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Analysis of the Tragedy of Vila Socó in Cubatão (São Paulo, Brazil) Using the Haddon Matrix: A Comprehensive Examination of Socio-Environmental Factors and Risk Mitigation Strategies

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Abstract

The tragedy of Vila Socó epitomizes the socio-environmental repercussions of rapid industrialization in Cubatão. Beginning in the 1940s with the construction of the Anchieta highway, the city experienced an influx of migrants drawn by burgeoning industries, leading to unplanned urban growth and the emergence of vulnerable communities like Vila Socó. This article examines the interconnected factors—such as demographic shifts, inadequate planning, and regulatory oversight—that culminated in the devastating fire of 1984, claiming numerous lives and highlighting systemic failures. Utilizing the Haddon Matrix, this study dissects the Vila Socó incident, emphasizing the roles of human error, infrastructure integrity, and socio-economic disparities in disaster causation. By contextualizing the tragedy within Cubatão's industrial trajectory, it underscores the urgent need for comprehensive risk assessment and proactive mitigation strategies in rapidly developing regions globally. Beyond its immediate focus, this work offers broader insights into the dynamics of industrial disasters and their socio-economic implications. As pipelines continue to play a vital role in global energy infrastructure, the lessons drawn from Vila Socó's tragedy resonate deeply, emphasizing the imperative of robust safety protocols and accountable governance to prevent similar catastrophes in the future.

Keywords

Haddon Matrix, Vila Socó Accident, Risk Analysis, Cubatão

1. Introduction

William Haddon Jr.'s conceptual model initially aimed to enhance traffic safety by applying fundamental principles of public health. This matrix serves as a valuable tool in crafting strategies to prevent various types of injuries. It offers a comprehensive framework for comprehending the root causes of injuries and devising multiple countermeasures to effectively address these issues [1].

The initial step in any planning process is to clearly identify the problem to be addressed, utilizing appropriate historical accident data and community social information. Subsequently, the Haddon Matrix is employed to explore potential interventions in the system to enhance safety further. While the matrix plays a crucial role in the field of injury prevention in medicine, its application in disaster management is still evolving.

Search tools were utilized to locate articles, published news, and studies on socio-environmental evolution in the region during the 20th century. Through the application of the Haddon Matrix, actions preceding, during, and following accidents are identified, shedding light on necessary post-incident changes that have yet to occur.

The structure, known as the Haddon Matrix, consists of a "logical matrix for reasoning around accident prevention strategies. It is a system that orders the causal relationships between agents and victims and facilitates the generation of new ideas to address the control of specific physical injuries. Some implemented strategies based on the complete list of accident prevention actions".

The Haddon Matrix analyses unfold across three phases: pre-event, event, and post-event, considering three key factors: "host" or human, "agent" or processes/equipment, and "social environment". This model meticulously analyzes risk factors and potential interventions to reduce both the frequency and consequences of injuries [2].

Dr. Haddon proposed a conceptual model to understand events using an epidemiological triangle encompassing host, agent, and environmental factors. Such a concept indicates systematic prospective research investigating the detection of countermeasures, his 10 strategies present provisions for interventions and prevent injuries, 1) Prevent hazard creation, 2) Minimize the hazard amount or exposition, 3) Prevent the agent release, 4) Keep the hazard release in the source, 5) Separate the hazard from the ones to be protected, using place and time, 6) Use physical barrier to separate the hazard, 7) Minimize damage using infrastructures modification, 8) Increase the resilience of the structure or host to be protected, 9) Provide emergency response, 10) Provide emergency care, rehabilitation and legal assistance.

Man-made disasters, where human agents can facilitate hazard release or hinder emergency response, underscore the importance of the Haddon matrix application in improving safety systems. By identifying the influence of social-physical factors on risk creation, event occurrence, and health-related responses, the matrix enhances our understanding of emergency situations [3].

The Haddon Matrix's versatility transcends typical accidents, encompassing not only their prevention and management but also extending to the readiness and mitigation efforts for natural disasters like floods and those exacerbated by climate change, particularly vital in economically disadvantaged nations. Understanding underlying socio-economic risk factors is crucial for effective mitigation planning, as highlighted by the matrix's exploration of anthropogenic drivers.

Floods not only pose a significant threat to the socioeconomic progress and development of nations but also have the potential to undo years of hard-won gains in poverty alleviation and economic advancement. The occurrence, intensity, and impact of floods can be mitigated through proactive identification and prompt response to risk factors. The Haddon Matrix framework considers pre-flood, flood, and post-flood stages. Human activities, such as greenhouse gas emissions, land use changes, deforestation, and haphazard urbanization, are primary drivers of flood risk. Inadequate infrastructure, poor urban planning, and socioeconomic vulnerabilities further exacerbate the risks. During flooding, issues with drainage systems, improper waste management, and concentration of populations in vulnerable areas become apparent. Post-flooding challenges include economic losses, environmental degradation, and the need for infrastructure repair and community resilience-building. The Haddon Matrix underscores the importance of poverty alleviation and governance focused on people-centered development, alongside the necessity for robust legal and policy frameworks related to flood management [4].

Beyond floods, the Haddon Matrix proves invaluable in assessing risks across a spectrum of incidents, from everyday car accidents to catastrophic events like the Bhopal chemical disaster. Its emphasis on the social environment is particularly crucial in chemical accident studies, highlighting the significance of socioeconomic planning and support mechanisms.

