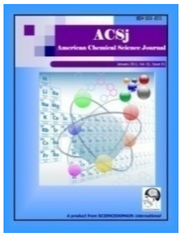

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Potential Devastating Domino Effect: A Case Study of Msasa Industrial Area, Zimbabwe

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NM and PD designed the study, methodology, provided literature and analysis, while author LDM supervised field work. All authors read and approved the final manuscript.

Case Study

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ABSTRACT

Aims: To assess the likelihood of occurrence of domino effect in a group of neighbouring companies in Msasa Industrial area.
Study Design: A case study approach was used.
Place and Duration of Study: Msasa industrial area, Harare Zimbabwe between June 2011 and June 2012.
Methodology: Information was sought through interviews, questionnaires and observations from 15 companies in Msasa. The What If Analysis (WIA) was also used to postulate the potential upsets that may result in accidents. A semi qualitative approximate domino effect analysis procedure was used to simulate the likely sequence of an event after its initiation.
Discussion: In the cluster, domino effect was most likely to be initiated and propagated by fires (pool, flash, fireballs or jet), explosions (confined vapour cloud explosions (CVCE), boiling liquid expanding vapour explosions (BLEVE), vented explosions, vapour cloud explosions, and dust explosions) and toxic release with effects ranging from being catastrophic, critical, marginal or negligible. It was found that there has been no domino risk analysis and hence was a strong possibility of destruction of the entire industrial area and neighbouring residential areas in the case of the forecast domino accidents. Toxic and dust releases were most likely to contaminate neighbouring residence leading to exposed toxic substance for long periods after the release.

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Conclusion: Msasa industrial area may pose a serious domino effect risk, hence the need to make it mandatory for domino effect analysis studies in industrial areas and sharing safety information with neighbouring companies and communities.

Keywords: Domino effect; environmental health risk; cluster safety; toxic release.

1. INTRODUCTION

The term domino effect denotes chain of accidents generated by an accident in one unit in an industry causing higher order accidents in other units either of the same factory or in other neighbouring factories [1]. More specifically they are accidents when a fire/explosion/missile/toxic load generated by an accident in one unit in an industry causes secondary and higher order accidents in other units [2]. Domino effects are also referred to as chains of accidents, knock-on effects, cascade effects or escalation effects [3]. Usually chemical plants are physically located in groups and are rarely located separately [4]. In Zimbabwe, only mines and some forestry companies are located in isolation or far from other companies otherwise most companies are in clusters or are part of an industrial park. These clusters of chemical plants may consist of atmospheric, cryogenic, and pressurized storage tanks, and large numbers of production installation equipment among other components. In such cases there are dangers due to incompatible work being carried out at close proximity hence the need to consider cluster safety. In and around these clusters goods are transported and stored in large volumes using road transport, railway carriage, tanks and in some cases pipeline. These large installations are often found in close proximity to populous residential neighbourhoods [5] or the companies have cottages where people live. According to Khan [2] a domino effect may be initiated from such scenarios by one or more of these causative events: (a) Fire: pool fire, flash fire, fireball, and jet fire. (b) Explosion: confined vapour cloud explosions (CVCE), boiling liquid expanding vapour explosion (BLEVE), vented explosion, vapour cloud explosion, and dust explosion. (c) Toxic release: instantaneous or continuous release of toxic light-as-air-gases; lighter-than-air gases, and heavier-than-air gases; release of toxic liquids and dust. Due to the rapid development of small and medium enterprises (SMEs) in developing countries such as Zimbabwe there is continuous growth of an even more complex situation with unknown processes and conditions in industrial areas. The incidence, severity and consequences of accidents arising from such a situation also tend to increase [5, 3]. Accidents can be distinguished as those that happen to individuals, those that happen to organizations, and those that happen to clusters of industries or large communities [6]. In most cases such accidents are extremely rare and this reduces the fear of their occurrence and investments in domino safety [7, 3]. Cluster accidents can be related to linked production, linked delivery services, as well as cross company domino effects. Concerns of 'domino' or 'cascading' effects are increasing due to increasing congestion in industrial complexes and increasing density of human population around such complexes [2]. Despite these facts, domino effects are usually not a priority of company policies [8, 9] Domino risk analysis is lacking in most developing countries. Due to dwindling gross domestic product in developing countries exemplified by Zimbabwe and consequent rise in informal industries; municipal and safety agents' laws governing location and distribution of industries are greatly ignored. Domino risk analysis is the process of gathering data and synthesizing information to develop an understanding of the domino risks of a cluster composed of different enterprises and/or a cluster composed of different plants belonging to the same company [10]. In Msasa industrial area the municipal maps no longer reflect what is on the ground and to date no domino risk analysis has been done. Thus this study therefore aimed at assessing if these changes have not decreased the cluster safety and hence increased domino effect and health risks. Without this attempt information on many accidents that can occur in Msasa industrial areas that have the potential to cause extensive damage to property and even leading to loss of lives will remain grey. The study is crucial as it might give an insight to safety planning and regulatory agency on ways of putting in place measures that cater for cross company effects. More importantly this would aid in organizing and implementing novel laws, regulations and emergency response planning procedures for the protection of the population and the environment and enhancing safety of chemical plants at a cluster level [11, 12, 13].

