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The Biggest Industrial Disaster In Brazil: Six Stages Of Development

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Abstract

The disaster in Brumadinho/Brazil, caused by the collapse of Dam I of mining tailings owned by the company Vale S/A (Vale), is considered the biggest industrial disaster in the history of Brazil, as it claimed the lives of hundreds of people, including Vale's own workers, third parties and residents of the community surrounding the organisation, as well as causing an unprecedented environmental impact. According to Turner 's Man-Made Disaster Theory, disasters develop in six stages: 1. notionally starting points; 2. incubation period; 3. precipitating event; 4. onset; 5. rescue and salvage; and 6. full cultural readjustment. The aim of this paper is to study the Brumadinho disaster in the light of the Theory of Man-Made Disasters and to identify whether this disaster followed the six stages proposed by the Man-Made Theory and could thus have been prevented. Data sources used included the official investigation report into the accident, carried out by a government body; the report drawn up by an independent committee hired by Vale; in addition to the reports of the Parliamentary Commissions of Inquiry (PCI) of the Federal Senate, the Federal Chamber of Deputies and the Legislative Assembly of Minas Gerais. The existence of the six stages of disaster development was identified during the study. It can be concluded that the Brumadinho disaster went through the six stages of development proposed by (Turner, 1978), more specifically the incubation period, in which signs that a disaster was about to happen became apparent and consequently measures could have been taken to avoid it.

Keywords: accident, disaster theory, mine

1. Introduction

On January 25, 2019, at 12:28 p.m., the rupture of an iron ore tailings dam identified as BI, belonging to Mina Córrego do Feijão, located in the municipality of Brumadinho, state of Minas Gerais/Brazil, operated by the company Vale S /A (Vale), caused dozens of injuries and the death of hundreds of Vale workers and third parties, and people who were in the area of flooding caused by the tailings. The mud flood caused by the rupture spread across the region downstream of BI, with a total of 665 victims recorded, of which 395 were found alive, and 270 were fatal (CIAEA, 2020). Five years after the disaster, three of the 270 fatal victims are still missing (Agência Brazil, 2024).

In an analysis carried out by the National Center for Environmental Monitoring and Information (Cenima) of the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama), it was found that mining waste devastated 133.27 hectares of native Atlantic Forest vegetation existing in the local area and 70.65 hectares of Permanent Preservation Areas (APP) along watercourses affected by mining tailings (Ibama, 2019). Furthermore, the water along 305 km of the Paraopeba River presented oxygen, turbidity and pH levels completely outside the standards allowed for consumption. The presence of iron oxide, manganese, copper and chromium was detected from the dam's tailings. As a result, the impact of contamination on the fauna, flora and water supply of the 21 municipalities located along the Paraopeba River was very great. The water was completely contaminated, with quality varying from terrible to bad, therefore, impossible to be used for multiple uses (ACM, 2019).

1.1. Disaster definition

Originally, research on disasters had its main focus in the domain of sociology. Currently, it attracts participants from all social and management sciences and is defined as a multidisciplinary and applied field (Kreps, 1984). For (Perry, 2007), anyone has the right to propose a definition of disaster, and the proposed definition depends on the purposes or interests of whoever defines it.

Therefore, over the years several definitions of disaster have been proposed (Britton, 1986; Chourlaton, 2001; Favero et al., 2014; McFarlane and Norris, 2006; Swuste, 2008). In this study, however, Turner's definition of disaster was adopted (Turner, 1978). This author defines a disaster as an event, concentrated in time and space, that threatens a society or part of it, with undesirable consequences, due to the collapse of precautions that until then were culturally accepted as adequate. Furthermore, this breakdown rarely develops instantly. Rather, there is an accumulation, over a period, of various events that are at odds with existing norms and beliefs (Turner, 1978). Furthermore, disasters that occur in complex systems have a high potential to cause harm to people, in addition to economic, environmental and social costs that affect not only organizations, but also society and the victims' families. Thus, following Turner's definition of disaster, the rupture of the BI dam is considered a disaster and will be called from now on in this article the Brumadinho Disaster (BD), in reference to the place where it occurred.

1.2. Disaster theories

All tables should be numbered with Arabic numerals. Every table should have a caption. Headings should be placed above tables, left justified. Only horizontal lines should be used within a table, to distinguish the column headings from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which the authors may find useful.

