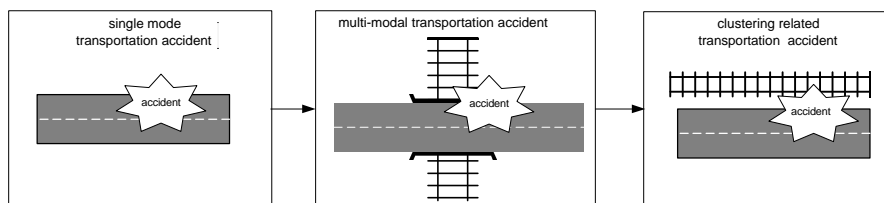


Figure 2: Finding clustering related transportation accidents.

By defining keywords per modality and applying the restriction of national scale, we found over 1200 single transportation accidents. Next, transportation accidents that contained several modalities were filtered out of the single mode transportation accidents by combining keywords of the various modes. As a result about 115 multi-modal transportation accidents remained. Then, clustering related transportation

accidents were filtered out of the set of multi-modal transportation accidents by studying the accident reports. This selection resulted in 31 clustering related transportation accidents. These 31 clustering related accident were studied in depth to identify domino-effects and synergism. Annex A briefly presents these 31 accidents describing the accident scenario and the consequences. Table 1 below lists the identified domino-effects and synergism. The number between brackets represents how often a certain domino-effect was found.

Table 1: Domino-effects and synergism [Rosmuller, 1997].

<u>Domino-effects</u>	<u>Explanation</u>
Accidents	Accident may cause additional accidents (12).
Emergency response	Parallel line infrastructures may be used to respond to accidents but may also be barriers for emergency response workers to access accident spots (4).
Traffic interruption	Hazardous material accidents may cause parallel line infrastructures to be shut down (31).
<u>Synergism</u>	<u>Explanation</u>
Hazardous materials chemical reactions	Simultaneous releases of hazardous materials may originate chemical reactions, increasing impact areas (0).
Hazardous material and physical mechanisms	Leaking gas may be confined under driving vehicles and at the same time being well mixed with oxygen by vehicle turbulence. Ignition of such clouds results in tremendous over pressures (1).

Step 2. similar transportation accidents

The scenarios of clustered accidents as listed in annex A are generalized by eliminating clustering related aspects out of these scenarios. Each of the clustered accident scenarios is generalized this way. Next, we defined search strings per generalized accident scenario to find similar accidents (comparable accident parameters) as the clustered accident in FACTS database. This first search string included keywords concerning transport mode, hazardous material involved, and physical phenomenon. In most cases a number of accidents met the keywords of this first search string. To select the best match, we defined a second search string, using more specific keywords per accidents such as release amounts, pipe diameters, damage mechanisms, and in some cases year of occurrence. This second selection enabled us to find accidents that accurately match the clustered accidents. In 2 cases we could not find an accurate match. For the 29 remaining accidents, we collected the numbers of fatalities and injuries.

To clarify our selection procedure we will use as an example FACTS accident number 370 in annex A. This accident concerns a clustered accident scenario in which a 219 mm diameter natural gas pipeline was ruptured, natural gas as released and subsequently ignited by a car (4 fatalities, no injuries). Generalizing this accident scenario means that the specific clustering aspect, namely the car as ignition source, is eliminated. Remains a 219 mm diameter natural gas pipeline rupture followed by an

ignition. Subsequently we defined the first search string containing the keywords: pipetransport, natural gas, ignition. As a result, a number of accidents (accident 370 included) were selected. Next, we defined the second search string, containing the keywords: pipe diameter about 220 mm and rupture. A few accidents remained. After in depth analyzing these remaining accidents, we selected FACTS accident number 10061 as the best match for clustered accident number 370. Analyzing accident 10061 revealed that neither fatalities nor injuries occurred.

Step 3. comparing accident consequences

Table 2 below contains the elementary data for generating insights in ways and extents clustering line infrastructures affects safety. In this table we summarized both clustering related and similar accidents, using the generalized accident scenarios as a corner stone.

