ARTICLES

ACTOR-NETWORK THEORY FOR SAFETY SCIENCE: REASSEMBLING SOCIAL AND TECHNICAL ELEMENTS

Teoria Ator-Rede para as ciências da segurança: Reagregando elementos sociais e técnicos

Teoría del Actor-Red para la ciencia de la seguridad: Reensamblaje de elementos sociales y técnicos

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ABSTRACT

Recent studies suggest challenges in developing safety science: broadening perspectives and methodologies for sociotechnical work comprehension and incentives so that the complexity effects can be analyzed with greater depth and safety research can become politically oriented in its models. This study explores the contributions of Actor-Network Theory as a methodological resource to reassemble human and non-human elements in safety science research, especially when considering the dynamic reality, variability, and uncertainty characteristic of complex sociotechnical systems. In light of the theoretical aspects of the Actor-Network Theory, such as controversies, political ontologies, and enactment, we discuss possibilities for the cartography of controversies in safety science studies. The discussion contributes, thus, with new methodological connections to research in safety science, exploring associations and new positions among different realities in the field.

Keywords: Actor-Network Theory, safety science, agency, controversies, complex sociotechnical system

RESUMO

Estudos recentes sugerem desafios para o desenvolvimento da ciência da segurança, quais sejam alargamento de perspectivas e metodologias para a compreensão do trabalho sociotécnico, incentivo para que os efeitos da complexidade sejam analisados com maior profundidade e para que pesquisas em segurança sejam politicamente orientadas em seus modelos. Este estudo explora contribuições da Teoria Ator-Rede como recurso metodológico para reagrupar elementos humanos e não humanos nas pesquisas em ciência da segurança, especialmente quando consideramos a realidade dinâmica, a variabilidade e a incerteza que caracterizam sistemas sociotécnicos complexos. À luz dos elementos teóricos da Teoria Ator-Rede, tais como controvérsias, ontologias políticas, enactment, discutimos possibilidades para cartografia de controvérsias em estudos em ciência da segurança. A discussão contribui, então, com novas conexões metodológicas para pesquisas em ciência da segurança, que explorem associações e reposicionamentos entre as diferentes realidades que compõem o campo.

Palavras-chave: *Teoria Ator-Rede, agência, ciência da segurança, controvérsias, sistemas sociotécnicos complexos.*

RESUMEN

Estudios recientes sugieren desafíos para el desarrollo de la ciencia de la seguridad, a saber, ampliar perspectivas y metodologías para comprender el trabajo sociotécnico, propiciar que se analicen con mayor profundidad los efectos de la complejidad y que la investigación en seguridad se oriente políticamente en sus modelos. Este estudio explora las contribuciones de la teoría del actor-red como recurso metodológico para reagrupar elementos humanos y no humanos en la investigación en ciencias de la seguridad, especialmente al considerar la realidad dinámica, la variabilidad y la incertidumbre que caracterizan a los sistemas sociotécnicos complejos. A la luz de los elementos teóricos de la teoría del actor-red, como las controversias, las ontologías políticas y la promulgación, discutimos las posibilidades de mapear las controversias en los estudios de ciencias de la seguridad. La discusión aporta, así, nuevas conexiones metodológicas para la investigación en ciencias de la seguridad que explore asociaciones y reposicionamientos entre las diferentes realidades que componen el campo.

Palabras clave: *Teoría del Actor-Red, agencia, ciencia de la seguridad, controversias, sistemas sociotécnicos complejos.*

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INTRODUCTION

Some industries must deal with numerous interactions and components, leading them to an inescapable residual of uncertainty. Due to this complexity (Dekker et al., 2011), the activities developed by these industries could not be stable at the safety level, requiring variability management and constant adaptations to operate successfully (Bergström & Dekker, 2019). Thus, these environments require highly skilled and technology-intensive professionals in an integrated manner, creating management systems that must avail themselves of human potential to cope with this variability (Farjoun, 2010; Weick & Sutcliffe, 2007; Woods & Hollnagel, 2006). These so-called Complex Socio-Technical Systems (CSS) are characterized by high social and technical diversity.