Several theories about disaster have been developed over time. Among them we can highlight Heinrich's Domino theory (Heinrich, 1959); the theory of "Swiss Cheese" and Normal Accidents proposed by (Reason,1998) and (Perrow,1999), respectively. The Denial Theory was constructed by (Hopkins,1999), while the Conflicting Objectives Theory was constructed by (Rasmussem, 1997). We should also add the theories of High Reliability Organizations by (Weick, 1989) and Risk Blindness by (Vaughan, 1996). However, this study was based on the theory developed by (Turner, 1978).

Known as the theory of Man-made Disasters, it is a model that has central historical and contemporary relevance for disaster researchers (Pidgeon and O'Leary, 2000). From the analysis of 84 accident reports over a 10-year period, the authors observed that disasters in large-scale technological systems are not fortuitous events, nor are they acts of God. Rather, they argue that disasters arise from an interaction between the human and organizational arrangements of sociotechnical systems established to manage complex and poorly structured risk problems (Pidgeon and O'Leary, 2000).

According to (Turner, 1978), so-called "organizational accidents" result from an incubation of errors and latent events that are at odds with what is culturally taken for granted, accompanied by a collective failure of organizational intelligence. Thus, for the authors, there are six stages of disaster development, namely, 1. notionally starting points; 2. incubation period; 3. precipitating event; 4. Onset; 5. rescue and salvage; and 6. full cultural readjustment (Turner, 1978).

The first stage consists of culturally accepted beliefs about the world and its dangers, precautionary norms established in laws, codes of practice, manners and customs. Stage two is defined by (Turner, 1978) as the accumulation of an unnoticed set of events that is at odds with accepted beliefs about dangers and norms for avoiding them. This stage has a variable period of time and can last for years. Stage three is defined as the event that draws attention to itself and transforms the general perceptions of the second stage (incubation period). In other words, it is the exact moment in which the disaster occurred that shows what had not been noticed during the incubation period. Stage four is characterized by the immediate consequences of the breakdown of cultural precautions becoming apparent. This is a relatively simple stage to highlight, as in a disaster, especially a large one, the consequences are quite evident. (Turner, 1978) defines rescue and salvage, stage five, as the immediate post-collapse situation that is recognized in ad hoc adjustments (for a defined effect or purpose) that allow rescue and salvage work to begin. Finally, in stage six an assessment survey is carried out and precautionary beliefs and norms are adjusted to fit the new understanding of the world. In other words, what was understood as culturally acceptable is no longer and needs to be reviewed and modified.

1.3. Aim of this study

The objective of this study is to analyze, in light of the Theory of Man-made Disasters, the Brumadinho Disaster (BD). Previous studies analyzed this disaster, seeking to understand its causes (Botelho and Vilela, 2022; Oliveira and Oliveira, 2019; Piciullo et al., 2022; Rose et al., 2023), however, none of them addressed it from the point of view from the perspective of a Disaster Theory. For example, (Botelho and Vilela, 2022) analyzed BD from the point of view of the lack of State structure for supervision. (Saes et al., 2021) addressed the error in Vale's risk perception. This research uses the lenses of the Theory of Man-made Disasters to look at the BD in a different way from how it has been looked at until now, contributing to understanding how events evolved until culminating in the disaster and what changes occurred post-disaster. A second objective is to identify whether Turner's Theory (Turner, 1978) can still capture the evolution of disasters occurring today and contribute to their prevention.

2. Method

All official documents and BD investigation reports published by government bodies were used as a source of data extraction, such as the Work Accident Analysis Report developed by the Minas Gerais Regional Labor Secretariat (SRT/MG) (Brazil, 2019b); the Accident investigation report developed by the Independent Extraordinary Investigation Advisory Committee (CIAEA, 2020), a commission of experts created by the management of the mining company Vale; as well as the Reports of the Parliamentary Commissions of Inquiry (CPI) of the Federal Senate, the Federal Chamber of Deputies and the Legislative Assembly of Minas Gerais (Brazil, 2019a; 2019c; 2019d). All these documents are publicly available on the internet.

Two expert engineers with experience in disaster investigation were invited to analyze the official documents, who voluntarily accepted the invitation. The authors of this article and the two guests met and discussed together the Disaster Theory developed by (Turner, 1978), to resolve doubts and align their understanding of the Theory between them.