Furthermore, the global phenomenon of migration, driven by social, economic, and political factors, has increasingly become a focal point in occupational health and safety risk assessments. According to the World Health Organization, the number of international immigrants surged from 153 to 281 million people between 1990 and 2020, with family and labor migration accounting for the largest increases [5].

The Haddon Matrix emphasizes the importance of housing planning and social interventions, particularly in the context of large-scale construction projects attracting migrant labor. The contemporary construction of large-scale projects necessitates governmental planning and licensing, aligning with societal norms, policies, and procedures aimed at enhancing public transport and bolstering the infrastructure of healthcare, education, and housing in smaller cities to accommodate new residents.

Eckerman's analysis of the Bhopal Gas Catastrophe through the lens of the Haddon matrix sheds light on various aspects. The pre-event phase was marked by a series of warning signs, including crop failures and famines in Asia during the 1950s and 1960s, prompting the implementation of the "Green Revolution" in India. This agricultural shift increased the demand for pesticides and fertilizers supplied by foreign manufacturers, setting the stage for heightened chemical production in Bhopal. Despite numerous warnings from journalists (over 6000 posters) and trade unions, both management and authorities turned a deaf ear to the looming catastrophe [6].

Initially, there was an inhabited slum situated adjacent to one side of the chemical plant area, while the other three sides were surrounded by fields. However, as the town of Bhopal expanded, residents began to settle closer to the plant, constructing makeshift shelters in its vicinity. Due to the dilapidated state of the perimeter fence, children and even livestock often wandered into the area. Moreover, the site served as a dumping ground for hazardous chemicals, with all effluents being disposed of in an open pit near the factory's eastern wall between 1969 and 1977.

Post-Bhopal industrial accident, extensive research revealed one of the primary causes of the high casualty count: the placement of the industry in close proximity to densely populated areas. This hazardous juxtaposition is not unique to Bhopal; similar scenarios are observed elsewhere, such as the Research Development Explosive Plant (PRDE) near Jaipur and the city of Chembur in Mumbai. These locations experience significant pollution due to the presence of oil refineries, petrochemical plants, fertilizer facilities, and thermal power plants, among others. Additionally, published studies have highlighted concerning statistics, revealing that thousands of schools nationwide are situated within a mile radius of chemical facilities, further exacerbating potential risks to public health and safety.

Risk assessment studies highlight the pre-event phase of the matrix, emphasizing safety measures that prioritize distancing hazards from the populace. They advocate for industrial relocation to avert catastrophic casualties, urging industries to move away from densely populated areas. This proactive measure aims to minimize the risk of public harm and casualties resulting from potentially hazardous accidents and explosions in the future [7].

During the event phase, the precise composition of the lethal cloud remains unknown, although its components are known to be heavier than air and settle at ground level. The composition may vary depending on the distance from the local plant. Exposure to these deadly gases could have been mitigated if inhabitants had access to transportation for evacuation, received early warnings via alarms, covered their faces with wet clothes, sought shelter indoors, walked calmly instead of running, and were informed about safe sources of water and food to avoid contamination.

In the post-event phase, authorities and civil society collaborate to register the deceased, survivors, and missing individuals. They provide essential services such as healthcare, medicines, clean water, and food to those affected, arrange funerals for the deceased, initiate citywide cleaning efforts, and offer comprehensive support to survivors. Additionally, safety precautions are implemented at the chemical plant, legal proceedings are initiated, and scientific research is conducted to prevent similar incidents in the future.

1.1. The Tragedy of Vila Socó

In the 1940s, the industrialization of Cubatão commenced with the construction of the Anchieta highway. This significant project prompted a notable influx of migrants to the region, precipitating a period of rapid demographic growth. However, the lack of comprehensive planning and proactive measures by public authorities resulted in profound socio-environmental consequences, affecting not only Cubatão but also neighboring communities in various ways.

Across industrialized nations, the workforce is influenced by three key factors: aging demographics, educational trends, and migration patterns. This article aims to illustrate how this surge in migration, combined with insufficient urban planning, exposed a significant portion of Cubatão's population to unforeseen risks, ultimately leading to the region's most tragic episode to date [8].

Much like Vila Socó, numerous other areas grappling with socio-environmental vulnerabilities require coordinated action from public authorities to prevent a recurrence of tragedy. Take, for instance, Vila Nair in the Jacuí Ecological Park in São Paulo. Unchecked population growth, typical in many regions across Brazil, has occurred without due consideration or assessment of potential risks to the burgeoning vulnerable populace. While conducting risk analyses, it becomes imperative to prioritize regions with looming residual risks, such as those witnessed in Vila Socó, as well as mountainous areas prone to landslides, akin to recent events in São Sebastião/SP. Importantly, there is an absence of any documented risk assessments conducted prior to the Vila Socó tragedy aimed at preempting such catastrophic incidents.

The aim of this publication is to elucidate the socio-economic evolution of the region, shedding light on the dearth of planning, risk analysis, and the negligence exhibited by both companies and public authorities, all of which contributed to the gravest tragedy in Cubatão's history.

Prior to the 1940s, Cubatão epitomized a quintessential interior city in São Paulo. Referred to as "caipira" (or "hillbilly") by residents of Santos and São Paulo, Cubatão's populace led modest lives predominantly centered on agriculture (see **Figure 1**).