2. METHODOLOGY

This study aimed to answer the research question:

Is there a likelihood of occurrence of domino effect in a group of neighbouring companies in Msasa Industrial Area?

Initially, a survey was carried out with safety personnel, questionnaires, interviews, document analysis and observation checklists were used. After the interviews, the researchers and respondents did sketch maps for each company showing the distribution of installations and storage facilities within and between the companies. The information obtained from interviews and sketch maps were analyzed to give the potential domino effect presented here.

Companies with high inventories were selected as primary units. The What If Analysis (WIA) was also used to postulate the potential upsets that may result in accidents. A simplified approximate Domino Effect analysis procedure was then used to simulate the likely sequence of event after an initiating event. The study area is shown in Fig. 1 below.

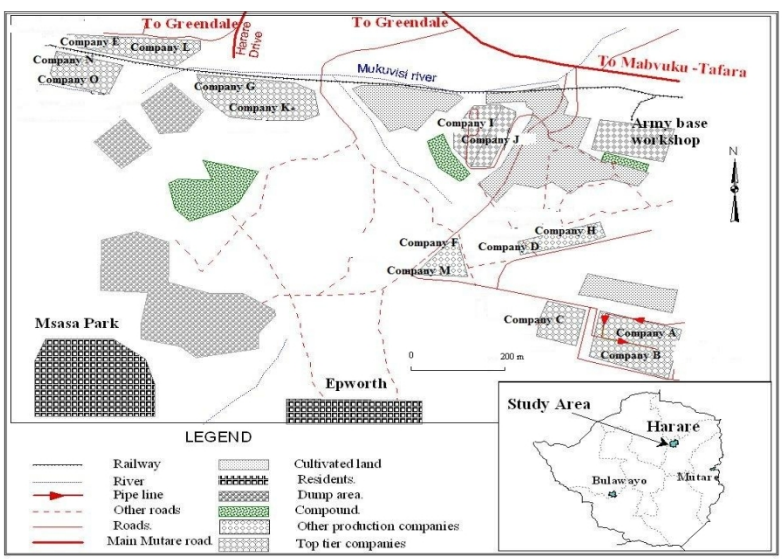

Fig. 1. Map of Msasa industrial area showing distribution of companies

A standard questionnaire was designed to address the research objectives and 25 copies were sent out for completion to safety personnel, these were managers responsible for upholding and enforcing safety related issues in the companies. To ensure comparability of results, one standard structured questionnaire was drafted for general managers or their equivalents at the targeted companies. The questionnaire had a mixture of structured and unstructured questions. The structured questions were mostly closed ended which gave the respondents limited options. These were very useful in collecting objective facts. Nevertheless, open-ended questions were also used to seek information that the researcher had little knowledge about, such as the type of energy stores that were likely to initiate or propagate fires and explosions in cases of industrial disaster or possible of toxic release scenarios etc. No options or predetermined answers were suggested which enabled the respondents room to respond freely.