Subsequently, the four research participants (the two authors and the two expert engineers) separately analyzed the official documents to identify the six stages of development of the Brumadinho Disaster, as proposed by Turner. For example, all participants extracted data from documents that highlighted stage 1 alone and so on for the other five stages.

After extracting data from official documents to highlight an internship, the four research participants met, and disagreements were eliminated by consensus. If there was no consensus that a given piece of data did not demonstrate the existence of a stage, the data was eliminated from the stage under analysis.

3. Result

3.1. Stage 1: notionally starting points

Table 1 shows the main evidence for the existence of stage 1, which consists of culturally accepted initial beliefs about the world and its dangers, they are precautionary norms established in laws, codes of practice, manners and customs. As an example of this stage, we can cite one of the excerpts taken from (Brazil, 2019c). It is possible to verify these initial beliefs about the safety and lack of risk of the B1 dam breaking:

"*A Vale repetiu aqui, depoimento após depoimento, que todas as medidas de segurança relativas à barragem B1 da Mina Córrego do Feijão, em Brumadinho, estavam de acordo com as normas e protocolos relativos a esse tipo de barragem*".

The precautionary standards established in laws, codes of practice, manners and customs, which also characterize the stage under discussion, were identified in the Vale disaster, as shown in the excerpt taken from (Brasil, 2019c): "*There was none, not even in my opinion. part, nor from my predecessors, any type of information about risk in relation to the positioning of that office. Why wasn't there? Because there were stability reports that said that the dam had no risk or that the risk was perfectly acceptable, within normal conditions*".

Table 1. Stage 1 - Notionally starting points.

Stage 1 - Evidence
"Whenever there was a discrepant oscillation record in the history, the guidance was to ignore the reading precisely because it did not correspond to the history. " (Brazil, 2019b)
"He reported that approximately three hours after forwarding the email, only Mr. Artur Ribeiro responded commenting that other instruments in the dam were within normal limits. Therefore, Mr. Tércio understood that the variations he reported were perhaps within normal limits, as he does not have the technical capacity to interpret the signals and is only responsible for reporting the variations detected by the equipment. " (Brazil, 2019b)
"Despite the recommendations made between 2010 and 2013 by the company Pimenta de Ávila, to carry out a liquefaction study, this study was only carried out in 2014, again by Geoconsultoria. This new study was carried out by reinterpreting the 2005 research campaign, and not by carrying out new tests. As a result, the susceptibility of the B1 tailings to liquefaction was highlighted, with the exception that the probability of a trigger occurring would be remote. Furthermore, in that study safety factors were obtained for the drained condition ranging between 1.6 and 2.1 and for the undrained condition ranging between 1.5 and 1.8." (CIAEA, 2020)
"However, evidence indicates that the internal dam audit report had already been shared with Peter Poppinga since at least 31/05/2016. Furthermore, Peter Poppinga sent, on 06/20/2016, an email to Murilo Ferreira (then CEO of Vale) with the aforementioned report attached, informing him that nothing serious had been identified in the internal dam audit report, saying that they would even have been praised by the Director of Internal Audit". (CIAEA, 2020)
"Vale repeated here, statement after statement, that all safety measures relating to the B1 dam at Mina Córrego do Feijão, in Brumadinho, were in accordance with the standards and protocols relating to this type of dam". (Brazil, 2019c)
"Senator Carlos Viana then reminded the deponent that he had stated, nine months before the tragedy, that the dams were impeccable and in a state of impressive quality." (Brazil, 2019c)
"There was no individualized information about any dam. And the information showed that all of them were in full stability and had a stability report." (Brazil, 2019c)
"There was, neither from me nor from my predecessors, any type of information about risk regarding the positioning of that office. Why wasn't there? Because there were stability reports that said that the dam had no risk or that the risk was perfectly acceptable, within normal conditions." (Brazil, 2019c)
"... until the moment of rupture, we always worked believing in the safety of the structure, based on the trust of all the information we had related to declarations, studies, analyses, inspections, instrumentation. So, until the moment of rupture, we always worked believing in the stability of the structure (Renzo Albieri - Manager)". (Brazil, 2019c)
"This revelation by Marcelo dos Santos was relevant because it was yet another indication that the situation of the dam in terms of the presence of water inside was much worse than Vale S.A. wanted to accept." (Brazil, 2019d)

3.2. Stage 2: incubation period

Table 2 shows several quotes extracted from the official reports used as reference that corroborate the existence of stage 2 in the Brumadinho Disaster. The incubation period is defined by (Turner, 1978) as the accumulation of an unnoticed set of events that is at odds with accepted beliefs about hazards and norms for avoiding them.