During this period, despite a downturn in economic activity, Cubatão remained devoid of slums ("*favelas*"). With sprawling rural properties, families sustained themselves by cultivating crops. The majority of inhabitants owned their land, obviating the need for rented housing. In the early 20th century, there were reports of banana farmers in the region leasing out portions of their land to migrants who flocked to the city due to labor shortages, particularly in banana plantations. According to the 1940 demographic census, Cubatão was home to a mere 6570 inhabitants [11].

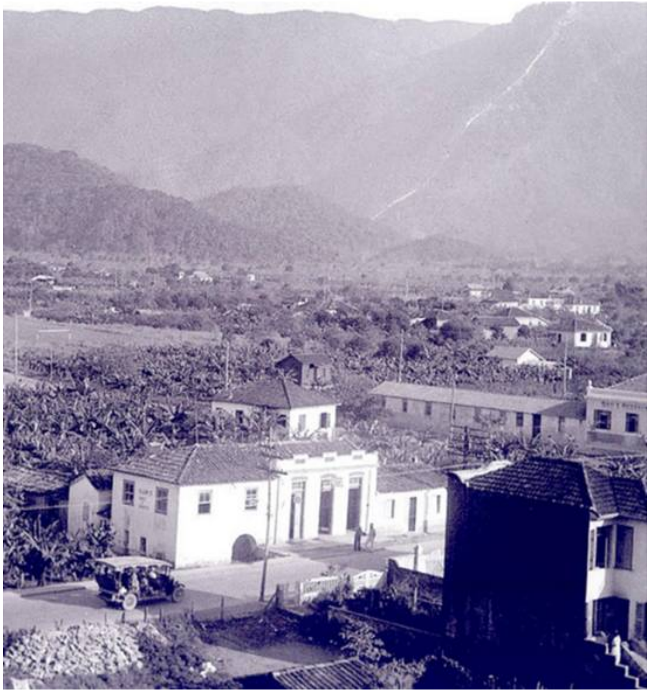
As said, the transformation of Cubatão's landscape commenced in the early 1940s, marked by the extension of the Via Anchieta Highway to the Serra do Mar, a rugged escarpment where highlands adorned with natural forests slope down to the Atlantic coast. This expansion heralded the arrival of a significant influx of migrant laborers to the region, coinciding with the emergence of the first favela. Dubbed "COTAS," this unauthorized settlement took root in the former camps of the Department of Highways (DER), tasked with the construction of the Anchieta road.

By 1950, Cubatão's population surged to 11,803 inhabitants from the 6570 recorded in the 1940 census [12]. Of this total, 40% identified themselves as migrants, with a significant portion residing in COTAS.

The construction of the Presidente Bernardes Refinery further catalyzed the unplanned influx of migrants, profoundly altering the city's demographic landscape. In contrast to the initial wave of migration associated with the construction of the Via Anchieta, these newcomers not only settled in COTAS, located on the outskirts of Cubatão, but also began encroaching upon the urban core. Concurrently, the establishment of a small settlement dubbed Favela do Oleoduto emerged near the refinery's pipeline.

The construction of the Refinery led to a surge in population, resulting in increased housing rental values to the benefit of Cubatão's local citizens. While temporary camps were set up for the workers, they were dismantled once the construction concluded, prompting many workers to settle in the Serra do Mar enclave.

Following the establishment of the Presidente Bernardes Refinery, Cubatão embarked on the development of its Petrochemical Complex in subsequent years, further fueling population growth. By the 1960 Census, the population had swelled to 25,166 residents [13]. Towards the end of the 1950s and into the early 1960s, the proliferation of large favelas began to take shape in Cubatão.



Source: COUTO, J M, The Economic History of Cubatão [10].

Figure 1. Picture of Cubatão city in 1935 [9].

The notable settlements include:

- Vila Parisi: Established in 1958 alongside the commencement of the Cosipa (São Paulo Steel Company) construction.
- Areais (Sítio Capivari): Emerged through the encroachment on private land by construction workers of Copebrás (Brazilian Petrochemical Company).
- Vila Socó: Originating in the early 1960s, it emerged through the occupation of the mangrove area along the Santos-São Paulo Pipeline.

While the Refinery attracted numerous migrants to the region, it was the construction of Cosipa, a massive and protracted project that significantly intensified migration to the area, leading to the proliferation of favelas such as Vila Parisi, Areais, Vila Socó, among others.

As per PERALTA [14], Cubatão boasted a population of 50,906 inhabitants in 1970, with migrants constituting 67.4% of the total populace [15]. While the growth rate in 1970 surged by 103% compared to 1960, by 1980, it moderated to 54.50%, with the population reaching 78,630. However, this decade witnessed unabated expansion in favela formation, exemplified by the emergence of Vila Natal in 1974 and Morro do Pica-Pau in 1978.

Highlights Cubatão's inherent geographical constraints, revealing that since its inception, the municipality has grappled with limited land suitable for habitation. Of its 148 km² area, 84.4 km² comprises mountains and hills (57%), while mangroves cover 37 km² (25%), and plains and embanked mangroves encompass 26.6 km² (18%). In essence, only a fraction, 26.6 km², constitutes suitable land for residential purposes, ranking as the 7th largest area in plains and filled mangroves.

However, industrial encroachment has encumbered some of these habitable areas, reducing the available land to approximately 16 km² for housing, commerce, and services. Consequently, the burgeoning migrant population faced escalating rents and property values, rendering them unaffordable for many. This predicament forced residents to settle on the fringes of these areas, often in inhospitable terrains such as mountains and mangroves.