An in-depth discussion of certain issues and clarifications was sought through the use of face-to-face semi structured interview. People interviewed included personnel from the planning department, the inspectorate and fire brigade in the City of Harare; Occupational Safety and Health (OSH) personnel, the inspectorate, risk officers and library and records personnel of NSSA; compliance engineers, risk personnel, and the inspectorate from Zimbabwe Electricity Distribution Company (ZETDC); safety personnel from 5 large companies, and two other randomly chosen people from smaller companies in Msasa. The room for probing enabled better understanding of the responses. The interviews allowed greater flexibility and the interviewer was able to observe the facial cues which would not be possible when using questionnaires. The interviewer thus provided a platform for clarification where respondents failed to understand. Sources of secondary data for this research were reports from the fire brigade, NSSA, ZETDC, newspaper files and the internet.

A pilot study was conducted to test the research instruments and ascertain whether the research questions asked were appropriate in finding the information sought. The study was undertaken using three companies in Southerton Industrial area that had similar characteristics to those in the sample. The similarities these had with those in Msasa Industrial area was that, one had a mixture of products like Company D in Msasa, the other had pesticides, organic solvent stores and fertilizers like Company K and Company C in Msasa. While the other just like Company J in Msasa has stored grain which is a source of energy. The profiles of company D, C, K and J are given in Table 3. The pilot study helped in reviewing the questionnaires as some of the previously asked questions were inappropriate. This made the researchers to modify the questions, repetitions and order of questions.

The pilot study was carried out to ensure reliability that the instrument yields the same results on repeated trials and validity in that the instruments were accurately reflecting or assessing the specific concepts that the researcher was attempting to measure. The data can be said to be reliable since triangulation was used to collect the information from the respondents by the use of checklist, observations, questionnaires and interviews. The limitation of one instrument was catered for by another and that respondents missed by the other technique can be captured by the other instrument.

From the 43 companies in the sampled area 19 are small to medium enterprises. Due to recent economic problems in Zimbabwe a huge number of manufacturing companies have closed doors. Even those that are operational, either they have recently resumed or are operating at ±40% capacity. Forty three standard questionnaires were hand delivered to respondents and fifteen were returned. The questionnaires were sent to Storage, logistics, Process and Chemical industries most likely to initiate domino effect scenarios at a larger scale. Seven semi structured interviews and checklist observations were successfully carried out. Larger companies were more cooperative than smaller and newer companies.

The What-If-Analysis is a brainstorming approach that uses broad, loosely structured questioning to postulate potential upsets that may result in accidents or system performance problems and to ensure that appropriate safeguards against those problems are in place. In this study it was used to create the domino effect scenarios for some companies with relatively large inventories. A modified and simplified Domino effect analysis procedure model was used to model the likely sequence of accidents by modifying Khan and Abbasi [2] procedure illustrated in Fig. 2, which is a qualitative model. The analysis done here did not involve software probability calculations as those generated by DOMIFFECT (a computer-automated tool incorporating the domino effect analysis methodology); the researchers used, amount and nature of substance stored and type of container to predict the accident and its progress. Installation distances were then used to simulate secondary targets and develop accident scenario (what would happen if the target was hit by fireball or missile).

