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Brumadinho: between prudence and probability, tragedy

Brumadinho: entre a prudência e a probabilidade, a tragédia

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ABSTRACT | Will it be possible, sometime in the future, to exactly explain what happened in the dam failure in Brumadinho? Although word "exactness" is often used within the world of engineering, it is often known to be an euphemism. The engineering art consists in projecting, building, implementing and managing different types of systems which might have both positive and negative consequences for workers, society and the environment. Some event or series of events culminated in the dam failure. Is tailings dam engineering aware of and able to control all possible events which together might cause a failure? There are two possible paths: one involves absolute knowledge — engineering has absolute knowledge of everything and is able to design projects in a way to avoid any harmful event. According to the other, while engineering does not have absolute knowledge of all the phenomena, its traditional know-how (empirical knowledge) and wide margins of safety make the odds of dam failure come close to zero. No one projects a dam just to fail. But dams are projected without absolute control of all possible events. When the entire situation is known, all that should be done to avoid failures is 100% known — and the price fixed. However, this never happens, the probability of the occurence of events are never completely known, they are not deterministic and uncertainty is always a fact.

Keywords | accidents, occupational; probability; stress, psychological; ergonomics; engineering.

RESUMO | Será possível, em algum momento no futuro, explicar com exatidão o que aconteceu no caso do rompimento da barragem de Brumadinho? Apesar de, muitas vezes, se utilizar a palavra exatidão no mundo da engenharia, sabe-se que, em muitos casos, trata-se de um eufemismo. A arte da engenharia consiste em projetar, construir, implementar e gerenciar diferentes tipos de sistemas que podem trazer consequências tanto positivas como negativas para os trabalhadores, para a sociedade, para o meio ambiente. Aconteceu um evento ou uma sequência de eventos que levou ao rompimento. A engenharia de barragens de rejeitos conhece e é capaz de controlar todos os eventos passiveis de acontecer e que, articulados, podem levar ao rompimento? Há dois caminhos: primeiro, o conhecimento total; a engenharia conheceria tudo e seria capaz de projetar de modo a evitar, com certeza, todos os eventos nocivos. Segundo: a engenharia não conhece a totalidade dos fenômenos, mas sabe que, fazendo como sempre se fez (com o conhecimento empírico) e com margens de segurança grandes, a probabilidade de rompimento se aproxima de zero. Ninguém projeta uma barragem para que ela se rompa. Mas se projeta uma barragem sem dominar na totalidade os eventos que podem ocorrer. Quando se conhece a totalidade da situação, o que deve ser feito para evitar o rompimento é 100% conhecido — e precificado. Entretanto, isso nunca acontece, a probabilidade de ocorrência de eventos nunca é completamente conhecida, eles não são determinísticos e a incerteza é um fato.

Palavras-chave | acidentes de trabalho; probabilidade; estresse psicológico; ergonomia; engenharia.

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INTRODUCTION

The aim of this essay is to raise questions. Posing questions might help us find paths to understand past events, but more significantly, paths to work with a more promising perspective in the future.

Would highly mathematical models including all the variables which influence mine tailings storage be able to reflect the ongoing process and indicate the exact moment a failure might occur? On the one hand, no such model is available[1], and on the other, with an empirical approach based on "good project and management practices", i.e. according to past success, the final outcome is the same: dam stability, depending on the margins of safety considered in the project and the maintenance procedures[2]. What are the odds of a disaster[3]? They might or not be known: tailings might undergo liquefaction close to the dam, thus reducing its containment capacity. And this might happen at any unpredictable time.

What happened in Brumadinho? One (or more) project errors? Maintenance mistakes? The fact is that knowledge in engineering is not absolute, and even if it were, it would not allow controlling the unfolding of events. To avoid threats to the stability of dams, empiricism and margins of safety are used as much today as in the distant past. Whatever goes on inside does not threaten dams when the margins of safety for pressure, thickness, height, etc. agree with those characterized as good practice.

Does this suffice? Not yet, because good practice and margins depend on a higher order of limitations, namely, the available budget. In the case of tailings dams, CapEx and OpEx do not result in any return. Therefore, they must be reduced as much as possible without putting the stability of dam in danger in a foreseeable future. Roman, Egyptian, Incan, Aztec, Mayan and Chinese engineering was empirical, based on good practices and margins of safety appropriate for their products to survive to this day. What is to be learned from this?