Despite grappling with socio-environmental challenges, Cubatão experienced three decades of notable economic expansion marked by job creation and increased tax revenue. However, throughout the industrial boom of the 1950s, 60s, and 70s, little to no regulation or oversight was enforced to mitigate the socio-environmental impacts of this growth. Consequently, obtaining employment in Cubatão was relatively easy until the late 1970s, with reports indicating individuals spending over a year searching for stable positions.

In the early 1980s, Brazil's economic downturn severely impacted the Cubatão Industrial Pole, exacerbating existing vulnerabilities. Investment from both the government and banks dwindled, leading to a halt in operations. [16] coined the term "wage slavery" to describe the situation, highlighting the fragmented nature of the labor force characterized by constant work rotation and nomadic employment patterns.

One of the most notable instances occurred in 1981 when the Cosipa expansion project abruptly halted, resulting in the dismissal of over 16,000 construction workers employed by various contractors. These workers were summarily evicted from their accommodations without any form of financial or housing assistance. As reported by GUTBERLET (1996) [17], the dire economic conditions led to the rapid construction of approximately 40 shanties daily in Cubatão during the early 1980s. Subsequently, in 1982 and 1983, the city's economic crisis intensified, with unemployment levels spiraling out of control.

The cessation of construction activities triggered a cascading effect, as the contracting companies not only terminated their employees to alleviate financial strains but also declared bankruptcy, abandoning the city. This exodus left thousands of individuals devoid of labor rights, exacerbating the plight of the unemployed populace.

Ecologist SAMUEL BRANCO (1984) [18] vividly captured the transformation that engulfed Cubatão in the early 1980s, painting a stark picture of the city's metamorphosis: "*The mutation we observe was drastic*: *the almost mystical preservation of the integrity of the environment has been replaced by plunder and depravity*; *the natural landscape*, *with its immense surfaces of clear*, *fishy waters*; *the exuberance of the mountain forests*; *the intricacy of the forests of coconut trees in the lowlands*; *the majestic and peaceful mangrove forest with its crabs*, *its fish*, *its oysters and shellfish*, *its birds and its incredible fertility*; *the cool breeze from the ocean*; *all of this replaced by a shapeless and ugly terrain*, *furrowed by infected*, *silted canals and polluted*; *by the toothpicks of dry and twisted trees*; *by the endless landfills made with scrap and slag from factories or with the earth resulting from the criminal dismantling of neighboring hills*, *these*, *in turn*, *reduced to ugly wounds of red earth*; *by the mud sterile and half-populated with delimbed and twisted mangrove plants*, *the incessant noise of machines and vehicles replacing the chirping of birds*; *by the hot*, *sticky breath of winds*, *heated and blackened by chimneys and no longer refreshed and purified by vegetation*".

The native man, or the "*caiçaras*" and their descendants, who were accustomed to the bucolic life of fishing, hunting, banana and cassava cultivation, as well as artisanal activities, and transportation in canoes and boats along the intricate network of canals that formed the majestic estuary, transporting bananas, hearts of palm, fish, baskets, or flour, were replaced by industrial wage earners or marginalized individuals living on the edge of the mangrove or even in substandard housing. These individuals were malnourished, maladjusted, and unemployed, embodying a sad image of retreat transformed into the degrading reality of the hotbed [18].

SAMUEL BRANCO (1984) [18] himself vividly describes the typical "hotbed" of Cubatão, a term widely discussed among the city's residents: "*The hotbed is where a man sleeps in shifts. Unable to start a family*, *secure his own home*, *or even afford a full meal*, *he rents a bed for eight hours a day. These uncomfortable*, *poorly arranged cots facilitate a continuous turnover*, *with three shifts of men rotating every* 24 *hours*, *balancing their industrial work hours with rest pe-*

riods, always finding a bed warmed by the body of a colleague who has just left".

An important insight from GUTBERLET (1996) [17] reveals that a significant portion of the population resided in impoverished neighborhoods, slums, and tenements. By 1984, only 5.9% of the residents were homeowners, 7.1% were on financing arrangements, 10.64% were tenants, and 23% occupied land illegally. It was only in 1984, when construction resumed on Cosipa's expansion, that people began to hope for improvement in the region's dire situation. Consequently, Cosipa generated approximately 15,000 jobs.

The 1991 Census [19] indicates a notable decline in population growth rate in Cubatão, marking a decrease below the state of São Paulo's rate, an occurrence unprecedented since 1950. Against this backdrop, the historical conditions leading to one of Cubatão's greatest tragedies, the devastating fire in Vila Socó, come into focus.

1.2. The Gasoline Pipeline

Globally, pipelines are often likened to the lifeblood of energy systems, with gas pipelines playing a pivotal role in driving economic development and ensuring social stability by bolstering the workforce. However, their operation is not without risk, as accidents stemming from material failure or damage can result in significant economic losses [20].

The failure of gas pipelines is a matter of considerable concern, given the potential for far-reaching consequences—be they economic, environmental, or, in the most tragic scenarios, involving loss of life. Despite strides in pipeline safety over time, incidents have underscored the ongoing need for vigilance [20]. In some instances, the causes behind these accidents were not discernible beforehand, rendering them difficult to investigate or predict preemptively.

Incorrect operation often stems from human error, typically involving mistakes made by operators. This category encompasses actions such as overfilling a tank, leaving a valve open erroneously, applying excessive pressure to equipment, or inaccurately marking areas for excavation.