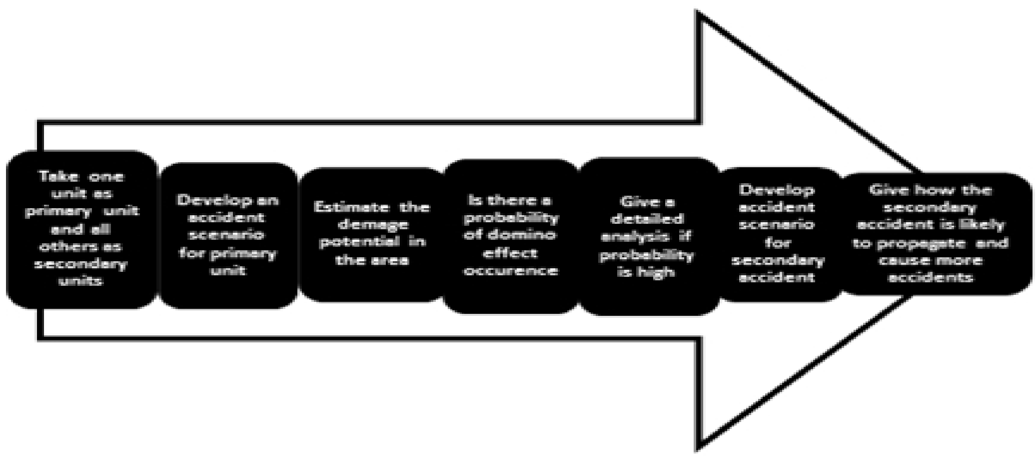

Fig. 2. Domino Effect Analysis (DEA) procedure derived from Khan and Abbasi [2]

The researchers adopted approximate figures of effect distances from data generated by DOMIFFECT from the work by Khan and Abassi [2] in almost similar installations, type of industry or chemical involved. This gives rough estimates on the damage that may occur. It was not possible to do a DOMIFFECT analysis. So the results presented here give a baseline scenario likely to occur in view of the DOMIFFECT results obtained by Khan and Abassi [2]. It is most likely that when the same procedure is employed here comparable results would be obtained. A study in which the company inventories were fed in DEA software would produce more typical data for the particular companies and hence the industrial area.

The research focused on assessment of the area in terms of damage in case mostly fire and to a lesser extend missiles accidents. The most likely cause of accidents being that of stored fuel or energy. Other domino effect precursors were also present in the area but the researchers focused on those that could initiate or propagate fire even outside the company premises such as subsistence farming which was noted in the area. The researchers also assessed the nature of business of the industry. The companies were checked on whether they had safety policies or not. The companies that had safety policies were also assessed so as to see if they included safety concerns or issues that included catering for accidents emanating from external sources or neighboring companies.

3. RESULTS AND DISCUSSION

3.1 Description and Inventory of the Companies

From the physical checks that were done the area comprise 43 operational companies. The 15 companies that participated in the study constituted 35% response rate. The classification and profile of the companies are given in Table 1 and 3. Msasa Industrial area is one of the largest industrial areas in Harare comprising the largest fertilizer manufacturing and national petroleum Distribution Company. The industrial area also is located close to low and high density suburbs. Other industrial areas in Harare are larger, with most companies closed and located far from residential areas. In addition this area has seen mushrooming of small and medium enterprises (SMEs) such that municipal maps no longer reflect what is on the ground. It is therefore possible that safety policies that were considered to locate companies no longer apply. This makes the area of great significance in the likelihood of a devastating domino effect.

From the questionnaires it was established that 3 companies did not have a safety policy. These were SMEs and all those that had a safety policy; all their policies were mainly for the specific organisation's operational safety and not cluster safety. Though risk analysis is part of the policies only 4 companies indicated that risk analysis is done, quarterly for two companies and yearly for one. For the other 8 companies they indicated that risk analysis has never been done.

From the interviews most large companies (> 300 employees) felt that cooperation with other companies in the cluster would contribute to a higher level of cluster safety as they have more to lose in the event of a domino effect affecting the Msasa industrial area. Large companies are those with larger inventories and in chemical industry large stores and installations of hazardous chemicals. If a disaster would occur toxic release would be catastrophic accompanied with massive damage of infrastructure. It could take years to rebuild or restock and they may never be able to operate again. If a smaller company like a haulage company is affected chances are that all or most of their trucks will not be on site at any given time and will therefore lose less hence they don't feel that cooperation for cluster safety is necessary. Fifty three per cent of the companies felt that cooperation among companies increased their safety, 47% saw it either as an unnecessary bother or impossible. Most (74%) larger companies felt that cooperation with neighbouring companies would reduce safety costs since the companies would pool their resources together and ensure that forecast hazard measures would be placed for all the companies saving costs as doing so individually would be more expensive. Most (81%) smaller companies felt it would not lead to lower costs as they also do not have much inventory of hazardous material and it would waste away their productive time as they also have fewer employees. This would mean a loss on their part as also they fear that the contributions towards safety would cost more for them and benefit bigger companies. The difference between large and smaller companies in need for collaboration and disclosure of safety information agrees with Reniers [8] indicated that larger companies have a lot of safety know-how, while smaller enterprises are often cost conscious and do not want to cooperate. Such differences in safety management approaches have significant implications for the prevention of domino accidents.

