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Systemic research model: four fundamental keys for a paradigm shift

Modelo de investigación sistémica: cuatro claves fundamentales para un cambio de paradigma

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Abstract

The text discusses the systemic research model and its application to transport events, highlighting the limitations of the linear research model. It argues that organizational and model change is possible through improving accident investigation methodology. The systemic model of investigation aims to move away from legal bias and single judgment to identify the conditions that contributed to generating an accident. The paper focuses on the primary requirements for this approach.

Resumen

En este trabajo se abordan los pilares del modelo de investigación sistémico y su aplicación en sucesos de transporte. A lo largo del artículo se describen las características del modelo de investigación lineal y sus limitaciones. Se plantea que el cambio organizacional y de modelo es posible. Para que suceda, es fundamental que la investigación de accidentes identifique y mejore su metodología. El modelo sistémico de investigación nos propone salir del sesgo jurídico y del fallo único, depositado en quienes operan la primera línea, para intentar responder cuáles fueron las condiciones de posibilidad que contribuyeron a generar un accidente. Aquí desarrollamos los requisitos primordiales.

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Changes to organizations and business models are feasible. It is essential that accident investigation identify and enhance its approach for it to occur. In order to answer what were the conditions of possibility that contributed to the accident, the systemic model of investigation suggests getting beyond the legal prejudice and the single failure-typically attributed upon workers with direct interaction with the processes.

1. The split with the judicial and economic compensation model

Transport accidents will be the subject of our analysis in these pages. For every time an accident occurs, at least two or three investigations require to be initiated: a criminal and/or civil law investigation; another one in terms of financial compensation and insurance; and a third one, the technical safety investigation. From this classification, we can refer two major competences for the investigation of transport accidents: the judicial, economic, and administrative; and the safety investigation.

For the first group, the focus and purpose are to identify accountabilities and issue penalties, acquittals, economic compensation and/or fines and sanctions. Entities responsible for these are the judiciary system, insurance companies, and—regarding breaches of rules and regulations—regulatory and supervisory bodies; which in the case of transport in Argentina are the National Civil Aviation Administration (ANAC); the National Commission for Transport Regulation (CNRT), in its railway and automotive modes; and the Argentine Naval Prefecture (PNA) [Spanish acronyms], among others. To this should be added the investigations that a transport service provider can conduct, in terms of an internal summary of workers involved in the accident. All these organizations have due power to carry out an investigation seeking knowledge, truth related to a crime, misdemeanor, indiscipline, and non-compliance with rules and regulations.

In relation to safety investigation, as in any judicial investigation, the requirement of independence is critical to achieving the objective. In case of safety investigations, independence is in relation to the judicial system and regulatory and oversight bodies. To demonstrate, let's consider the Law 27514 by which the Transportation Safety Board (Junta de Seguridad en el Transporte, JST) was created in Argentina, with the mission "[...] to contribute to transport safety through accident investigation and the issuance of recommendations." Article 2 states: "The following constitute principles of transport safety policy; (a) Independence, based on delimitation between the functions of regulation, provision and control of transport services (...) Investigation must guarantee impartiality, transparency, and scientific rigor."

Now, the first fire hoop to jump through in safety, for a systemic investigation, is to NOT identify the workers as accountable, nor judge their acts under legal terms. For a long time and still today, negligence, recklessness, indiscipline, etc., can be read as causes of accidents. These are legal terms that shouldn't be deployed in safety investigation reports.