The severity of combustion in a pipeline incident is influenced by factors such as the material, type, and contents of the gas being transported. Highly volatile liquids are particularly susceptible to combustion accidents. Hongfang *et al.* conducted an analysis of the average response time to pipeline gas accidents in the United States from 2010 to 2017 [21]. They found that over 50% of these accidents resulted in soil pollution, with more than 40% affecting environmentally sensitive areas. The researchers concluded that vandalism was the primary cause of such accidents, followed by mismanagement and pitting.

The story of Vila Socó is intertwined with the rise of the Presidente Bernardes Refinery and shares a common origin with other favelas in Cubatão. Initially, construction workers, predominantly migrants who represented the region's industrial growth, settled in makeshift areas unfit for habitation due to low wages or periods of unemployment.

Professor Azis Ab'Saber [22] from the Institute of Geography at the University of São Paulo once remarked, "*Nowhere else in the world has such a devastating and rapid impact of polluting industries on tropical escarpment forests been observed as in the industrial district of Cubatão*". With over 2000 families, Vila Socó stood as one of the largest favelas in Cubatão [10].

On the front page of issue No. 322 of Jornal do Brasil, dated February 26th, 1984, the headline reads: "*Fire in Cubatão kills* 67 *and injures* 200". At approximately 10:30 pm on February 24th, 1984, residents of Vila Socó (now Vila São José) in Cubatão, São Paulo, noticed a gasoline leak in one of Petrobrás pipelines connecting the Presidente Bernardes Refinery to the Alemoa Ship Terminal (see **Figure 2**).

The pipeline traversed a swampy area right in front of the village, which was built on stilts. On the night of the 24th, an operator misaligned a recently replaced valve and initiated the transfer of gasoline into a closed pipe (an operational failure), resulting in high pressure and rupture. This caused approximately 700,000 liters of gasoline to spill across the mangrove. Some residents, seeking to make a profit by selling the fuel, collected and stored a portion of the leaked product in their homes.

As the tides moved, the flammable substance spread throughout the flooded region. Approximately two hours after the spill, ignition occurred, leading to a fire. The flames quickly engulfed the swampy area saturated with gasoline, igniting the stilt houses in the village.

Jornal do Brasil published:

"*The firemen and civil defense controlled the fire shortly before dawn. A large relief operation mobiliz*ed firefighters, 270 *men from the Military and Civil Police*, *vehicles*, *and ambulances from hospitals*, *private companies*, *the Army*, *and the Navy. The mayor of Cubatão issued a decree declaring a state of partial public calamity in the affected area*.

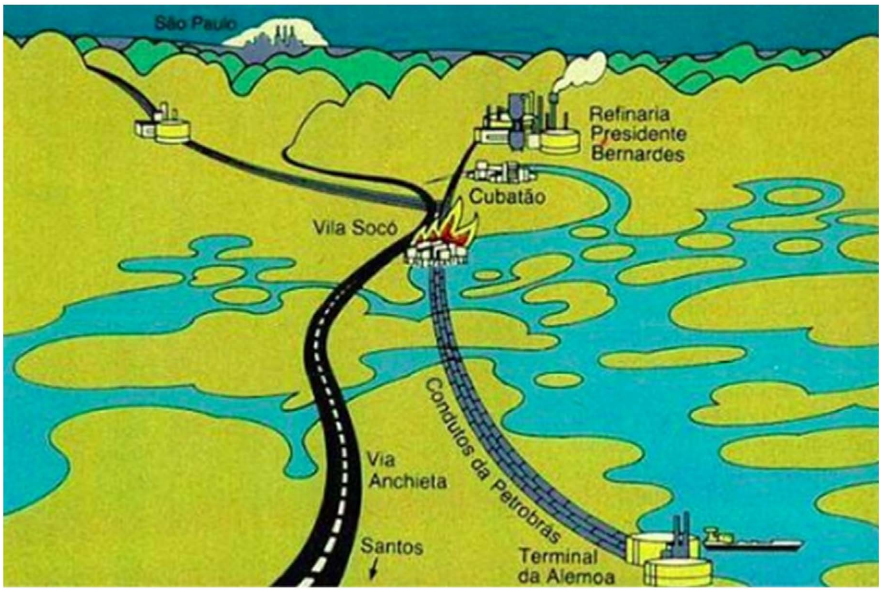


Figure 2. Infographic of the fire location [23].

Three-quarters of the Favela, which had an area of one and a half kilometers long and 100 meters wide, were destroyed. Few buildings remained standing. The rest was rubble, calcined material, and twisted iron.

Until last night, the aftermath operation continued. The removal of the earth around the leased pipe, and it was possible to see a hole where the gasoline came out. Technicians worked with oxygen masks under the protection of firefighters, ready to act in case of any other problem. The number of deaths at 4:30 *pm was* 67 *but could increase*: 32 *seriously injured people have more than* 50% *of their bodies covered by third-degree burns. At* 6 *pm, the collective burial began at the Cubatão Cemetery.*"

Following the tragedy, the official death toll stood at 93, yet some sources suggest the actual count could be much higher, possibly exceeding 500 fatalities. These unofficial figures are derived from various sources, including reports of students who failed to attend school and instances of entire families perishing with no one to claim their bodies.