Table 1. Summarised categories of industrial companies in the area of study

Category	Number
Storage / logistics	5
Process / Chemical	8
Clothing	1
Other	1

As typical of any industrial area a variety of companies coexist bringing together different hazards as found by Reniers [8]. One act or scenario that may not be dangerous to that company may pose great risks to the neighbouring organization. Besides the intercompany risks, there exists subsistence farming plots with dry ignitable plant residue, food vendors cooking or warming food using fire along the streets, fuel tankers lining at fuel depot which also adds on to the safety and environmental health risks.

Table 2 shows hazardous substances present in the companies and associated scenarios in the area considered for the case study. Scenarios presented by these substances are fires, explosions and toxic release.

Table 2. Scenarios to be considered for hazardous substances present in the companies in the area considered for the case study

Name	Scenario considered to be caused by substance
Acetylene	Fire
Acetone	Fires
Ammonia	Toxic dispersions
Butane	Fires
Chlorine	Toxic dispersions
N – hexane	Fires
Heptane and isomers (gasoline)	Fires
Hydrogen	Fires
Hydrogen Chloride	Toxic dispersions
LPG	Fires and explosions
Methane	Fires
Nitrogen Oxides	Toxic dispersions, Fires
Other Solvents	Fires, toxic dispersions
Gypsum	Dust explosions
Fertilizers	Explosions
Sulphuric acid	Toxic dispersion, oxidizing

Table 3 gives the company profile that is domino related showing the installations, energy sources, number of employees and neighbours and inventory of hazardous chemicals. These are the most likely to initiate or propagate domino effects as well as their most likely area of effect. The fifteen companies employ a total of 1942 employees. Company K has 150 residential cottages with approximately 900 inhabitants. Effect distances derived from Khan and Abassi [2] for BLEVE, CVCE, pool fire, fireball, shock waves, toxic release and missiles useful in finding the probability of another company being affected by the forecasted scenario. If the area lies within the effect distance it is most likely to be affected directly. The number of neighbours gives the probable directions a domino effect will follow.

Table 3. The companies' domino effect and environmental health risk related profile

Company name	Types of installation	Type of energy source	Type of likely fire/explosion	Effect distance radius	No. of neighbours	No. of workers	Nature of business
1.Company A	16 x ±20000 L fuel tanks 5x30cm diameter pipelines	Petrol, Kerosene, Diesel	Pool, Flash	2km	2	323	Petrochemical Depot, distribution, and storage
2.Company B	Underground fuel tanks ±25000L fuel	Petrol, Diesel, Kerosene	Jet, fireball Vented explosions	1km	2	46	Fuel storage
3.Company C	Pressurized gases in 60-200kg tanks (butane, acetylene , and oxygen pesticide reactor tanks	±20 organic solvents & flammable substances	Flash, jet fire, Vented explosion, BLEVE, CVCE	500m	2	157	Pesticide& Chemical manufacture& Distribution
4.Company D	Cotton processor Boiler Pressurized gas tanks	Cotton lint, Polyethylene rolls, Coal	Vented, pool,	100m	4	25	Cotton processing &manufacture
5.Company E	- - - - - - -	Large stores of wood	Pool fire	50m	3	27	Building material storage
6.Company F	Pressurized gas tanks 30x60kgs acetylene, Organic solvents	Acetylene, Oxygen	Vented explosion, jet fire	200m	1	59	Miscellaneous Activity
7.Company G	-----	Clothing	Fire ball	50m	4	78	Clothing Factory
8.Company H	Paper mill	20tn Paper & paper products	Pool fire, dust explosions	70m	6	79	Paper manufacture and distribution
9.Company I	Boiler, welding workshop, 2000L underground fuel storage tanks,	Diesel, gypsum Petrol 5tonnes board paper, acetylene	Fireball, pool fire, vented explosions	800m	3	347	Rhino products manufacture
10.COMPANY J	- - - - - - - -	Packed grain	Vapour cloud emission	700m	3	85	Grain storage ,packing& distribution
11.Company K	Fertilizer reactors, welding equipment,	H_3PO_4, H_2SO_4 600tonne fertilizer, pressurized gasses,	Vapour cloud , dust &vented explosions, fireballs, pool and jet fire	1km	5	513	Fertilizer manufacture ,distribution& storage
12.Company L	Underground fuel tank,20 000L	Diesel, Petrol	Vented explosions, CVCE , BLEVE, jet fire, fire ball	1km	4	23	Filling station, and fuel depot
13.Company M	Fuel tanks	Diesel Petrol, Lorries	Pool fire, fireball, BLEVE	800m	2	106	Transport company
14.Company N	Solvent stores	Solvents, paints	Pool fire fireball	200m	2	53	Miscellaneous activity
15.Company O	Paint containers	3000L paint, acetone, other solvents	Pool fire, fireball, BLEVE	200m	2	21	Paint & painting products storage& distribution