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In Argentina, we can cite as a reference the attributed cause to the Argentine Private Airlines (LAPA, Spanish acronyms) flight 3142 accident, occurred on August 31, 1999, identified and described by the public agency responsible for the investigation of air accidents at that time (the former Civil Aviation Accident Investigation Board, Junta de Investigación de Accidentes de Aviación Civil, JIAAC) as: "Lack of discipline of the crew, who did not execute the logical reaction of aborting takeoff, and checking the fault signaled by the sound alarm that began to be heard when giving engine and continued until the attempt of rotation." (Safety Investigation Report, JIAAC, 1999)

But this sort of bias did not just occur in Argentina but was rather a global problem. To illustrate this with an example, Sabey and Taylor (1980) analyzed the results of a study conducted by the britishTransport and Road Research Laboratory, whose main objective was to identify the main contributing factors involved in road accidents. The laboratory study covered a total of 2.130 accidents. Based on the analysis of the data obtained, Sabey and Taylor identified that:

- 41 % of drivers involved in the studied events were classified as at-fault for the accident.
- In 95 % of the studied accidents, driver and pedestrian error and lack of aptitude were identified as the main contributing factors.

It becomes evident that the split with the judicial model and economic compensation, sets safety reporting on the right trail, moving away from the partial duality that identifies human error and technical failure, shall also make for the investigation to consider the context."

Examples such as the above abound in safety investigation by virtually every agency during the twentieth century. In short, the work of the different boards of investigation was biased by the judicial and economic registry, identifying the operators as accountable, or else, qualifying their acts with judicial terms. Below we can see a table from the 1951 Yearbook of the JIAAC, which eloquently illustrates the problem:

Table 1. Accident Causes

Technical deficit	29,3
Material failure	15,9
Neglect	13,8
Poor maintenance	9,8
Fortuitous	7,3
Misjudgment	4,8 ←
Reckless flight	4,8 ←
Imprudence	3,7 ←
Negligence	3,7
Precautionary landing	1,2

Source: 1951 Yearbook, JIAAC

If safety investigation does not overcome that initial hoop, two problems emerge: first, the organization responsible for conducting the investigation will be repeating reports subjects that belong to other bodies. This would put Government's investment in accident safety investigation to waste and spend resources in different organizations for the same task(s). And second, this would be like killing mosquitoes instead of fumigating the infested pond. In other words, the structural factors which triggered the accident would remain untouched.

The systemic model jumps right through the hoop, overcoming the challenge by adopting an analytical process with the following features:

- Describes the system and its conditions of possibility for the occurrence of an accident.
- Explains the gap between the desired performance of the system and the actual performance without identifying workers and without adjectivizations or value judgments.
- Includes an editorial quality and control phase, that reviews the final report and avoids judicial, economic or punitive compensation biases.

2. The systemic model includes a cross-sectional analysis that, starting from the triggering factor, reconstructs the context to the highest reasonably practicable level

Accident investigation, since at least the first Industrial Revolution, was biased by the judicial and economic register, as well as determined by the dualism "pay or stop paying", without any impact on accident prevention or safety. At the beginning of the twentieth century, we find the origin of accident investigations, the purpose was prevention. Many authors argue that the birth of occupational safety and health, as a scientific discipline, took place in 1931, and take the publication of the book Industrial Accident Prevention by the American author H. Heinrich as a milestone.

In this founding book Heinrich deployed three fundamental premises:

1. Unsafe acts of persons are responsible for 88 % of industrial accidents.
2. Accidents are the result of a single linear causality
3. There is a fixed relationship between major accidents, minor injury incidents and near-incidents/accidents without consequences. The well-known Heinrich Pyramid: 1, 30, 300.

The linear Heinrich model (cause-effect) and its variants, such as the cause tree, are analyses that identify a root cause, deposited to a greater extent in the operators (88 %) and to a lesser extent in mechanical or physical failure (12 %). This is a binary bias which marks a clear separation between a human and a material cause. Thus, the "unsafe act of a person" was translated as human error, while the "mechanical or physical threat" was interpreted as synonymous with technical failure. This is inherited from a system representation of static relations that supposedly can be broken down into parts and reassembled; and from transport interpreted as a linear and non-complex system, subsequently assuming that there are only fixed relationships between components.

> ***"Systemic analysis model is the one that will allow us to settle the political debt, open the frontier beyond technology and science, and explore the political dimension of safety."***

Evidence is irreducible, we are bombarded by statistics that tell us that human error is the cause of 70, 80, 90 or even 100 % of the accidents —as already shown in previous examples.