Table 2: Summary of clustered and similar accidents.

Accident scenario and <u>hazardous material</u> involved	Clustered accidents			Similar accidents		
	Facts no.	Fatalities	Injuries	Facts no.	Fatalities	Injuries
Derailment of a freight train caused <u>ammonia</u> release from tank wagon.	3894	9	53	269	3	46
Ignition of <u>natural gas</u> vapor-cloud released from a 1220 mm diameter	1539	-	-	3080	-	-
Rupture of a 324 mm diameter <u>natural gas</u> pipeline.	712	3	-	2531	-	-
Detonation of tank wagon loaded with <u>monomethylamine</u> during switching operation.	2065	2	113	376	-	-
Ruptured 219 mm diameter <u>natural gas liquids</u> pipeline released vapor cloud that was ignited.	370	4	-	10061	-	-
A <u>benzine</u> loaded tank collided with viaduct during heavy rainstorm.	734	-	-	2205	-	1
Ignition of vaporized propane cloud released from a 203 mm diameter <u>propane</u> pipeline.	951	3	2	716	-	-
A collision of two freight trains caused release of <u>diesel and fuel oil</u> pollution.	2476	1	-	12169	-	2
A LPG loaded tank vehicle overturned and fell upon 50 mm diameter <u>LPG</u> pipeline.	1861	-	-	57	-	-
A main pipeline leaked <u>natural gas</u> .	614	-	-	10061	-	-
A bulldozer struck and ruptured a 219 mm diameter refined petroleum products pipeline.	3646	1	-	716	-	-
A ruptured 812 mm diameter <u>kerosene</u> pipeline caused oil release and pollution.	3064	-	-	6435	-	5
An excavator ruptured a <u>natural gas</u> pipeline and natural gas was released.	709	-	-	10061	-	-
Derailment of tank wagons loaded with <u>sulfuric acid</u> ruptured pressurized natural gas pipelines.	4416	-	-	4354	-	-
A truck loaded with <u>light naphtha</u> collided and got on fire.	7605	1	1	11113	-	-
Short-circuiting caused rupture of natural gas pipeline (8 atm.).	3955	-	-	5292	1	2
A backhoe hit inadvertently a valve of a <u>gasoline</u> pipeline causing spill and evacuation.	8757	-	-	9602	-	-

Table 2: Continued.

Wreck of a derailed train lay above <u>gasoline</u> pipeline.	10742	2	31	585	-	-
Natural gas escaped from 711 mm diameter <u>natural gas</u> pipeline. And was subsequently ignited by the sparks.	10355	>600	>700	9245	-	> 8
Groundwork activities damaged a main <u>natural gas</u> pipeline causing gas release.	10133	-	-	6451	-	3
Damaged meterbox of a main <u>natural gas</u> pipeline.	10345	-	-	No accurate match	No accurate match	No accurate match
During digging a main <u>natural gas</u> pipeline was hit and natural gas was released developing in a vapor cloud.	10964	-	-	10061	-	-
A loaded <u>LPG</u> truck sheared of its relief valves.	10894	-	-	11995	-	1
Groundwork activities ruptured a 150 mm diameter pressurized <u>natural gas</u> pipeline.	10726	-	-	13595	-	-
A tank vehicle leaked <u>acetyl chloride</u> .	12643	-	5	14032	-	1
Collision with car and road tanker caused <u>kerosene</u> leakage.	12292	1	-	11259	-	-
A ruptured 500 mm diameter <u>crude oil</u> pipeline caused oil spill	11451	-	-	10196	-	-
Groundwork activities punctured <u>natural gas</u> pipeline.	11419	> 70	> 30	8964	-	1
Train collision at level crossing causing train overturning over buried 152 mm diameter <u>aviation fuel</u> pipeline and 254 mm diameter <u>unleaded gasoline</u> pipeline.	14080	-	-	No accurate match	No accurate match	No accurate match
Ruptured 305 mm diameter <u>crude oil</u> pipeline.	12171	27	30	3091	-	-
Digging caused failure of a main <u>natural gas</u> pipeline.	14005	-	-	13349	-	-