3.2 The Likely Sequence of Domino Effect in Msasa Industrial Area

The What-If analysis was used to give the probable accidents originating from four of the companies in the area. Amount of substances stored, its nature and container material were used to identify the primary units and to forecast scenario development.

3.2.1 The domino effect originating from Company C

An accident in the organic solvent storage unit would start a fireball that would generate a heat load with high energy enough to cause damage over an area of more than 200m in radius. Damage of the chlorine and chloride storage areas would result in toxic release affecting a radial distance of 15-20 km. The fireball would affect Company A, Company B, and Company D which are within 200m radius. If CVCE also occurs from the solvent it would generate great over pressure and shockwave over an area of more than 500 m radius, simultaneously. This may result in units placed within the 500m striking distance to fail, leading to more fires and/or explosions. The probability of domino effect due to this accident scenario is estimated to be very high. The fire is likely to spread to the pesticide storage units and result in the release of toxic liquids and gasses. As fire spread to Company D (200m), a cotton processing company, a secondary domino effect is propagated by the highly combustible cotton lint and huge stores of polyethylene. The direction and speed of the fire are affected by the prevailing wind direction and temperature conditions that may accelerate or decelerate the fireball. In the opposite direction the fireball and CVCE from Company C can be directed to the tankers that are usually queuing in the road leading to the Company a fuel depot causing fresh explosions to erupt. Fire eruptions here will hit the Feruka petroleum pipeline outlet inside the Company B fence and multiple explosions will occur. As a result the fire balls, jet fires and vented explosions from the combined effect of all companies can cover an approximate distance of between 2 - 5 km leading to fresh explosions from all the other companies in the area including Company K (1.5 km away), where phosphoric acid and fertilizers are highly explosive or release toxics if hit by a fire ball or missile triggering fresh accidents thereby perpetuating the chain of heat, shock waves and toxic release.

The fire will most likely spread to all its six immediate neighbours as explained above including Company J, Company I and the Army Base workshop. Company J will have a vapour cloud explosion and dust explosion due to the grain dust and huge stores of combustible grains. Gypsum from Company I which is inflammable, could lead to an instantaneous or continuous release of the dust to the air after being heat by fireballs and the burning grains 20m away from Company J. Dust from Company J and Company I will contaminate and reduce visibility in the busy Mutare highway, pollution in Greendale residential area, Army staff quarters and Company K staff residence.

3.2.2 A domino effect originating from company K

NO_X (nitrogen oxides) and SO_X (sulphur oxides) release occurs frequently from Company K this has critical consequences to neighbouring communities as workers. Frequent release of SO_X and NO_X could be noticed by corrosion of buildings and satellite dishes at the staff quarters. The domino effect originating from a probable accident in the fertilizer synthesis unit, by a system failure may result in a BLEVE followed by fireball and dispersion of toxic gasses such as ammonia, NO_X and SO_X. The intensity of shock waves, missiles, and overpressure created would be high enough to cover a 450 m radii area, initiating secondary and tertiary accidents in the units placed within this area. This would affect the Wholesale;

Company O and Company G close by. Despite the neighbouring companies which may be affected, internal domino effect occur within Company K installations. The BLEVE will affect also the urea and phosphate plants as secondary targets.