Charles Perrow, in his book Normal Accidents, tells us that the tendency to attribute the cause to the operator is prominent and identifies that in maritime accidents human error is the cause of more than 80 % of accidents —conclusion reached after reading 200 accident reports which only judged the ship's captain and state "that he should have done zig instead of zag" (Perrow, 1984: 233).

Models help us discard the irrelevant to the problem that we need to solve (i.e., explain the accident) and put focus on what we need. Model explain how a system works, how things happen, and what were the conditions for possibility of the accident. They also predict the future, offering opportunities for improvement [Safety Recommendations] so that the accident doesn't happen again.

It is logical to require simple answers to our questions, although a model "should be as simple as possible, but not simpler" as Albert Einstein said. Using a linear model of accident analysis in a complex system is to give a "simpler" answer, that has no real impact on the problem we must solve. Therefore, models are chosen not because they are good or bad, but because of their usefulness. Although every model has limitations, some are more useful than others.

In this sense, linear models are limited in their usefulness, since:

X

- They don't help us think about what happened before the human error or mechanical failure that caused the accident.
- They consider the transportation industry a simple system.
- They can't address the complex systems' problems in accordance to their characteristics: interactive complexity and unexpected interactions.
- The idea of "root cause" is simplistic and cannot always be determined (what is the true root cause in complex accidents?)
- Consider that a cause per se causes the accident. In complex systems, "factors" related to the accident are listed, necessarily, but none is self-sufficient to cause an accident.
- They have little preventive power since they identify the symptoms but not the disease. They leave viruses intact.

What is this about viruses? The answer began to be given by Edwar Suchman in 1961, when he published A Conceptual Analysis of the Accident Phenomenon. He was the one to use the metaphor of disease (epidemiological model) to represent an accident. According to this approach, the author compares an accident with the occurrence of a disease, especially with contagious diseases where "infectious agents" enter a predisposed host with certain conditions.

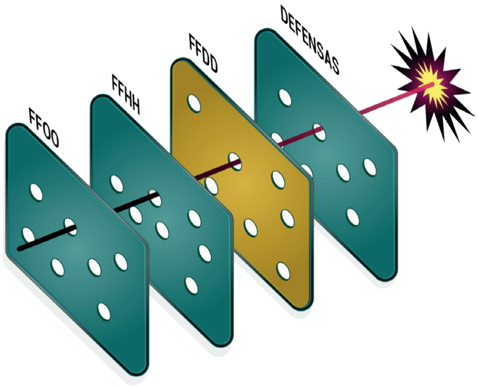
In the late 80s, J. Reason resumed the epidemiological model with the purpose of responding to catastrophic accidents of complex sociotechnical systems, such as those of Three Mile Island (1979), Bhopal (1984), Chernobyl (1986), Challenger (1986), Zeebrugge (1987), among others. In his book Human Error (1990) he explains the metaphor of Suchman's infectious agent (virus) as latent factors, and represents them as holes, categorizing them as the greatest threat to safety in a complex system. In this way, it moves away from the focus on errors made by operators and material or physical failures, which become only the hosts of the virus (triggers).

In reference to latent factors, Reason classifies them as human factors (HFs), organizational factors (OFs) and defense factors (DFs). Being the triggering factor (human or mechanical failure), now, a consequence:

> Human error is a consequence and not a cause [...] Errors are configured and caused by precedent factors rooted in the workplace (HF) and organization (OF). Identifying an error is simply the beginning of the search for causes, not its end. (Reason, 2010: 173)

Reason takes a Nietzschean hammer blow to Heinrich's model by saying that human error is not the root cause of accidents, and that it is not even a cause, but a consequence of latent factors that were generated upstream. In turn, the author introduces a new factor (unlike Heinrich and Suchman) to explain the accident: the defenses. Beyond the triggering, human and organizational factors, there must be a virus in the defenses (weak immune system) for the accident to occur.

Figure 1. Reason's method.