In these contexts, organizations and individuals must integrate the creation of safety with work amidst unstimulating conflicting goals and scarcity of resources (Masys, 2012). Not infrequently, we observe that management in these systems uses an epistemological reductionism, s ANT ting from a Cartesian worldview, associated with command-and-control imperatives, centralization, and bureaucratization, seeking ever-increasing levels of conformity (Dekker, 2014a, 2014b, 2018). It follows that traditional methodologies and theoretical models developed to deal with these realities end up isolating elements of these systems, resulting in a piecemeal understanding of the whole.

In the scope of organizational studies, we refer to industries with the potential for major disasters, such as aviation, health, nuclear power generation, and oil and gas. Although they deal with continuous adaptability and uncertainties, these organizations have operational safety services detached from their core business and are constantly pressured by the need to manage unstructured problems in short periods (Cooper, 1992, 2007; S. Dekker, 2014).

Regarding safety sciences, an ontological problem about the relativization of complexity (Haavik, 2014) is known. Faced with such heterogeneous realities, we commonly rely on preconceived models and frameworks to search for an understanding of these systems. Suppose only a part of the whole is highlighted and fitted into a model that explains the whole. In that case, a mischaracterization of the field realities, which continue to be performed: in this sense, essential elements (such as culture, regulatory non-neutrality, and other non-technical aspects) are relegated to the status of noise for not fitting within the explanatory scope of specific theoretical and methodological lenses.

Safety management in complex socio-technical systems involves heterogeneous associations between human and non-human actors. In offshore oil platforms, for example, constantly changing flows coexist among regulations, technological innovation, physically distant engineers, front-line workers, health, environmental preservation issues, consortium companies, regulatory agencies, business strategies, production, regulation, sea and vessel conditions, uncertainties, and variability.

Although different theories have been contributing to enhancing our understanding of the risks and constraints involved in managing these activities - for example, High-Reliability

Organizations (Laporte & Consolini, 1992) and Human Error (Reason, 1992), some authors in safety science have been drawing attention to results obtained from traditional models (Amalberti 2001, 2013; Dekker 2018, 2022). Generally, these works highlight the need for safety science to shift to approaches that can override prescriptive models and mechanistic applications that follow normative and dualistic regularities (Le Coze & Pettersen, 2008). Such methodological primacy tends to disregard the complexity of the socio-technical reality, reducing it to the analytical reach of a given epistemology or methodology. In this regard, the Actor-Network Theory can play an alternative role to this determinism to the extent that it can describe such systems as ongoing socio-technical projects (Latour, 1999, p.13).

In associating human and non-human agencies that continuously perform, the relational ontology of ANT emerges as a gateway to the understanding of l variability and complexity of systems (Law, 2004). Haavik (2021) recaps some of the debate on new safety visions, signaling the importance of research to broaden interest in understanding relational elements and the political dimension of reality. However, despite addressing the non-dichotomization of agencies between humans and non-humans and between social and technical, the author can choose how to operationalize such research. Haavik (2021) also takes up ANT (Callon, 1986; Latour, 2005; Law, 1999; Mol, 1999) as a promising theoretical-methodological approach to analyze these limitations - involving causes, functions, factors, and relations defined as the intention of preconceived analytical trajectories -, although still little explored in the contexts proposed here.

This work dialogues with these viewpoints, especially regarding the use of ANT to explore the complexity of intricate socio-technical systems as an analytical alternative for describing dynamic realities with socio-technical hybridity (Latour, 2005; Law & Urry, 2004; Mol, 2002; Callon, 1986). To this end, we draw our attention to the cartography of controversy method, which enables researchers to move across the boundaries of the safety sciences status quo.