It was possible to identify in the analyzed documents several examples of discrepant events that accumulated during the incubation period. For example, the *"...precariousness of the structures* ***of the B1 drainage system, such as obstructed or eroded surface channels for the flow of water from the dam, and problems in the water pumping system from the B1 reservoir, at least between December 2018 and January 2019***" (CIAEA, 2020).

Also, according to the (CIAEA, 2020), the sum of the events highlighted above culminated in the collapse of dam 1 at the Córrego do Feijão Mine, as can be seen in the following extract:

"***It should be noted that, at least since 1995, there were records of internal drainage problems that resulted in high water levels in the dam. Evidence was also found of malfunctioning of the existing internal drainage system in the elevations. Of the 56 (fifty-six) flow meters that were installed in B1, only 12 (twelve) showed flow in 2018. Furthermore, the way in which the waste was disposed of, the contributions from streams and springs in the area contributed to the saturation condition. reservoir area and the infiltration of surface and underground waters***".

The presence of stage 2 can also be verified in (Brazil, 2019a), this report records that *"...the crucial characteristic of Mina Córrego do Feijão* ***– which stands out to anyone – is that the cafeteria and the administrative area, among other structures were located just over 1 km downstream of the B1 dam. However, Vale simply never bothered to relocate such structures to a safer location, even with repeated indications that the health of the B1 dam was not going well***".

Table 2. Stage 2 – Incubation period.

Stage 2 - Evidence
"As evidenced in several documents presented by the company Vale S.A., downstream of the B I there were structures such as a railway freight terminal and ore treatment facilities, and, approximately one kilometer away, a center for administrative activities (offices, cafeteria, changing rooms, warehouse etc). " (Brazil, 2019b)
"Vale's Managers and Regional Directors were aware of the hydraulic fracture and the interruption of services. However, no other solution was effectively implemented by the company until January 2019 to lower the water table in B I, which contributed to keeping the water level high 'water inside it. " (Brazil, 2019b)
"Therefore, the various reports produced by auditing companies since 2015 indicate that the surface drainage of B I was very poorly maintained by the company, with cracks, silting and water pooling. The problems were recurring year after year. Any water that pools in a channel or channel, presenting this damage to the concrete, penetrates the dam. When the aforementioned structures are silted up, water can overflow and also penetrate the dam's dikes. " (Brazil, 2019b)
"Also in relation to the overflow system, the precarious conservation of the structures can be noted. The bottom gallery was very silted and had points of infiltration in the ceiling. The outlet slab of the overflow system was silted and eroded downstream. Finally, the The dissipation basin from B I to B VI was covered by vegetation. " (Brazil, 2019b)
"As evidenced in several documents presented by the company Vale S.A., downstream of the B I there were structures such as a railway freight terminal and ore treatment facilities, and, approximately one kilometer away, a center for administrative activities (offices, cafeteria, changing rooms, warehouse etc). " (Brazil, 2019b)
"It is also noteworthy that, since its installation and especially from November 2018, the radar indicated significant movements in the dam that were not properly considered. We see, therefore, that there was no effective monitoring of water percolation, nor of the movement of the water table or the movement of the mass." (Brazil, 2019b)
"It should be noted that, at least since 1995, there were records of internal drainage problems that resulted in high water levels in the dam. Evidence was also found of malfunctioning of the existing internal drainage system in the elevations. Of the 56 (fifty-six) flow meters that were installed in B1, only 12 (twelve) showed flow in 2018. Furthermore, the way in which the waste was disposed of, the contributions from streams and springs in the area contributed to the saturation condition. reservoir area and the infiltration of surface and groundwater." (CIAEA,2020)
"In addition, evidence indicates precariousness of the structures of the B1 drainage system, such as obstructed or eroded surface channels for the flow of water from the dam, and problems in the water pumping system from the B1 reservoir, at least between December 2018 and January 2019." (CIAEA,2020)
"When asked who would have determined the buildings that were destroyed by the dam collapse, as well as who would have determined that they remained there, once again the deponent failed to point out the culprits, saying that "There was no individualized information about any dam and the information showed that all of them were in full stable condition and had a stability report". (Brazil, 2019c)
"A series of oversights and negligence, which normally remain hidden in reports that are incomprehensible to a layman, came to light after the tragedy. The chain of command and the flow of information, even though there was an attempt to present them as failures, fulfilled their role: Vale's management and board knew the risks and decided to assume them." (Brazil, 2019c)