Source: Prepared by the JST.

The Reason model was named the "Swiss cheese" model because it represents viruses as holes. Why does Reason introduce this new factor (defenses)? Because at the time he wrote Human Error, he was influenced by the third ongoing Industrial Revolution (and on the eve of a fourth), and one of the answers given to the accident problem in complex systems during this stage was to introduce "defenses-in-depth or automatic defense systems."

The concept of "defenses-in-depth or automatic defense systems" is based on a philosophy considering risk as "energy to be contained" through layers of defense, which channel the energy of the sources of danger. This concept was born in the nuclear industry, which considers that proper design of the atomic plant are the defenses that aim to contain the unwanted release of atomic energy and prevent catastrophe from occurring.

> Automatic Safety Devices (ASD) are created, which must cover the widest variety of accidents postulated by design. In addition to many support subsystems, there is a line of defense that is offered by ASD: devices that, after perceiving a state other than tolerated, automatically "trip" the reactor, shut down the turbines and/or reduce excess pressure. (Reason, 1990: 249)

Another Nietzschean hammer blown by Reason occurred with the incorporation of defenses-in-depth in a model of accident analysis, since human error or mechanical failure not only ceased to be causes and became consequences, but the last line to stop the accident no longer was the human being but the defenses-in-depth.

> ***"Human error is not the root cause of accidents, and that it is not even a cause, but a consequence of latent factors that were generated upstream. In turn, the author introduces a new factor (unlike Heinrich and Suchman) to explain the accident: the defenses".***

It was from the Swiss cheese model that, in 2013, Argentina began to design its own systemic model and apply it in accident investigation bodies. Thus, a cross-sectional analysis was initiated, which includes the deficiencies or absences of the defenses, the human factors (investigating in what aspects the technologies and systems influence the behavior of the frontline operator) and the organizational factors (intervention of the policies of the regulatory and supervisory entities, as well as the management of the organizations that provide such services in operational safety). Therefore, by "at the highest reasonably practicable level" we mean to allocate RSOs to transport entities and service providers, which are the organizations best positioned to implement mitigation measures to safety risks, and who have the authority and powers to act to the fullest extent possible.

In conclusion, just as it becomes evident that the split with the judicial model and economic compensation, sets safety reporting on the right trail, moving away from the partial duality that identifies human error and technical failure, shall also make for the investigation to consider the context. I used this adjective, partial, since duality holds one pan on the weighing scale too inclined towards human error.

Figure 2. Confrontation of the Linear model vs. Swiss cheese model

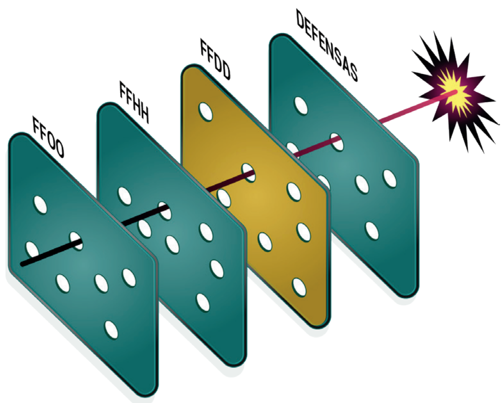
Heinrich concluded that 88 % of the unsafe acts were unsafe acts of first line operators. The human being became the last line of defense before the accident. Once the duality "human error or mechanical failure" was solved, the accident report concluded.

VS.

Where the Heinrich model concluded the accident report (human error - mechanical/physical failure), the Reason model begins and tells us that these are no longer causes, but consequences, and thus is the starting point of the accident report.

Then, we must look into the defenses that were absent or failed, and upstream we will find the factors (human and organizational) that provided the conditions of possibility for the accident to occur.

The last line to stop the accident are the defenses-in-depth, and not the human being.



Source: own elaboration.