Based upon table 2 we conclude that:

- Comparing the number of fatalities and injuries per accident scenario reveals that on clustered line infrastructures the same scenario result in most cases in more severe accident consequences than in situations in which line infrastructures are not clustered.
- Analyzing involved transport modes reveals that pipelines are amply represented. However we do not think that pipelines are relatively dangerous. Moreover we think an explanation for this ample representation could be that pipelines are easier to cluster more tightly than other transport modes because of pipelines' underground dimension. Thereby, pipeline release volumes are relative unlimited compared to possible release volumes of tank vehicles, barges, and rail wagons. This relative unlimited hazardous material release opportunity of pipelines implies that effect areas of pipeline accidents may exceed effect areas of the other modes, other thinks equal. As a result of the combination of this potential expanded effect area and possibility for tight clustering, pipeline accidents may easier involve other line infrastructures in accident scenarios.
- Opposite to pipelines, waterways are scarcely represented in clustered accidents (see also Annex A). Although inland navigation hazardous materials shipment volumes exceed road and rail shipment volumes, we assume that because of widths of waterways in combination with less possibilities for tight clustering, waterways are scarcely represented in our search results.

4. Conclusions

Our goal was to give insights using empirical data in ways accidents consequences are affected when developing transport corridors. As a result of our database analysis, we conclude that given an accident, negative human accident consequences (fatalities and injuries) are more severe in case line infrastructures are clustered compared to line infrastructures that are not clustered. In addition, the analysis of clustered accidents (see annex A) revealed that accidents on clustered line infrastructures may result in various accident consequences that are particular related to this clustering aspect. These particular accident consequences include traffic interruption and both positive and negative opportunities for emergency response activities.

As result of these findings we think safety should be given special attention in situations when one intends to cluster line infrastructures. As shown in this paper, database analyses could generate useful information to support safety analysts' even in situations that are less well known or even 'new'.

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Annex A: Clustering related transportation accidents

Facts no.	Location (country), Yr	Involved transport mode	Scenario and involved <u>hazardous material</u>	Traffic interruption
3894	Crete (USA), 1969	Railway Highway	Derailment of a freight train caused <u>ammonia</u> release from tank wagon.	Highway shutdown for about 2 days
1539	Veendam (NL), 1973	Pipeline Highway	Sparks from high tension line ignited the <u>natural gas</u> vapor-cloud released from a leaking valve, as a part of a 1220.0 mm diameter natural gas pipeline.	Highway shut down for several hours
712	Farminton (USA), 1974	Pipeline highway	Rupture of a 324 mm diameter <u>natural gas</u> pipeline. An automobile probably ignited the released vapor cloud.	Unknown
2065	Wenatchee (USA), 1974	Railway Highway River	Detonation of tank wagon loaded with <u>monomethylamine</u> during switching operation.	Highway shutdown
370	Devers (USA), 1975	Pipeline Railway Highway	Ruptured 219.1mm diameter <u>natural gas liquids</u> pipeline released vapor cloud that was ignited by a passing car.	Interrupted rail and highway traffic for several days
734	Seattle (USA), 1975	Highway Railway	A <u>benzine</u> loaded tank collided with viaduct during heavy rainstorm.	High-voltage electric transmission lines (3 days shutdown)
951	Donnelson (USA), 1978	Pipeline highway	External mechanical damage failed a 203 mm diameter <u>propane</u> pipeline. An unknown source ignited the released vaporized propane cloud.	Melted electric power and telephone lines
2476	Yverdon (CH), 1978	Railway highway	A collision of two freight trains caused release of <u>diesel and fuel oil</u> pollution nearby lake and highway	Highway shut down for several days
1861	Noordwolde (NL), 1979	Highway pipeline	A tank vehicle overturned and fell upon 50 mm diameter <u>LPG</u> pipeline.	Pipeline shutdown
614	- (NL), 1979	Pipeline highway	A main pipeline leaked <u>natural gas</u> along highway.	Highway traffic interruption for 48 hours
3646	Bayamon (PR), 1980	Pipeline highway waterway	A bulldozer struck and ruptured a 203 mm diameter refined petroleum products pipeline.	Highway and river shut down (about 4 hr)
3064	Manssas (USA), 1980	Pipeline River	A ruptured 812 mm <u>kerosene</u> pipeline caused oil release and pollution.	Polluted reservoir and river 5 days shut down
709	Almen (NI), 1980	Pipeline Waterway Highway	An excavator ruptured a <u>natural gas</u> pipeline. Natural gas was released.	Waterway and highway traffic interruption
4416	- (USA), 1982	Railway Pipeline	Derailment of six tank wagons loaded with <u>sulfuric acid</u> ruptured three pressurized natural gas pipelines.	Pipeline shut down and railway traffic interruption
7605	Weatherford (USA), 1982	Highway Railway	A truck loaded with <u>light naphtha</u> collided and got on fire.	Unknown