3.3. Stage 3: precipitating event

Table 3 shows excerpts taken from the evaluated documents that evidence the existence of the precipitating event. This stage is defined by (Turner,1978) as the event that draws attention to itself and transforms the general perceptions of the second stage (incubation period). In other words, it is the exact moment in which the disaster occurred that shows what had not been noticed during the incubation period. To exemplify the existence of this stage in the disaster under study, we highlight the excerpt taken from (CIAEA, 2020):

"*Based on the analysis of the videos of the rupture, it can be seen that the mud originating from the B1 tailings flowed at high speed as a viscous liquid along the valley downstream of the Ferro-Carvão stream, which confirms the hypothesis of liquefaction*".

The event is also seen rushing in and drawing attention to itself, like the very definition of stage 3, in the excerpt transcribed below, taken from (Brazil, 2019a):

"*On 1/25/2019, at 12:28'30", completely oblivious to the danger that surrounded them, hundreds of employees and contractors were having lunch in the cafeteria, working in the administrative area, visiting the changing rooms or resting nearby, when a noise was heard deafening*".

The perceptions about the safety of the dam and also about how Vale dealt with the safety of its employees, collaborators and the neighboring community, accumulated throughout stage 2, were modified with the precipitation of the event (stage 3), as we can see in the following excerpt taken from (Brazil, 2019c):

"*The dam broke on January 25, 2019. What caused the break was not an unpredictable event (e.g. an earthquake, a hurricane). Quite the opposite, TÜV SÜD's supposedly technical criteria were wrong, given that the dam broke*".

Table 3. Stage 3 – Precipitating event.

Stage 3 - Evidence
"Based on the analysis of the videos of the rupture, it can be seen that the mud originating from the B1 tailings flowed at high speed as a viscous liquid along the valley downstream of the Ferro-Carvão stream, which confirms the hypothesis of liquefaction." (CIAEA, 2020)
"The Vale tragedy is an accumulation of tragedies. The inestimable human loss; the countless dead animals; the environment destroyed for years, perhaps decades; the dreams and assets of a lifetime buried by carelessness, negligence, greed, usury, irresponsibility, indifference, and carelessness of a company that was once a model." (Brazil, 2019c)
"The Brumadinho tragedy was the biggest work accident ever recorded in Brazil, with more than 120 workers killed, including employees of the company Vale S/A, owner of the mine, and employees of outsourced companies that worked at the site." (Brazil, 2019c)
"On January 25, 2019, Minas went through one of the saddest chapters in its history. The collapse of the tailings dam at the Córrego do Feijão Mine, in Brumadinho, was the biggest crime tragedy ever experienced in our state." (Brazil, 2019d)
"On 1/25/2019, at 12:28'30", completely oblivious to the danger that surrounded them, hundreds of employees and contractors were having lunch in the cafeteria, working in the administrative area, visiting the changing rooms or resting nearby, when a noise was heard deafening." (Brazil, 2019a)

3.4. Stage 4: onset

There are several extracts from the documents analyzed that demonstrate the dimension of the consequences of the disaster under study (Table 4), confirming the existence of the fourth stage of development of disasters proposed by (Turner, 1978). This stage is characterized by the immediate consequences of the collapse of cultural precautions becoming apparent. This is a relatively simple stage to highlight, as in a disaster, especially a large one like Brumadinho, the consequences are quite evident.

As an example, we extract from (Brasil, 2019b) the following excerpt in which the immediate and more general consequences of the disaster are visible:

"*The rupture resulted in 249 confirmed deaths and 21 missing people (data from September 5). On its way, the waste destroyed part of the Córrego do Feijão district (killing six residents), an inn (killing nine of its workers, including the owners, and five guests), a railway viaduct and several rural properties*".