We will thus present a brief historical overview of ANT, including essential concepts about controversies, political ontologies, and performativity (Law & Urry, 2004) and its methodological approach. We review organizational studies (Moraes, Andion, & Pinho, 2017; Tureta, Américo, & Clegg, 2021; Hussenot, 2014; Bussular, Burtet, & Antonello, 2019) that somehow contributed to the understanding of relationships and research steps and describe the cartography of controversy method (Tureta et al., 2021).

That said, this study aims to explore the contributions of Actor-Network Theory as an analytical and methodological resource to regroup human and non-human elements in complex socio-technical systems, especially within the debate of safety science studies.

SAFETY SCIENCES AND COMPLEX SOCIOTECHNICAL SYSTEMS

Over more than a century, the safety sciences have evolved from paradigms firmly grounded in the natural sciences to progressively incorporating new approaches and technologies, leading some organizations to the stage we now know as ultra-secure (Amalberti, 2001; Dekker, 2019).

Succeeding these achievements, the debate about the stagnation in safety levels in complex sociotechnical systems and the growing search for regulatory compliance and prescription gained momentum concerning the inability of traditional methods to continue developing operational safety levels (Amalberti et al., 2005; Dekker, 2014b; Hale & Borys, 2013a, 2013b).

Historically, the models and practices adopted in safety sciences were constantly challenged in some of the major accidents of the 21st century (Le Coze, 2013). The models that have prevailed have failed to keep pace with the increasing complexity experienced in practice and the emerging challenges that need to be revisited and problematized on an ongoing basis. Furthermore, between the old and the new, different models and approaches that have emerged in the field must incorporate advances in managerial, political and social sciences, and epistemological and philosophical areas to reverberate the knowledge available in the safety field (Haavik, 2021; Le Coze, 2012, 2013). Examples of these models can be found in the Swiss Cheese model (1990), the dynamic safety model by Rasmussen (1997), the High-Reliability Organizing Theory by Weick and Sutcliffe (2007), and the Resilience Engineering (Hollnagel et al., 2011; Woods, 2018).

In the scope of the Cartesian worldview, the traditional approach to operational safety management places humans as the leading reason for variability. Humans have been recurrently appointed as the weakest links of structured systems, thus becoming the problem to be solved, the element to be controlled (Dekker, 2014a, 2018). Le Coze (2013) explains that, more recently, movements such as Resilience Engineering (Hollnagel, et.al, 2011) have begun to deconstruct this discourse by recognizing the human potential in the face of variability, reconciling their inconsistencies, asymmetries, and conflicting goals and resources regardless of the inescapable residual of uncertainty and risk in these systems.

Considering the epistemological basis of safety sciences, we observe a great effort to search for approaches other than purely functionalist, which have hindered the development of a systemic vision that encompasses human agency and its heterogeneity. Thus, we must detach ourselves from the limited intention of assuming reality as predictive and linear and leverage understandings that view an organization as a procedural and dynamically negotiated flow (Weick et al., 2007; Cooper, 1976). *Operational safety* is a permanently unfinished activity that requires detecting and reacting to potential and actual problems and mobilizing socio-material resources.

Hence, debating the safety science approach within organizational and management studies makes sense. With this, we emphasize Czarniawska's organizing theory (2013) which sees procedural and heterogeneous perspectives of organizing as more related to process than structure. Cooper (1976), for example, shed light on new possibilities within organizational and management studies to understand the organizational phenomenon, ranging from procedural and diffuse perspectives for human thinking and acting to counterpose objectivity, rationality, and predictability. In this matter, the organization needs to be constantly questioned since it is an open field, unable to be understood deductively. It is becoming (a process), a non-being.

In light of this discussion, we envision ANT (Callon, 1986; Latour, 2005; Law, 1999, 2004; Law & Urry, 2004; Mol, 1999, 2002;) as a potentially promising approach and a gateway to understanding

organizational flows as intrinsic elements of complexity, which, in turn, will make possible social and technical re-aggregation and the highlight of non-human agency, political ontologies, access to the unspoken, and controversy cartography. It seems common sense to experience an unknown negotiated agreement and an invisible practice caused by rationality that focuses solely on the outcome of what was idealized. Explaining relationships and untold stories have become essential investigation aspects in operational safety management since it is a process that needs to be built continuously (action/verb) rather than as a goal (substantive) to be achieved.