When dams are built without any precise planning and management model, but based on past practice and margins subjected to austere budgets, without any scientific and technical rationale, the odds of failure increase together with the degree of budget austerity. Shortly, it is impossible to know absolutely everything, including that which was never anticipated but that might indeed happen. This is the basis of the latest scientific approaches, such as complexity theory[4-6].

The assumptions grounding the discussion on what will be done and how and the cost-benefit ratio of engineering projects should be brought to light. One necessary question is that on the definition of the beginning and end of projects. How a project should be considered, from the perspective of time, risks and their consequences[7]? In any case, the assumptions underlying the rationale behind the conception, design, implementation and operation of any undertaking should be called into question[8].

In the present essay we propose a reflection and discussion on what sustains practices and the need to take aspects which are frequently left aside into account. For this, we selected the recent disaster at Brumadinho as case study, which causes can be traced back to decisions made by actors endowed with such power. In our analysis we also borrowed notions from various fields to achieve a more accurate understanding of the events, in particular those related to engineering production projects, more specifically work projects, such as activity-centered ergonomics[9,10] and the psychodynamics of work[11]. In addition, we also had resource to broader scoped views on engineering and other fields, as e.g. complexity theory[5,12].

LINKED QUESTIONS

The first question is whether incidents of this magnitude are or not crimes. This fits our endeavor, even though we are not experts in the law. To be sure, we do not intend to answer this question, since several aspects require more thorough analysis, from the process for decision making to the attribution of responsibility to decision makers and how the project risks were considered.

The dam failure in Brumadinho is one of the worst work accidents ever in the history of Brazil, if not the worst. It is one of the worst incidents in terms of environment, of enterprises, it signaled the end of life to many and brought death to countless animals and plants.

In this type of accidents, especially work accidents, decision makers are always responsible. They can and

must be blamed for the choices they made in regard to organizational management and the determination of the production means, work process and tasks. Many decisions are made based on data resulting from interventions by different company actors, service providers and individuals participating in government overseeing and guidance.

The issues related to responsibility attribution, deciding on whether a crime — by deceit or neglect — was or not committed, establishing possible compensations and condemning individuals should be decided by the corresponding experts. However, some choices were made before the disaster occurred and should be duly analyzed, keeping in mind that to omit is also a choice.

SAFETY ASSUMPTIONS

The more traditional views on industrialization are based on attempts to find causal relationships likely to account for events[13]. Blaming — i.e. assigning the full responsibility for a wrong to someone — is still a ubiquitous practice. In such case, analysis is based on the rules and procedures which should guide the actions of social actors at organizations to identify eventual deviations which might be considered as the alleged cause. Therefore, the underlying idea is that systems are safe or include mechanisms for risk control which considerably reduce the odds of accidents. Again, the essential assumption is that compliance with the prescribed rules and procedures assures the safety of any operation.

Most work accidents in Brazil are analyzed from the victim blaming perspective. Blame is usually attributed to actors directly involved in operations, with little decision-making power and who often died and can no longer defend themselves. The infamous unsafe act is considered to be the main cause of work accidents in our country. However, one should call into question whether it is systematically possible to comply with the prescribed procedures to ensure the continuity of operations, whether the many variables inherent to production systems[14,15] — especially the highly entropic ones — are under control, and whether the equipment is in excellent working conditions. Thorough analysis of production — even in the absence of any accident — shows that only seldom all the due maintenance conditions, especially those considered in preventive and predictive approaches, are met. Yet operations are not discontinued under such suboptimal conditions as a function of the assumed margins of safety. To assert that accidents are most often due to human error — i.e. to errors by those directly involved in operations — is utterly irresponsible to say the least, when one considers the actual conditions of production.

When decision making at organizations — here, the company charged of the mining operation at Brumadinho — enters analysis, the probability of finding someone responsible is rather high. Such are individuals at different hierarchical levels of the company and at overseeing and licensing agencies. What factors do the individuals responsible for decision making in regard to the safety of an operation — thus enabling it to evolve in a certain way, production to continue under unsafe conditions, cafeterias, administrative buildings and inns, among others, be built downstream and in the path of eventual floods — take into account?

BETWEEN PROBABIBILITY AND PRUDENCE

The crux of the matter is to establish what type of approach to safety will help us understand incidents for the purpose of prevention. The assumption that unsafe acts are the main causes of minor work accidents is based on the idea that there is some proper and safe method and consequently, that it suffices to comply with the due procedures. However, this assumption is not very useful to change production scenarios, because it derives from the notion that safety is inherent to the full system, that problems arise when workers do not implement sufficiently reliable measures and that accidents are due to deviations from the expected behavior.