In (Brazil, 2019d) we find the damage caused to the environment by the disruption of BI:

"*Thousands of animals, domestic and wild, were victimized. Some, found trapped in the mud, still alive, were very injured or in a difficult rescue situation. In the first days of February, a team from Fundação SOS Mata Atlântica that analyzed the waters of the Paraopeba River between the broken dam and the municipality of Pará de Minas, 90 kilometers from Brumadinho, attested to the death of the river up to that point*".

(Brasil, 2019b) highlighted, among other consequences, that the Brumadinho disaster was the biggest work accident in Brazil in addition to a worldwide disaster. According to this report, the disaster was the biggest work accident in Brazil, as in addition to dozens of injured workers, it caused the death of hundreds of Vale's own employees and those of its subcontractors.

Table 4. Stage 4 – Onset.

Stage 4 - Evidence
"On January 25, 2019, at 12:28 p.m., the B I iron ore tailings containment dam at the Córrego do Feijão Mine, owned by the company Vale S.A., located in the municipality of Brumadinho, sixty kilometers from Belo Horizonte, M.G. The rupture resulted in the biggest work accident in Brazil as it caused, in addition to dozens of injuries, the death of hundreds of workers from the company and its subcontractors, as well as the external population who were in the area of the flood. caused by the tailings, not to mention the environmental and social impacts, which together made it a disaster on a global scale." (Brazil, 2019b)
"The rupture formed waves of waste that advanced on workers, vehicles, equipment, ore treatment and loading facilities and various work sites. It is estimated that the speed of the mud reached around 80 kilometers per hour." (Brazil, 2019b)
"The rupture resulted in 249 confirmed deaths and 21 missing people (data from September 5). On its way, the waste destroyed part of the Córrego do Feijão district (killing six residents), an inn (killing nine of its workers, including the owners, and five guests), a railway viaduct and several rural properties." (Brasil, 2019b)
"The tailings plume reached the Paraopeba River and impacted the water supply for indigenous and quilombola communities and also for several cities, including Brumadinho, Pará de Minas and Belo Horizonte. Several rural properties were also affected on the banks of the Córrego do Feijão and the Paraopeba River." (Brazil, 2019b)

3.5. Stage 5: rescue and salvage

Rescue as the immediate post-collapse situation, which is recognized in ad hoc adjustments (for a defined effect or purpose) that allow rescue and salvage work to begin (Turner, 1978).

Below we highlight some examples of these measures (Table 5). As in the report by (Brasil, 2019a) which highlights that "*The rescue of victims and the search for survivors began immediately*".

According to (Brasil, 2019d), ambulances were also mobilized and measures were taken to ensure that beds were available for the victims. Furthermore, a support system was created for victims and their families, as seen in the excerpts below:

"*Dozens of ambulances from neighboring municipalities, the Brazilian Red Cross and private health services traveled to Brumadinho. A support system was created for victims and their families, who were waiting for their loved ones to be located*".

"*The network of the Hospital Foundation of the State of Minas Gerais (Fhemig) was placed on stand by, with immediate transfer of patients from the Hospital de Pronto Socorro João XXIII, in Belo Horizonte, a reference in trauma, to make places available for possible survivors*".

However, it was also possible to verify failures on the part of Vale regarding rescue and rescue, as we can see in the following example that talks about Vale's Emergency Action Plan for Mining Dams (PAEBM):

In item 13.2, Material Resources, it is stated that "*the materials to be used in responding to emergencies will consist of fire trucks, ambulances, fire extinguishers and other equipment to be defined according to the scenario*" and that "*each operational unit must maintain updated inventories of urgent and emergency care equipment".* However, in this list of equipment to be used in case of emergency at the Mine, its location was not even presented".

Table 5. Stage 5 – Rescue and salvage.

Stage 5 - Evidence
"In item 13.1, Human Resources, it is said that the emergency response team will be composed of at least firefighters, a nursing technician, a doctor and a volunteer brigade member (the latter is not mandatory), it turns out that the document does not describe the number of each of these professionals who will make up the team nor the names of these professionals, nor are their operating procedures in case of emergency described." (Brazil, 2019b)
"In item 13.2, Material Resources, it is stated that the "materials to be used in emergency response will consist of fire trucks, ambulances, fire extinguishers and other equipment to be defined according to the scenario" and that "each operational unit must keep inventories of urgent and emergency care equipment updated." However, neither this list of equipment to be used in case of emergency at the Mine, nor its location, was presented." (Brazil, 2019b)
"Another point that should be included in the Mine's Emergency Plan, and which was not demonstrated by Vale, are the operating procedures of the emergency brigades to act in each of the emergency situations identified at the Mine." (Brazil, 2019b)
"Despite the extraordinary efforts of the Fire Department of the State of Minas Gerais, to date, ten of these jewels have not yet been found." (Brazil, 2019d)