On the same day as the incident, an open police investigation was initiated, and the São Paulo Attorney General's Office appointed a prosecutor to lead the investigation and oversee criminal proceedings. Over the course of a month, the prosecutor, now retired, and his colleague meticulously gathered evidence, including records of previous leaks, reports from the Medical-Legal Institute, documents from the Cubatão city hall, blueprints of the pipeline installations, and testimonies from survivors, witnesses, and personnel from relevant institutions such as Petrobras and the Companhia Docas do Estado de São Paulo (Codesp). Finally, on June 4th, 1984, the prosecutors filed a formal complaint in the District of Cubatão.

The legal analysis, replete with meticulous detail and evidence, ultimately attributed the fire to human error, specifically an "operational error." However, the tragedy was deemed to have occurred due to the negligence and inaction of 24 individuals. At the forefront of the list of defendants stood the president of Petrobras, who also served as the former minister of Mines and Energy in the government from 1974 to 1979. Other authorities implicated included the mayor-intervenor of Cubatão at the time, who had been appointed by the military government.

Petrobras acknowledged that the leak resulted from a failure to maintain the aging pipelines adequately. Initially, eight company employees were convicted in the first instance, but they were subsequently acquitted after lodging appeals.

A former resident recounts the resettlement process in Vila Natal, where she currently resides, following the fire. For two months after the tragic event, she and her four children stayed with her brother in Guarujá until they were able to move into their new home. As compensation for her losses in the fire, she received Cr$ 1.5 million in cash. This amount, adjusted for inflation and monetary correction, now equates to approximately R$ 10652.54 according to calculations from the Central Bank platform, or around USD 2000.00 in today's currency.

Although she possesses an "address permit," she does not hold the deed to the house and did not have the option to choose Vila Natal as her new residence.

Today, Vila Socó still occupies the same location, albeit without the mangroves or stilt houses that once characterized it. The area underwent urbanization in 1985 in response to residents' requests. While the gasoline pipelines remain in place, they are now buried underground. Yellow stakes along the neighborhood's leisure area sidewalks mark the path of the pipelines, ensuring awareness and safety for the community (**Figure 3**).

Little progress has been made in rectifying the injustices suffered by those impacted by the tragedy. Although some agreements were reached regarding compensation, there were notable gaps in the process. "Children up to 12 years old were not compensated because they were not considered part of the productive labor force," reveals a former councilor elected by the Workers' Party at the time of the disaster [24].

Understanding the broader context of the region's development during the industrialization of Cubatão is crucial for comprehending the direct impact on the socio-environmental vulnerability of the workers involved in this process.

Accidents involving pipelines and industrial disasters continue to occur worldwide, both in developed and developing countries. While most may not reach the scale of the Bhopal chemical accident, numerous chemical and volatile hazards pose significant public health risks. Companies often dispute their role in these accidents and downplay their health effects, showing reluctance to provide adequate compensation to the victims.

In injury analysis, the Haddon Matrix concept encompasses the accident process, including pre-event, event, and post-event phases. While various models for analyzing the extent of injuries have been developed [25], the Haddon Matrix uniquely incorporates the social and economic environment into its analysis. Although traditionally applied to events like traffic accidents and children's burns, it can also be invaluable in studying and comprehending mega-accidents such as the Vila Socó and Bhopal gas leakages [26].

Figure 3. Vila Socó scene after aftermath [23].

2. Methodology

The research is set in the city of Cubatão, specifically in Vila Socó, located between the Anchieta highway at km 57 and Avenida Bandeiras, along the Petrobrás pipeline connecting the Presidente Bernardes Refinery to the Alemoa Ship Terminal. The primary source of data for this study comprises newspaper headlines and reports from the time of the tragedy and subsequent articles.

The investigation spans from the 1940s, marking the construction of the Anchieta Highway and the onset of migration in the region, through the 1980s when the tragedy occurred, up to the present day, illustrating the enduring impact of the accident on the region.

The research methodology involves a comprehensive analysis of historical records, including newspapers, reports, and articles, to gather detailed information about the events leading up to the Vila Socó tragedy and its aftermath. By examining primary sources, the study aims to reconstruct the sequence of events, identify key factors contributing to the disaster, and evaluate the responses and actions taken by various stakeholders before, during, and after the incident.

Additionally, the study employs the Haddon matrix as a framework for analyzing the incident and proposing preventive measures that could have averted or mitigated the tragedy. This matrix organizes actions into pre-event, event, and post-event phases, allowing for a systematic evaluation of the factors influencing the outcome of the disaster and the effectiveness of response efforts.

Through a detailed examination of historical data and the application of analytical frameworks, the research aims to provide insights into the socio-economic and environmental factors contributing to the Vila Socó tragedy and draw lessons for enhancing industrial safety and disaster preparedness in similar contexts.

3. Results and Discussions

Based on the information, it is possible to discuss and present what was done and what should have been done so that the Vila Socó tragedy did not occur or even reduce the effect. For this purpose, the Haddon matrix was used, which organizes actions that could have been carried out before, during, and after the incident (**Table 1**).

Several preventive measures could have averted or mitigated the tragedy. The placement of Vila Socó near the pipeline inherently endangered the population, as prior to the incident, pipeline construction and operation licenses failed to account for the social environment, risk analysis, and emergency action plans. The plight of migrant laborers and their families was disregarded in favor of prioritizing the economic interests of private sectors, a stance all too common globally during that era. This disregard for the rights and well-being of impoverished populations and migrant laborers facilitated the exploitation of cheap and precarious labor, driven by the desperation of individuals facing food shortages and limited employment opportunities. This systemic neglect culminated in some of the worst chemical disasters, including the tragic events in Bhopal.