In the case of both minor accidents — which unfortunately are a part of the everyday work routine of many — and those rated disasters, the organization's choices should be called into question. There always are those who decided for some technology, those who chose some form of labor division[16] and those who opted to maintain operations even when there were signs indicative of problems. Choice involves responsibility and, as was stated above,

as a rule, some approach likely to ensure low odds of accidents is selected. Why?

When dealing with probabilities, we are within the world of that which is known. Calculations are made based on data from the past, from that which already happened, from that for which there is information to enable calculation. Even when deeper approaches are used, it is still a matter of that which is known, of that which might be extrapolated to increase safety, and not of uncertainties, of phenomena emerging from an unknown coupling of variables.

In regard to such calculations of probabilities, one question in order concerns that which was included in the equation. What type of events are considered in probabilistic analysis? If only previous accidents, past flaws and that which was detected, one should ask about that which was not considered, such as maintenance issues, small incidents and the famous "jury rigging" to keep operations going.

Even when there are flaws in this type of approach, it does not lose its relevance. The issue at point is to bear in mind that there are no certainties, no warranties, and that even involving some degree of extrapolation, prudence should be the main rule in the management of production processes, particularly the highly entropic ones.

Another question concerns the quality of probabilistic calculations. Refined calculations are hardly performed within the corporate environment for the purpose of decision making. The calculations proclaimed to be the basis of in-depth studies and used in research are too complicated and their actual application demands high levels of knowledge. Then, statistical data should be collected and treated by means of some methods[17], which are exclusively used within the academic milieu. There are many interests involved in the actual conditions of production, and the reliability and interpretation of data should be taken into consideration. It would come as little surprise to find situations in which, for some reason or other[18], small signs of problems were not considered as sufficiently significant as to implement some corrective action.

The assumptions behind a prudence-based approach would be much different. More in particular, such approach would pay attention to aspects left aside for being held to be trivial or posing negligible risk. Certainties are less when one acts prudently, because the flaws of the data entered in calculations become evident, the existence of significant levels of degradation in operations is admitted, as well as the fact that operational procedures are not able to account for everything that actually happens. Shortly, systems are defined as dynamic, and for many reasons they exhibit significant degrees of unpredictability[19].

A POSTERIORI ANALYSIS

Upon analyzing past accidents, the idea is to arrive, on the basis of documents and narratives, to some factual truth. However, this goal is impossible. The actually possible, and relevant, outcome consists in several different views, which might contribute to the discussion of causes. That which is always obtained is distorted. In the case of the directly involved actors, the outcome is a narrative modulated by trauma, which if did not cause actual injury, had potential to cause it. Each and every traumatic situation has impact on the memory of subjects. One may not imagine that narratives faithfully represent facts exactly as they occurred. In the case of the actors with some responsibility in the management of events[20], there is a risk to focus the narrative on what it should be done, to assume some deviation in someone's behavior, this being the main cause of the accident.

In the case of deaths, obviously, those who underwent the experience cannot bear witness, and those who did not or survived will have much difficulty to provide a narrative according to the chronological order of events. When do the various events which led to an accident begin and end? Who are the actors involved in each step? What information did they have so as to understand what was happening in a given situation? Too much information, even when valuable, does not effectively represent what has happened, but provides mere approximations. This fact accounts for the relevance of the sciences of work, such as ergonomics and the psychodynamics of work, as concerns the narratives of the involved actors. Knowledge of actual production is necessary for prudent decision-making. Therefore, before an accident occurs, organizations should develop strategies to enhance and consider the opinion of the involved workers in decision

making. Constructing narratives based on the experience of different actors, likely to point to the problems they face, the progression of malfunction and the attempts to solve troubles in production, is essential for this type of approach. Such narratives afford more accurate knowledge of actual production for the purpose of implementing more prudent strategies to cope with risks, centered on production transformation processes. The demonstration that it is not possible to operate according to standard procedures — because they are based on the nominal production mode rather than on actual operations — is a major contribution of activity-centered ergonomics[21]. Production would hardly occur were the behavior of workers to be exclusively grounded on previously established procedures. Such is the case of the well-known standard operations used by protest movements.

COSTS AND FINANCE

As a function of neoliberal and "managerialist" ideas, considerable changes took place in private, and also public organizations along the past decades. These changes had significant impact on the return on investment policies, which are now more focused on quick return, often without any other interest besides the financial ones.

"Financialization"[22] makes production as such lose importance, and managers become generic: they become able to manage any type of production provided they keep their focus on the rules which enable quick returns.