3.6. Stage 6: full cultural readjustment

Table 6 shows evidence of the total cultural readjustment proposed by (Turner, 1978). At this stage, assessment research is carried out and precautionary beliefs and norms are adjusted to fit the new understanding of the world. In other words, what was understood as culturally acceptable is no longer and needs to be reviewed and modified.

We can highlight as an example of the existence of this stage in the Brumadinho Disaster the veto on the construction, maintenance and operation of facilities intended for administrative, living, health and recreation activities located in areas downstream of a dam subject to flooding in the event of rupture, considered as situations of serious and imminent risk and subject to interdiction (Brazil, 2019b).

Still according to (Brasil, 2019b), other measures were taken after the collapse of the Brumadinho dam, characterizing stage 6 of disaster development proposed by (Turner, 1978), as exemplified by the following extract:

"*The use of the method of construction or raising of mining dams called "upstream" is now prohibited throughout the national territory. The current upstream dams must be de-characterized within certain deadlines established by the ANM*".

The total cultural readjustment can also be evidenced in this excerpt: "*The impact of the Brumadinho tragedy, shortly after the Mariana accident, led inspection bodies and the company itself to change procedures to ensure greater safety for the population living in the surrounding dam's area*" (Brazil, 2019c).

Within the scope of the Legislative Branch, the Legislative Assembly of the state of Minas Gerais approved, less than a month after the catastrophe, Law 23,291 of 2019, which prohibits the construction of upstream raising dams and determines the adoption of safer technologies (Brazil, 2019d).

Table 6. Stage 6 – Full cultural readjustment.

Stage 6 - Evidence
"The use of the method of construction or heightening of mining dams called "upstream" is now prohibited throughout the national territory. Current upstream dams must be de-characterized within certain deadlines established by the ANM." (Brazil, 2019b)
"The construction, maintenance and operation of facilities intended for administrative, living, health and recreation activities located in areas downstream of a dam subject to flooding in the event of a rupture is prohibited, considering such situations of serious and imminent risk and subject to ban. The current ones need to be removed by 10/12/2019." (Brazil, 2019b)
"The safety factor for stability analyzes and susceptibility studies to liquefaction in the undrained condition must now be calculated based on ABNT NBR 13.028/2017, international standards and good engineering practices, being prohibited for stability analyzes and studies of susceptibility to liquefaction in the undrained condition, values below 1.3 for peak resistance. In Ordinance 70,389/2017, this factor was at the discretion of the auditing company. Furthermore, the resistance parameters must be defined based on the analysis and interpretation of updated and representative geotechnical test results, as defined by the designer, carried out on the material constituting the dam and reservoir itself." (Brazil, 2019b)
"For cases in which the safety factor, in drained or undrained conditions, is momentarily below the minimum values established by standard ABNT NBR 13.028/2017 and as described in the caput, the mining dam is immediately closed and the entrepreneur is obliged to suspend the operational contribution to the dam and to notify the ANM through the SIGBM, as well as to implement control and mitigation actions to guarantee the safety of the structure and assess the need to evacuate the downstream area, until the safety factor returns to values minimum." (Brazil, 2019b)
"Dams with high Associated Damage Potential (DPA) must have instrumentation monitoring (piezometers, water level meter, inclinometer etc.) in real time and full time until 12/15/2020. Previously, in 70.389/2017, it was mandatory only for dams with high DPA, but that also affect people and have a construction method upstream. Now any dam with high DPA needs to have full-time, automated monitoring of its instruments. This has increased the number of dams with this type of monitoring." (Brazil, 2019b).
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4. Discussion

4.1. The evolution of disaster

The stages of development of a disaster proposed in Turner 's Theory (Turner,1978) were present in the Brumadinho Disaster, as evidenced in Section 3. Not only Vale employees, but also the population neighboring the company, believed in safety standards of the company and the solidity of the BI tailings dam. This excess of confidence and security means that certain situations and/or events are not questioned or seen as normal by the individuals involved. This scenario shows how the institutional environment influences the way problems are dealt with.