Annex A: Clustering related transportation accidents continued

3955	Rotterdam	Railway pipeline	Short circuiting caused rupture of natural gas pipeline.	Underground traffic interruption
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8757	(NL), 1982 Staten Island (USA), 1985	Pipeline Railway	During groundwork a backhoe hit inadvertently a valve of a <u>gasoline</u> pipeline causing spill and evacuation.	Gas and electricity shut down
10742	San Bernadino (USA), 1989	Railway Pipeline	Wreck of a derailed train lay above <u>gasoline</u> pipeline.	13 days pipeline shutdown, railway traffic shutdown
10355	Novorsibirsk (SU), 1989	Pipeline Railway	Natural gas escaped from 711 mm diameter <u>natural gas</u> pipeline. Sparks of electric wires from passing train ignited the gas.	Unknown
10133	Rheden (NL), 1989	Pipeline highway Railway	Groundwork activities damaged a main <u>natural gas</u> pipeline causing gas released in sewer system.	Railway shut down for half an hour
10345	Valkenburg (NL), 1990	Pipeline highway Railway	A parked trailer rolled down the slope of a highway and collided against meterbox of a main <u>natural gas</u> pipeline.	Railway traffic interruption for several hours
10964	Venlo (NI), 1990	Pipeline Highway Railway	During digging a main <u>natural gas</u> pipeline was hit. Natural gas was released, developing in a vapor cloud.	Railway and highway traffic interruption
10894	Toronto (CDN), 1991	Highway Railway	A loaded <u>LPG</u> truck sheared of its relief valves.	3 hours traffic interruption on gas and electricity supplies, highway and railway
10726	Vianen (NL), 1991	Pipeline highway	Grounwork activities ruptured a 150 mm pressurized <u>natural gas</u> pipeline.	Highway traffic interruption for 2 hours
12643	's -Gravendeel (NL), 1992	Highway Railway	A tank vehicle leaked <u>acetyl chloride</u> causing enormous queues during start of holidays.	Railway interruption for several hours
12292	Runcorn (GB), 1993	Highway Railway	Collision with car and road tanker caused <u>kerosene</u> leaking on railway. Overhead rail power lines ignited the fuel.	railway traffic shutdown
11451	Bad Dürrenberg (D), 1993	Pipeline highway	A ruptured 500 mm diameter <u>crude oil</u> pipeline caused oil spill and highway traffic interruption	Highway traffic interruption for several days
11419	Caracas (VZ), 1993	Pipeline highway	During digging near a highway in rush hour traffic a main <u>natural gas</u> pipeline was punctured, the pipeline ruptured, and engulfed a parallel highway.	Unknown
14080	Intercession City (USA), 1993	Railway pipelines	Vehicle at level crossing was jammed and train collided and overturned over buried <u>aviation fuel</u> pipelines that were not damaged	Pipeline shutdown (about 13 days) Railway shutdown
12171	Maturin (YV), 1994	Highway pipeline	Buses jammed to roadside and crushed a <u>crude oil</u> pipeline.	Unknown
14005	Apeldoorn (NI), 1998	Pipeline	Boring and digging at wrong place caused failure of a main <u>natural gas</u> pipeline.	Railway traffic interruption for 7 hours