ACTOR-NETWORK THEORY: CONCEPTS AND POSSIBILITIES

The Actor-Network Theory (ANT) helps us to value social and technical elements in the analytical understanding of reality. These new approaches in safety sciences, supported by adaptability, highlight the need to understand SSC as socio-technical environments to the extent that humans and materiality belong to relationship networks that reconcile and reposition themselves in unprecedented ways. Both the social and the technical, thus, cannot be understood with defined or static limits as they need to be regrouped to achieve their essence in the relations they establish, and in the arrangements driven by the practices.

ANT 's study object is the relationship between human and non-human actors (objects, artifacts, technology, among others) (Latour, 2005). In this sense, we can introduce the relational ontology of ANT because relations affect, produce, and are produced by each networked actor. There is no fixity, such arrangements are provisional, and there is a relational, unstable, and dynamic flow. Through this lens, humans and non-human agencies can be analyzed symmetrically, which makes it possible to reengage social and technical elements without the primacy of one over the other. From this perspective, ANT does not devalue humans, nor does it subject human acting to immaterialities. The actor-network idea values the connection of heterogeneous elements, also considering the artifacts' agency (from the relationship they establish) as they promote transformations that can achieve significant relevance in understanding the social. For Latour (2005, p. 74), the actor is the one who acts: "to employ the word actor means that it is never clear who or what is acting, when people act, because the actor, on stage, is never alone when acting."

Understanding a socio-technical environment (such as an offshore platform in the oil and gas industry, nuclear industry, or air transport) involves descriptions of the relationships between human actions, social practices, and the use of objects that shape and transform our fields of activity (Latour, 2005). In this sense, we understand ANT as a gateway to re-aggregate human and non-human factors from a relational perspective, and their agencies in the analytical exercise of research in a field characterized as a complex socio-technical system. Entering an area via ANT encompasses tensions between agency and structure, actor and network, material durability, and actor agency. This process happens because practices produce and are produced by entities in relation, whether human or non-human (Law, 1999; 2004).

The first moment of ANT

Within the first moment of the theory, we can highlight the notions of social, actor-network, symmetry, agency, and translation (Czarniawska & Hernes, 2005; Law, 1994; Latour & Wolgar, 1979; Latour, 2005; Mol, 1999). In organizational studies, ANT's relational ontology advocates broadening the idea of 'social' by considering analytical symmetry between human and non-human actors. The concept of social, in Latour, presupposes associations that carry shared meanings. On the other hand, the term 'actor network' refers to inextricability, correlation, and reciprocal dependence - one does not exist without the other (Latour, 2005; Law, 1999).

The notion of actor, in turn, should be understood as "the moving ANT get of a broad set of entities swarming towards it" (Latour, 2005, p. 75); therefore, it should not be understood as the founding dimension of an act; but in the course of its relational dynamics. When we say that an actor is an actor network, we are concomitantly highlighting imprecision as to the origin of action. The network, then, as Latour (2005, p. 194) explains, "is a trace left by agents in motion."

For Latour (2005), the actors that make up the discursive network have agencies that cannot be analyzed in isolation, as they have been part of the social sciences in separating the social from the technical. In the ANT framework, technical artifacts are not neutral. In short, non-humans "are constituted and acquire their attributes through the set of relationships they establish with other entities" (Camillis, Bussular, & Antonello, 2016, p. 78). This agency, then, can be described from the perspective of 'symmetry,' In the constitution of networks, we cannot, *a priori*, determine the supremacy of one actor over the other. We need to track human and non-human agencies in the social constitution simultaneously.