But why were the signals sent ignored by Vale? This question does not have a direct answer. But according to (Hopkins, 1999) one answer lies in the “culture of denial”, an elaborate set of beliefs that leads one to believe that “disaster will not happen here”. This culture existed in Vale before the disaster, as evidenced in Section 3.

In this context, stage 2 is being outlined. The incubation period for a disaster can range from days to years. In the case of the Brumadinho Disaster it lasted years, as evidence indicates that the incubation began with the acquisition of the Dam by Vale in 2001, with the lack of data on the construction of the BI and with the continuation of its elevations without information that would guarantee the safety of that dam (Brazil, 2019a; 2019d; Oliveira and Oliveira, 2019).

The closure of stage 2 occurs with the immediate beginning of stage 3, that is, the precipitating event, which brings with it a paradigm shift, as it modifies everything that until then was perceived and understood as correct, as safe throughout the period. of incubation. Those norms and beliefs that were understood and accepted as adequate and sufficient are destroyed as the third stage progresses.

In stage four, the consequences of the previous stages become apparent and, in the Brumadinho disaster, they were devastating, as highlighted by (Feliciano and Pasqualeto, 2019): There was damage to the entire environment, whether in its natural aspect (since the vegetation, fauna and soil in the locality were degraded and the mud reached the Paraopeba River), whether in its artificial aspect (with the destruction of houses, inns and public places) and, especially, in its work aspect (with the death of several dozen Vale workers who were in the mining company building).

Stage five was demonstrated by the actions carried out during the rescue and salvage period. It required the intervention of government bodies such as military and civil police, fire brigade, Civil Defense etc., also

involving help from outside the country. It was the largest rescue operation in history according to a report by (Arbex, 2022).

The total cultural readjustment, stage 6, brought with it the drafting of draft laws, prohibiting the construction of dams using the upstream method throughout the national territory, in addition to the decommissioning of existing dams raised using this method (Brazil, 2019b). Furthermore, the National Mining Agency (ANM) imposed an obligation on companies responsible for mining dams, regardless of their construction method, to update their emergency plans and assess the need to remove administrative facilities that are in areas of influence. of dams (Brazil, 2019c).

4.2. Use of the theory of Man-Made Disaster

(Le Coze, 2013) questions whether "old" theories are up to date to capture current disasters. In the specific case of BD, the Theory of Man-Caused Disasters managed to capture its evolution, the pre-disaster company culture, the incubation period, and the post-disaster period. Because the Theory of Man-made Disasters is about how technical, social, institutional, and administrative arrangements can produce disasters. Therefore, in our opinion, "old" theories do not have an expiration date but need to be used more by organizations to capture signs and prevent disasters. And the signals emitted need to be captured and attended to by organizations.

4.3. Limitations and future studies

The main limitation of this study was the use of official documents and BD investigation reports published by government agencies as a data source. There is a difference between how investigators reconstructed the causes of the disaster and how disasters are caused. In other words, "What caused the disaster?" It's not the same question as "What did the investigators say about the disaster?" Understanding this difference is a starting point for any retrospective analysis of disasters. Furthermore, as these are investigation reports from government agencies, there may be political bias in the investigation that may affect the data in the reports. For example, researchers may not have autonomy.

A future study would be to use other disaster theories to analyze BD, such as Conflicting Objectives (Rasmusssem, 1997), and compare whether the findings are similar and/or whether they complement each other.

5. Conclusion

This article aimed to study the Brumadinho Disaster from a different approach to those carried out in previous studies. The Theory of Man-made Disasters proposed by (Turner, 1978) was used as a lens to take a new look at the disaster. Through these lenses, it was possible to see its evolution and how the signs that a disaster was beginning to take shape were ignored, that is, the disaster was not the result of chance and could have been prevented. Thus, the Theory of Man-made Disasters proposed by (Turner, 1978) proved to be current and capable of capturing the signs that there are flaws in the security system and corrective measures need to be taken to prevent disasters.

The results of this study present a different form of what has been presented about BD to date. The results can provide important information for disaster prevention, since the signals emitted during the evolution of the disaster enable actions to avoid them, such as specific interventions and an objective assessment by the organization of its security system. Finally, the results of this study allow comparison with other studies on BD, which can contribute to improving safety interventions.

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