To achieve better alignment between the different actors at organizations, mainly the higher management, they are paid according to their performance, i.e. according to the outcomes, especially the short-term ones. Implementing aggressive policies and moves to another company to avoid developing attachment are a part of this ideas. Yet, the consequences in terms of operational safety might be disastrous.

What would a high-level manager decision be if they were made to choose between safer, but more expensive, methods and safe — but less — cheaper ones?

As this is a matter of probabilities, and they are low, the routine business operation is kept unchanged. Within the same context, since the amount of production is the focus at the expense of the development of production as such, i.e. the financial return, very little is invested in research of new techniques and there is no interest whatsoever in industrial development projects[23].

Obviously, these characteristics do not apply to each and every organization. However, this type of analysis is based on a more general view that, unfortunately, became highly prevalent.

The production scenario before accidents such as that in Brumadinho should be analyzed from a different perspective. The reason is that changes in the value of some raw material and the pressures from governments and stockholders might lead to increasingly hazardous situations, especially because investment is increasingly measured and assessed in the short term. If something goes wrong "it's a part of the business risks." However, it is not a matter of business risks, but of the consequences of accidents, of losing the knowledge of the various production chain levels, of losing technical knowledge and the opportunity to develop innovative engineering in some region or country, as e.g. in Brazil.

ADVOCATING COMPLEX THINKING

The aforementioned considerations, presented as a general inquiry, indicate that outdated ideas, based on 19th century epistemological views — if not earlier, which core was to isolate the phenomena for the purpose of understanding and acting on them — still prevail in the world of production.

The relevance of such perspective — deeply rooted in Descartes' ideas and then on Positivism — is undeniable. Yet it is no longer sufficient! Systems are highly entropic, risks are unbearably high. Likely small accidents might become disasters as a function of their circumstances. One can no longer deny the relevance of a different epistemological approach to technology, the economy, labor and society at large. We suggest dealing with these matters from the perspective of complexity[24-26].

One of the first tasks within a complexity paradigm is to understand what is the purpose of production[27,28]. If this type of inquiry is not a part of any engineering action — and even more in the case of

high-risk undertakings — something is wrong. To believe that production and its impacts are restricted to the organization's boundaries and immediate surroundings is to oversimplify the scope of analysis. In our case, the consequences of accidents expand across time and space, their impacts being very difficult to evaluate. Any estimation of damage[29], no matter how earnest and even when considering multiple aspects, will always be partial. In addition to concrete issues, such as water pollution and the destruction of agricultural lands, some losses concern the riverside communities. What to do when it is no longer possible to keep homes, plantations, livestock farming? We might go even further to state there are considerable immaterial losses: loss of trust in organizations, in technical and engineering solutions, in decision makers and even in the government. These aspects cannot be quantified, but have substantial consequences, including the fact that mistrust opens the door to cynicism and disbelief.

Mineral production has strategic relevance. If we look close around us, almost everything derives from some mineral. The human dependence on minerals is increasing, and their production might be a source of wealth not only to organizations, but to the overall population. However, producing no matter how, without prudent measures to avoid disastrous externalities, is senseless.

One further issue concerns the distribution of losses. Harms which might represent a substantial loss to an organization — but which can be compensated by insurance or new investments — might represent a total loss to less lucky others. To approach a phenomenon considering only some of its variables is insufficient in the light of complex thinking[30].

It is not possible to only consider what is of interest to some or is more evident; also that which is not visible should be taken into account. That which is not seen is often the fruit of a narrow scoped and simplified view of reality. A complex approach precisely seeks to reveal the invisible.

Another assumption of complex thinking concerns the need to consider different perspectives in projects and in the management of any production system. Decision making is still strongly influenced by teleological tenets: the relationship between means and ends is all that matters, this being a strategic-instrumental perspective that pays little attention to the actual activity of the various actors and their possible contribution to decision making, especially at strategic levels[31]. However, the stakes are even higher. By neglecting axiological perspectives, values and ethical and moral aspects are not considered a key pillar of decision making. When the impacts for all who work and society at large are considered in a more encompassing way, one will always need to call into question what is being produced and how and what the actual benefits of production are, including aspects related to professional development and culture.

Thus subjective rationality (*pathica*) enters the picture, i.e. the concern with subjects, their subjectivity, coexistence and the manifold aspects associated with a more thorough knowledge of human beings. This discussion is anchored in contributions from the psychodynamics of work, which has intensive interaction with psychoanalytic anthropology.