The Primary absorbers placed 80 m away from the ammonium phosphate synthesis unit, would be impacted by the primary accident. The intensity of shock waves and heat generated due to this accident would affect area of over 300m in radius hence affecting other installations and staff residence. The impact of secondary accident would trigger a tertiary accident in the other synthesis units placed within 100 m from the synthesis plants. There is a high probability of generating a fireball. This chain of accidents may result in a sudden release of flammable or ignitable gasses such as hydrogen and or oxygen from other synthesis units; generating CVCE and a fireball which may cause development of severe shock waves, and intense heat in the vicinity. The severity of shock and heat waves for this scenario would result in damage over an area of 400 m radius. This scenario too has higher probability of causing domino effect. Most installations units and chemical storage areas are likely to fail in secondary accidents, whereas neighbouring industries such Company O, storage units of the refinery, and units of Company L are likely to initiate tertiary and higher order accidents. The absorber unit of the urea plant is also susceptible to accidents, as it handles toxic chemicals at extreme conditions of temperature and pressure. The accident scenario for the absorber unit can be developed as BLEVE followed by dispersion of toxic gas. Since the unit deals with large quantities of ammonia under high pressure, there is a high probability of occurrence of BLEVE and toxic release. The released chemical would disperse in the atmosphere, building a severe toxic load. An intense over-pressure and associated shocks may cover an area of 250 m radius. The lethal toxic load would spread over a radial distance of more than 3km. Thus the staff quarters, Greendale, Msasa Park and Epworth and the whole industrial area are most likely to be affected.

3.2.3 A domino effect originating at company B

A probable vented explosion of Petroleum products due to fire is the most likely to be an initiating event. Other scenarios probable but marginal release of fuel fumes which are inhaled by workers. If an accident at one of the fuel oil storage units at the Petroleum line premises was to occur probably due to use of a cell phone or the accidental ignition such as switching of the automobile cigarette lighter would result in the burning of fuel oil as pool fire which would cause building up of intense heat load. Heat sufficient to cause damage or boiling or surpassing of boiling temperatures of stored liquid would be observed over an area of more than 400m radius causing pool fires. Secondary and higher accidents due to the pool fire in fuel oil storage units are certain to occur (a probability of almost 1). Pool fire from Petrozim causes secondary accidents in fuel storage facilities being rented by Company A leading to more pool fire. The fire would spread to Company C’s chloride storage unit, reaction unit and also the organic solvent storage units, the cotton storage at Company D and the grain store at Company J. This will engulf the whole industrial area with fierce fire consuming the whole industrial area with simultaneous release of various chemicals from combustion, chemical reactions at high temperatures or release from damage of sealed storage. The whole industrial area together with neighbouring residential areas Greendale, Epworth, the Army Base quarters, Company K staff Quarters, Msasa Park ,Tafara, Mabvuku and Amby all within the 18km radius could be devastated. Most companies are likely to be drawn into tertiary and higher order accidents.

The likely secondary accidents that may occur due to this event are caused by fire balls, missile and jet fires mostly moving at high speeds. When a fireball or jet fire hits the pipeline outlet a CVCE is most likely to occur in the underground tanks and pipeline. Vented explosions would result also from the confined underground tanks and storage units in all sectors of the industrial area. Chlorine storage units will most likely contribute to instantaneous toxic release and vapour cloud explosions as it is non-flammable and non-combustible. Chlorine is a highly toxic and non-flammable chemical stored under pressurised conditions at Company C. Missiles effect would initiate secondary accidents in the units placed near to it such as those in Company M and Company F. It would endanger other units and thus may initiate tertiary or higher order accidents. The individual effect radius of each company would, together, cover the entire industrial area. The eventual area-of-impact would cover the entire Msasa industrial area. It is evident that secondary accidents will envelop other hazardous units.