Table 1. Haddon Matrix applied to the accident case of Vila Socó, Cubatão/SP.

	Host	Vehicle/Agent	Physical Environmental	Socio and Cultural Environment
PRE	-In the 40ths the planning of house construction near city with public infrastructure for workers family's location. -Social structure for the migrants' families as school and public health -Combating the housing value speculation in the area. -Prohibition, supervision and removal of residents in risk area.	-Investment in pipeline maintenance -The installation of monitoring system of security valves. -Installation of physical separation barriers from pipeline to communities. -Boxes for gas containment during eventual leak. -Install and use alarms and leak detectors. -Promote the presence of firefighting devices near by the pipeline.	-Analysis of risks of soil erosion to avoid additional leaking events. -Contain de leaked gasoline to avoid further contamination and fire. -Analysis of the environmental impact on water resources, mangroves, and rivers due to leaked gasoline. -Promote city public structure of transport to emergency leave the area.	-Develop and promote the application of the law with the protection of the population first. -Reduced the Socio-environmental problems in the area. -Promoting the families transfer to the near city with public infrastructure. -Strength the Environmental Legislation To recover the degraded areas. -Safety culture and frequent trainings for evacuation in emergency events. -During the construction and installation of large-scale constructions demand social infrastructure to labor force migration and families.
EVENT	-Demand the immediate risk area evacuation, alarm, transport, and ground orientation. -Alarm of gas leakage in pipeline. -Warning of imminent risk to catch fire. -Ask the assistance of the public fire force, police department, the gas company, the electric company, and civil defense. -Provide medical Emergency assistance and hospital transportation to the injured. -Isolate and control the access to the area. -Collect the contaminated water and food.	-Total automatic interruption of gasoline flow in the pipeline during leakage. -Installation sprinklers and fire safety device to keep the flames away from the pipeline to prevent new Explosion.	-Promote the leaked gasoline containment to prevent further spread of the flames. -Contain the water used to extinguish the flames.	-Demand the company responsible for the event to pay and pursue any need in the emergency. -Call the authorities to control the access, isolate the area and maintain the order. -Ground guidance and people transportation to a safer place.

Continued

POST	-Register small gas leakage occurrences to understand and prevent the big ones. -Health monitoring for those affected by the event. -Financial compensation for the families. -Relocation of the families from the risky area. -In-depth survey of the number of people affected. -Follow-up with social and psychological assistance. -Funeral assistance. -Complete list of those found and lost with their location -Give clean food and water to the victims. -Give medicine to the victims. -Legal support for the population.	-Register the faulty valve, and the volume of the leaked gasoline -Environment study of the affected region. -Confirm if the fire extinguishers, the alarm systems, and the containment boxes are working properly. -Application of pipping safe procedures to avoid incidents. -Undertake safety precautions at the pipeline.	-Monitoring the environmental decontamination of the area. -Survey of affected fauna and flora. -Study of the gasoline impact on soil, water, and the environment in the region.	-The accident Investigation and exemplary punishment for those involved. -Strength the legislation prohibits the company from maintaining its operations while there is low risk in the pipeline use. -Promote de safety culture and safety communication in the area.

*Some Pós-event strategies serves as pre-event strategy for future potential incidents.

During that period, another critical factor was the pressing need for increased investment in industrial installation and maintenance. Profit-driven management prioritized short-term gains over the long-term sustainability of industrial infrastructure, neglecting essential maintenance efforts aimed at ensuring optimal performance and longevity of the plant. This shortsighted approach failed to capitalize on the potential of the industry to become a sustainable source of economic prosperity for the region. Moreover, the absence of environmental planning compounded the issue, transforming the city into a glaring example of environmental neglect. Coupled with ineffective environmental regulations and inspections, this lack of foresight paved the way for similar, albeit smaller, events that could have been prevented with proper oversight and regulation.

During the event, the Oil and Gas Company swiftly halted gasoline pumping in the pipeline, while public forces mobilized promptly, providing essential medical aid and facilitating transportation to nearby hospitals for the injured. However, incidents of looting occurred, highlighting the need for a more robust emergency response strategy, including complete isolation of the affected area and controlled entry points.

The post-event phase was pivotal for understanding the shortcomings and enhancing the emergency response system to prevent such tragedies from recurring. Unfortunately, this phase was marred by inadequacies, as problems within the hierarchical system, instances of corruption, societal attitudes toward the affected individuals, and undue influence from refinery authorities hindered effective implementation.

The Haddon post-event phase plays a pivotal role in documenting vital information such as the deceased, survivors, their whereabouts, and those still missing. It also addresses the healthcare needs of victims through cohort studies, ensuring they receive appropriate treatment and medication, as well as access to clean water and food. Additionally, this phase encompasses organizing funerals, registering and cleaning the devastated area, and providing economic support to survivors. Furthermore, safety precautions are implemented for pipeline operation, and legal proceedings are initiated against those responsible for the event.

However, even after the event, the rights of migrant laborers remain largely unaddressed. Many residents, despite enduring years of hardship, are reluctant to leave their homes in the area. Others have witnessed their belongings being looted or consumed by the flames. Contributing factors to the rapid spread of the fire include the presence of combustible materials such as wood and gasoline, coupled with the inadequacy of firefighting equipment to contain the blaze effectively.