3. The systemic model includes the new scale of the Fourth Industrial Revolution and complex socio-technical systems

In the description of the previous key, we expressed how Reason, by including the defenses in an accident analysis model, incorporated the new technology of the Third Industrial Revolution. Continuing the concept of the development of industrial revolutions to the present, Klaus Schwab, a German economist and founder of the World Economic Forum in 2016, characterized the Fourth Revolution as a "fusion of technologies and their interaction across the physical, digital and biological domains", which blurs the boundaries of traditional sciences or technologies, with great advances in artificial intelligence, robotics, nanotechnology, quantum computing, biotechnology, internet, 3D printing, autonomous vehicles, among others. This revolution is not limited to automation, but refers to industries 4.0, intelligent systems and/or smart factories.

Transportation, like any cutting-edge industry, lives and experiences this great Industrial Revolution. It is worth asking ourselves, then, what are the radical changes that have developed so far in the Industrial Revolution. Between the operator and the process or the consequence of the work, there are countless layers, systems or subsystems, with fused technologies. The direct human-machine interface disappeared and the SHELL interface shows a limited representation of complex sociotechnical systems. The essence of a sociotechnical system cannot be grasped by any simple representation.

Another major change has been the progressive distancing of operators from the processes they used to directly control. In the early days, between the human being and the physical task mediated tool; then machines; automatic systems; later, software, applications; and countless subsystems of increasing complexity. Currently, many competences and responsibilities of operators and supervisors are transferred to other systems.

From craftsmanship and manual labor during the First and Second Industrial Revolution, workers had direct manipulation of tools and machines, as well as immediate detection of results; it was seen and controlled. Today there are systems that act on their own, and the main task of the operator is monitoring. The new systems act beyond the worker: direct action on the tool, machine and production processes is eliminated. The worker's doing is replaced by monitoring and/or supervising, with access to information filtered by the system; The worker only accesses what he needs to know (need-to-know basis).

In this new systems scenario, continuing to identify the frontline worker and a single component failure as the root cause of an accident would give us not only a limited perspective, as explained in the second key, but we would be looking at a system that does not exist; the investigator would be carrying out his work in a parallel world of simple and direct relationships, identified in a stationary way. The systemic model considers the characteristics of the systems of the Fourth Industrial Revolution: interactive complexity, unexpected interactions, close coupling, opacity of the systems, human supervisory control and software safety, among other new concepts derived from current technological development.

> ***The systemic model considers the characteristics of the systems of the Fourth Industrial Revolution: interactive complexity, unexpected interactions, close coupling, opacity of the systems, human supervisory control and software safety, among other new concepts derived from current technological development".***

Before finishing the fourth key, allow me to make a "warning" to move away from (in Perrow's words) "the litany of complex systems vs. the advantages of simple systems":

> The litany of problems of complex systems and the advantages of linear systems might lead one to believe that they are far preferable and that complex systems should be transformed into linear ones. Unfortunately, this is not the case. Complex systems are more efficient (in the narrow sense of productive efficiency, which does not take into account the dangers of accidents) than linear systems. There are fewer downtimes, less underutilized space, less tolerance for low-quality results and more multifunctional components. From this point of view, in terms of design efficiency and installed equipment, complexity is desirable. (Perrow, 2009: 121)

Now, intervening in that parenthesis that Perrow leaves us, we can take as evidence that, thanks to complex systems, the aeronautics, nuclear and many industries have reached the status of ultra-safe.

The notion of ultra-safe systems was enunciated in the mid-1990s by Professor René Amalberti (2009) in his book Human Action in High-Risk Systems.

> The catastrophic accident percentage is around one accident per million movements (departure-arrival) (1 x 10-6) in air transport; This figure is also reached in rail transport, in the nuclear sector and other industries. This is an exceptional figure for the individual level considering that a professional pilot performs 100-200 movements a year, so in 30 years of profession he will have made between three to six thousand movements. (Amalberti, 2009: 32)

Back to present time (Fourth Industrial Revolution), the scientific discipline of accident investigation began to design analysis models beyond the well-known model of the Swiss cheese, emphasizing this model made it possible to develop new models, with the so-called systemic approach.