3.2.4 Domino effect originating at Company J

There is a likelihood of dust explosions from Company J, this is coupled with occasional but potentially catastrophic fires from external sources. This is because Company J has huge stores of grain which are very combustible. Maize and rice is stored in grain bags in sacks stacked together with quantities over 500 tonnes at any given time. These are large energy stores. Thirty meters away from the grain storage facility is noticeable subsistence farming right on the fence of Company J. There is a high risk of fires posed by the subsistence farmers who burn grass and plant remains to clear and prepare their land for the next season or next crop. The safety personnel at the Company J site expressed with concern the activity of the farmers as they cause fire emergencies every now and then.

Fire from the subsistence farmers could be transferred by wind to one grain storage facility which has a wall that is semidetached from the roof. As the grains catch fire a dust explosion is most likely to ensue, shattering of asbestos over the store rooms leading to further pool fires and fireballs that could be transferred by wind to passing fuel trucks from the oil depot, Company A, leading to vented explosions. The possibility of the truck passing is very high as at least a truck is loaded with fuel each hour at Company A. The army base which is just across the road about 70m away from Company J will be affected together with the staff quarters there. The close proximity of the grain stores to the Company I offices (20m) and welding workshop (30m) may result in the shattering of windows and burning of wooden furniture but with not much propagation of the fire to other areas. If the fire reaches the welding workshop it is most likely to affect the acetylene gas cylinders leading to vented explosions that might lead to jet fires and missiles. These accidents are not severe and might be contained. Due to the intense heat load from burning gas, inflammable gypsum and vermiculite will give rise to a dust explosion and pollute a radius of about 500m from Company I. This will pollute Company K staff quarters, nearby stream, Company J, the Army base workshop and Company F which is further down.

3.3 Domino Risk Sub Clusters

Basing the distance between the companies J, D, C, A and B; they form a cluster in which if one accident starts at any one company it is likely to produce the same effect to the other companies. Accidents in this cluster will also affect other companies in the proximity. It is recommended that cluster safety committees need to be initiated to curb the associated risks. Due to proximity to each other and higher effective distances, the group of companies comprising companies A, B, H, C, F, D and M put the sub cluster at a higher domino effect risk. Because of high amounts of fuel stored and handled at companies A and B, the sub cluster need to have close monitoring of both intra and intercompany risks.

4. CONCLUSION

The case study highlights the need to make domino effects studies an integral parts of all risk assessment exercises in all industrial areas. This is especially important in transition economies such as Zimbabwe where other pressures companies are facing may negatively affect intra and inter safety responsibility. Basing the results of the present study it can be concluded that five types of primary events may initiate domino effects in Msasa: fire, overpressure/shock waves, missiles, toxic load, and a combination of one or more of these. The rise of companies and the consequent lack of systematic planning in Msasa have increased the risk of domino effect. Four credible accident scenarios have been developed in which an accident in one of the units of the four industries would start a chain of accidents involving other units of the same industry, or the units of nearby industries. This case study indicates that regardless of the danger posed by one company or installation, severity of damage or effect depends on the consequent targets affected by the primary units and the proximity of the installations or chemical stores to the accident scene. Thus it is important to carry out domino effect analysis on already existing industries and emerging ones to enhance cluster safety and emergence preparedness.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Interview Guide for Company Employees

Demography

Position of the Respondent ________________________Number of Employees _______
Nature of Business ________________________ Number of neighbours________

1. Does your company have a safety policy? Yes__ No___

2. Does your safety policy (if you have) cover safety issues from neighboring companies? Yes ___No____
Comment____
____
____

3. Are there any joint safety collaborations with neighboring companies?
____
____
____

4. Do you believe that risk analysis cooperation with neighboring enterprises will lead to a larger degree of company safety regarding domino accidents (cross company accidents)?
____
____
____
____

5. Are you aware of the activities happening at the neighboring companies?
____
____
____
____

6a. Do you have any energy store that is most likely to initiate or propagate a fire, explosion, or toxic release?

Name	Amount
_____________	____________
_____________	____________
_____________	____________
_____________	____________

6b. What other installments or sources of fuels or pressurized combustibles or flammables do you have that could lead to explosions or fires.

Installment etc.	Description
_____________	______________________________________
	______________________________________
	______________________________________
______________	______________________________________
	______________________________________
	______________________________________

7. Overleaf can you sketch your company lay out indicating installments, storage facilities; distances between installations and storage facilities and the distances to the neighbours.

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