Many years have elapsed since the event, yet legal actions continue to unfold, encompassing investigations, convictions of those accountable, provision of financial compensation, delivery of medical aid, monitoring of local contamination, and enhancements in urban planning to prohibit the establishment of vulnerable areas in the future.

Industries must prioritize investment in risk mitigation to amplify the cost of accidents. Public access to safety documentation enables regular checks with regulatory agencies, fostering public engagement in safety protocols and bridging the gap between perceived and actual risks. Promoting safety awareness through comprehensive educational initiatives is paramount for instigating a paradigm shift towards safety consciousness. In Bhopal, management negligence and failure to implement emergency protocols precipitated the gas leak disaster [27].

Post-event analysis of numerous similar accidents has catalyzed the development of International Safety Management Systems (SMS), offering a systematic approach to safety management encompassing organizational structures, accountability, responsibilities, policies, and procedures. International standards provide overarching guidelines and principles for organizations to craft policies, set objectives, and establish processes aimed at enhancing process safety [28]. Through this framework, root accident causes and terminologies are categorized into groups such as unsafe management, unsafe machinery/tools, hazardous environments, personal factors, and unsafe behaviors.

Following the Bhopal disaster, safety professionals convene for meetings, workshops within individual units, and seminars on industrial safety to address statutory requirements and enhance awareness. The Ministry of Labor and Employment recognizes industrial safety excellence through safety awards bestowed upon deserving industries. Furthermore, various countries and industries globally have intensified efforts to promote awareness, education, training, and capacity development for enhanced mitigation and preparedness in industrial safety and disaster management. The tragedy spurred a paradigm shift towards emphasizing reliability, availability, maintainability, and safety standards. Legislative provisions governing industrial site establishment and relocation have been fortified by the government. Regulatory agencies are urged to foster collaboration and partnership with industries, steering away from a punitive approach towards one that fosters self-regulation and mutual development.

Industries should be incentivized to embrace modern management tools like ISO 9000 and ISO 14001, among others. In small and medium-scale sectors, safety hinges on four key factors: thorough process risk assessment, robust engineering to address potential deviations and process demands, and attentiveness to human factors. For chemical and polymer industries, safety measures encompass the development of comprehensive EHS (Environmental Health and Safety) management systems, including certifications such as OSHAS 18000 and ISO 14000. Safety audits conducted during both pre-commissioning and post-commissioning stages of the plant are crucial. Additionally, employee training programs covering topics such as personal protective equipment (PPE), lead poisoning prevention, equipment safety, HAZOP (Hazard and Operability Study), conveyor safety, and work zone monitoring for factors like RSPM (Respirable Suspended Particulate Matter), noise, and heat are indispensable. Establishing safe operating procedures for all equipment within the plant further fortifies prevention efforts against future disasters.

The current state of affairs transcends debate; the frequency and severity of accidents underscore an impending toll on human life, an inevitable consequence of rapid industrialization and liberalization. While various factors contribute to disasters and explosions, corporate cost-cutting practices, insufficient investment in safety infrastructure, and a dearth of safety culture among employees stand out as primary culprits. Drawing from T.S. Eliot's timeless wisdom, the past serves as a potent lens through which to envision present and future industrial safety. Lessons gleaned from past catastrophes underscore the imperative for stringent industrial safety standards, meticulous safety planning, and proactive risk mitigation strategies. The silver lining lies in our grasp of solutions; now, implementation is paramount. By prioritizing emergency planning and robust safety management systems, we can minimize the occurrence of disasters akin to Bhopal in the future. A robust safety management system operates flawlessly up to 99.99%, yet it is the 0.1% of incidents that demand our focused attention [27].

The studies developed after many pipelines incidents helps to develop the concept of blast wall to evaluate its protective performance for adjacent pipelines under explosion conditions. The primary factor influencing damage to the pipeline load impact are the blast center distance and leakage area and the implementation of the blast wall proves highly effective in preventing pipeline failure [29].

Safety is often expressed by compliance, rules in various forms, including standards [30]. The standards are core reference points that guide the design, construction, and management of hazardous infrastructure such as high-pressure gas pipelines.

4. Conclusions

In conclusion, Cubatão was previously a rural city, had its population, environmental, and economic transformation from the 1940s onwards with the construction of Via Anchieta, which connects the São Paulo state capital with Santos harbor complex and saw unplanned enormous population growth in the flow of migrants to the region from the 1950s onwards with the construction of the Presidente Bernardes refinery. The economic growth in the area brought with it a lack of social and environmental infrastructure, meaning that migrants did not have the basic needs to live in the region, leading them to build their homes in risky and unsuitable places for housing. At the time of the accident, a study concluded that in favelas like Vila Socó, despite apparent awareness of the problem, the public authorities did not promote any action to minimize the risk vulnerabilities of the poor labor force and their families.

Using the Haddon Matrix, several actions are organized and if applied could prevent tragedies like in Vila Socó from occurring and even during the event, some measures could minimize the impact, mainly on the number of deaths. Assessing the aftermath of the tragedy, the actions taken to repair the damage or to prevent new cases are negligible and maintain the population risks that a new tragedy could happen in any other place with gasoline pipelines and high social vulnerability. The significance of socio-environmental factors in accidents is undeniable; they exist independently of whether they are acknowledged or not. Post-event analyses of pipeline accidents serve as invaluable global resources, aiding in the development and promotion of standardized methods for compliance and industrial process safety.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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