With his theory of normal accident, Perrow (1984) proposes to act on complex couplings, interactive complexity and unexpected interactions, changing the axes of risk management from severity and probability to severity and costs of alternatives.

Hollnagel (2004), in Barriers and Accident Prevention (2009), presents the Functional Resonance Analysis Method – FRAM, which is based on the phenomenon of stochastic and functional resonance.

Nacy Levenson (2004) develops the Systems Theoretic Accident Model and Processes – STAMP, an approach that considers accident as a control problem and not a failure problem, and that involves complex dynamic processes where there are no component failures. In this way, it considers individuals, organizations, and technology at the same level of granularity.

Lastly, it is worth noting again that since 2013 the JST developed its own model of accident analysis taking, as many authors did, the model of Swiss cheese with some adaptations towards systemic thinking. A brief description of the novel aspects of this mode, could be as follows:

- The concept of factor causes was eliminated.
- The individual level is a triggering factor and then the factors in the defenses, human and organizational factors are considered at the same hierarchical level.
- The Safety Recommendations (RSOs) are directed to the system.

4. The systemic model allows the design of safety policies at the highest level, causing structural changes

When making a systemic analysis of accidents, we identify structural factors and realize that this is not only a scientific technical competence, but also, that there still is a space slightly explored by investigators and safety specialists. I am referring to the "political dimension". The development of regulations issued by oversight and regulatory bodies is a political instance, and the practices of frontline operators are a consequence of these policies. Therefore, as described above, if RSOs are directed at the system, they translate into policies.

This approach moves away from "utilitarianism", which only tries to use technical-scientific arguments to answer the problem of risk management. Although accident investigation and analysis can be formulated in scientific terms, the correct response to how to affect the conditions that produced the accident is beyond the technical-scientific and is articulated with politics. The policies are general specifications of how management expects operations to be conducted, and that's where the RSOs go.

To boldly conclude this article, I'd like to say that the systemic analysis model is the one that will allow us to settle the political debt, open the frontier beyond technology and science, and explore the political dimension of safety. Just as it is not enough to train the worker or to add more layers of defenses, or to make promises that we will be better prepared to face the next catastrophe, it is not enough to focus exclusively on the technical analysis without introducing the political dimension. "Many organizational theorists who study safety problems have done so in this way: they have neglected power and interests in their studies" (Sagan, quoted in Jorge Walter and Francisco Pucci, 1994: 95). "Perrow suggests that, ultimately, the problem is not risk but power: the power to impose risks on the many, for the benefit of the few" (Perrow, quoted by Nancy Levenson, 1993: 17). The power to continue with the analysis of the single fault deposited in the operator or investigate the system. The results of the investigation of accidents in the systemic sense are intended to influence the agents that have the power to guide a change in the system, since, it is also the power, that creates the conditions of possibility for catastrophe to be triggered in the system.