While we do not intend to deal with all the assumptions of complexity theory in the present essay, a few more still need to be discussed.

Any production system tends toward disorder, just as the living systems, since nothing can be fully automated (and much less the automatic functions which depend on programmers). No matter their position in the hierarchy, the role of human beings is to regulate such tendency. Action and decision making result in different levels of order.

According to the assumptions in Morin's view of complexity[5,6], based on entropy principles, there is a tendency for the disorder in systems to be constant. Therefore, the aim of the actions of the various actors is to attain new, different and possibly safer levels of order. This relationship between order and disorder is part of the dynamics of any process. However, disorder might be excessive, eventually disastrous as a function of the system's entropy. No matter how little, entropy is always present and the task of production actors is to search for regulation mechanisms to reach new levels of order and thus avoid greater disaggregation of the system.

This type of notion might help us understand disasters, because it makes us reflect on the uncertainties and incompleteness of any possible approach. This should lead us to be more humble and prudent upon considering the safety of any type of production.

CONCLUSION

Restricting engineering projects to that which is visible and that which was delivered at the onset of the operations of any company or institution is reckless. Just as in the case of products one should consider the life-cycle of any undertaking, one may not imagine that any venture will live long without responsible management which takes the various aspects of sustainable production into account[32,33].

On these grounds, we considered in our analysis aspects related to work and the possibilities for professional development, the continuity of production including processes able to reuse raw materials, permanent maintenance and renewal of industrial parks, the search for new technologies and products, the inclusion of services which add to the value of production, and even the processes for dismantling facilities. Attempts at transferring the responsibility for any of these aspects to others are the fruit of short-termist views which seek to obtain as much benefits as possible in the near future.

One further challenge derives from the notion of potential damage. To approach safety with exclusive focus on the risk of accidents, even disastrous, and based on probability estimates, without including the consequences of such incidents, is irresponsible, to say the least. Upon developing safety systems, it is important to consider the extension of damage and make such systems spread across space and time.

For this purpose, one should bear in mind that no system is entirely safe, but risk is always present. Therefore, avoiding rivers from being involved, developing containment systems, precluding downstream and destructible constructions and forbidding people to live on the margins of rivers in the path of floods — as was the case in Brumadinho — is prudent.

Quantifying risk might also lead to a cynic attitude, i.e. the mere calculation of compensations in case of damages and the cost of the corresponding insurance to spare the company. While situations leading to company close down are not desirable, one might suggest that implementing prudent measures might be a task for the government, provided the organizations' management and objectives are more transparent.

To conclude, there is an ongoing discussion originated in the sciences of work, the psychodynamics of work in particular. We should inquire how different workers at these companies experience such high-risk scenarios. Mental defense mechanisms are available for this purpose and help mitigating fear by reducing the awareness of danger[34,35]. An almost monolithic discourse is deployed at many production settings to assure people that everything is under control.

However, as many studies interested in listening attentively to workers showed, the fact that something is indeed wrong is a significant part of their narratives. Yet, this point of view usually does not get much attention. One of the reasons is the tendency to dismiss danger to ensure production. Such defense mechanism is common among project and production managers and company executives. Defensive risk denial is neither rare among workers, as a function of their need to keep their jobs. This is why it is so common for someone to say, even in a patently dangerous situation, that operations can continue, since, after all, the odds of incidents are very low. Asserting that production can go on despite risk and the magnitude of the possible consequences almost corresponds to magical thinking, guided by mental defensive mechanisms which hinder a more judicious analysis. This type of behavior is very common when people believe there is no other option; the mental defense subconsciously builds up, blocking the analytic skills and the choice of other behaviors.

Then there is the confrontation with reality and the knowledge that emerges from it. Several studies on activity-centered ergonomics — in which the narratives of workers involved in operations, as well as those of engineers and other professionals close to production are considered essential — indicate that there are always hints that something is not happening as anticipated, that procedures are not sufficient and that is necessary to find solutions which are not standardized in companies[36]. Yet, very few or no one takes heed of these hints; any similarity to the consequences of the mental defense mechanisms, such as organizational silence, is no mere coincidence.

To be sure, the present essay does not explain everything and is, indeed, very far from such pretention. There are countless other issues relative to power relations, domination, the loss of relevance of trade unions (including that of engineers) and of production

for financial returns... Yet we believe that this essay might help readers think, reflect and even act differently so as to avoid the occurrence of disasters and the expansion of damage. If one single death is unacceptable, what to say of the consequences of the accident in Brumadinho?

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