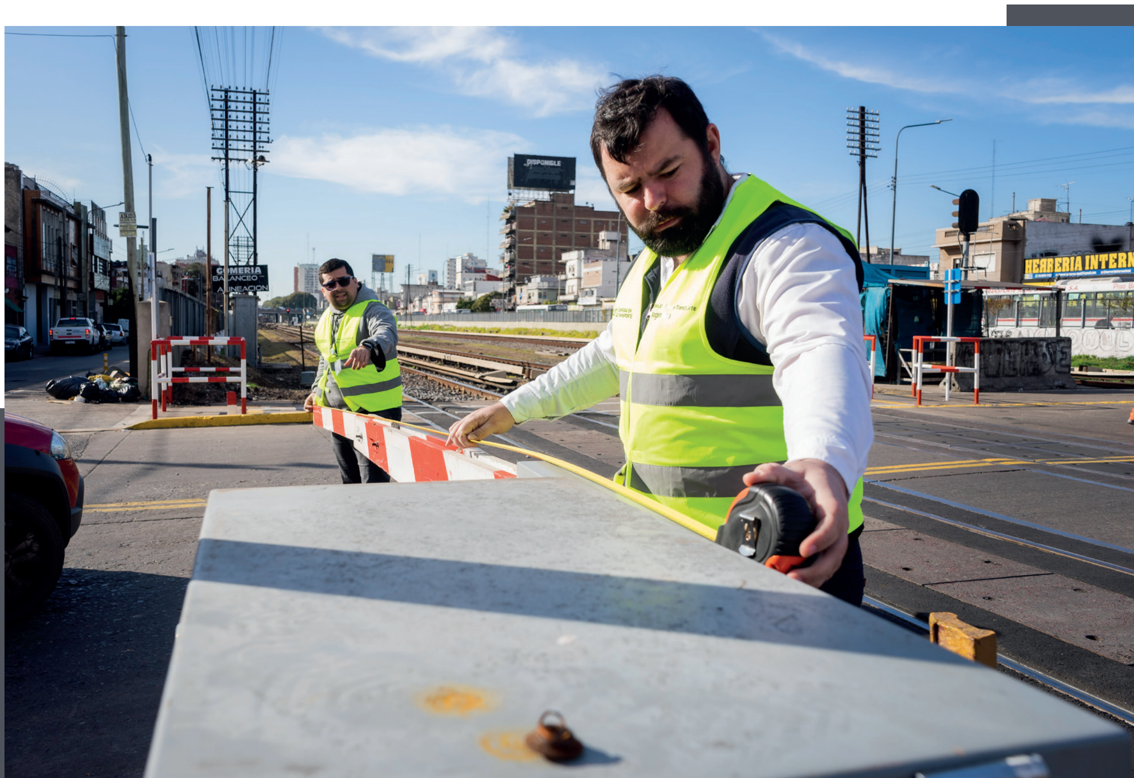
Finally, a reflection on ethics. And to do this, we will ask ourselves a question: what is the importance of defining an accident analysis model? The investigator goes to the wreckage of the accident with an uncertainty that he needs to quickly reduce to give some immediate answers, and the facts he validates are not independent of the accident model he adopts. If the organization does not explicit the model that shall be used to explain the accident, the investigator will use his own. Thus, each accident will be left to the discretion of each investigator and, as we said before, perhaps the simplest and most linear path is the one that will be taken.

I consider that an investigation organization should enunciate its model, and it is this enunciation that ensures the objectivity, the product of a sociotechnical study and a political decision. A state accident investigation cannot leave the accident explanation to each investigator. It is a state responsibility to define its public transport safety policy, and a safety model and strategy. If the model is not chosen, stated, and set forth for it to be apprehended, then there is no State policy.

The reconstruction of the accident in a final report must then be the alignment of the State's safety policy, with the accident investigation model adopted by the agency in charge. The model is a condition of possibility to change State policies related to safety.

> ***"It is a state responsibility to define its public transport safety policy, and a safety model and strategy. If the model is not chosen, stated, and set forth for it to be apprehended, then there is no State policy".***

If we consider ethics as a practice that is evidenced in actions, the final report is the last and main action of an accident investigation body, by which many things are measured. The introductory note that the JST incorporates in its Safety Reports, which explicitly presents its model, is the organizational commitment to the model that has been chosen. This makes it clear, the model is the practice of the organization, with independence from any individual practice of the investigators. The ethical statement of the organization presented in the introduction is the ethical statement of all its members, and thus becomes an organizational value.



CONCLUSION

The present article, with which the JST's RSO Safety Journal is inaugurated, seeks to convey that, when thinking about events in terms of preventing their recurrence, there are some accident explanations that are more powerful than others; explanations that impact and strengthen the safety architecture of the system; explanations "that move the needle" of the safety reading. From the moment the JST adopted a systemic analysis, it disregarded the judicial register and the linear models, because these no longer have a place in complex socio-technical systems, in the Industrial Revolution, and in the management of large risks. Our dear reader, accident investigation is a major intellectual, ethical and political challenge.

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