Agency is a result of 'translation' (Law, 1999), constituted by socio-material associations between humans, artifacts, and labor, for example. The translation process, in turn, can be understood as creating a connection that did not exist before, operating modifications in all network agents, and generating associations that can be traced. Translations are not definitive or distinct, as they also depend on the actors that act in the network, considering the updates and changes of perceptions, actions, and ideas that initially belonged to other actors in this network (Callon, 1986). Hence, we can consider momentarily stabilizations in this relational structure frequently negotiated by the elements that make up the network.

It is crucial to consider the translation stages initially proposed by Callon (1986) in the controversy theory: problematization, interest, engagement, and mobilization of allies. Problematization refers to a "system of alliances established between entities to define their identity and goals and to create a mandatory point of passage that all actors must accept to achieve what they want" (Tureta et al., 2021, p. 8). On the other hand, interest can be related to what actors do to stabilize other actors around what interests them, 'protecting' them from other actions aimed at different identities (Callon, 1986). However, the 'stabilization' will only be possible if the engagement phase refers to what is done, to the energy used in the negotiations for the effectiveness of alliances among the actors around a common objective. The fourth stage explains the mobilization around this specific idea; we can identify a central actor that "gives

voice to all those silenced during the formation of the network. The various entities act in unity, as a network of actors, through a representative spokesperson". In the stabilization phase, "the controversy ends in the compromise of a negotiated order" (Tureta et al., 2021, p. 9).

The second moment of ANT

This moment, known as *ANT and after*, is marked by the revision, inclusion, and exclusion of some concepts, through questioning, such as the transition from the perspective of translation to enactment and the gap of the political dimension of performed realities (e.g., Lee & Brown, 1994; Walsham, 1997). Some of these questions go back to the idea that translation would imply a certain fixity or stabilization as a point of arrival, where negotiations or repositioning among networked actors are terminated (Corcuff, 1995). The arrangement of the associated elements here, however, focuses on analyzing how networks and associations are stabilized; translation, in this case, sheds light on the perspective of a discourse that prevails after the displacements of actors.

The notion of enactment, in turn, represents dynamic perspectives that go back to the hows and whys things do and are done (De Camillis, Antonello, 2016). In this way, the processual idea gives the condition to be and to come to be - "process has primacy over things" (Rescher, 1996, p.2) – in which human and non-human actors enact their existence continuously. The process is central to enactment, as much as alterity and multiplicity. In short, we are talking about overlapping realities (Mol, 2002) and, thus, referring to one another in their relational networks (Law, 1999).

In contrast to modern traditional approaches, which hold to a concept of singularity, in which there is a single reality to be described or discovered by researchers, or, conversely, to the relativistic proposal of plurality, put into perspective by different viewpoints, there is a fractal understanding, an intermediate point. This condition, characterized by Mol (2002, p. 148) as the understanding of the constitution of multiple realities and their objects, passes through an ethnography of situated practice.

About safety sciences (Dekker, 2014a; Haavik, 2014; Le Coze, 2012; Turner & Pidgeon, 1997), this difference becomes important for the analysis of complex socio-technical systems since multiplicity does not refer to different views on the same object. It refers to a relational network of actions enacted by its different actors that produce, at other points, objects and realities that are partially overlapping but imply various analyses, diagnoses, and responses.

These realities are constantly negotiated, and their associated methods, discourses, and results end up composing what Mol (2002) characterizes as political ontologies, playing an active role in defining which realities gain voice or are silenced (Law & Urry, 2004; Mol, 1999). In this context, different associations make possible the construction of facts that do not always agree but coexist. The author exemplifies the concept with the diagnosis of atherosclerosis: the clinical symptoms that would lead to a diagnosis are not always confirmed in the laboratory, and vice versa. In this sense, when observed separately, a patient can be treated or not, depending on this diagnosis. Clinical and laboratory tests imply a "political" choice of reinforcing or

silencing one of the two realities. Thus, we can highlight a fundamental element of ANT: the construction of associative networks implies the non-neutrality of its actors, be they social, natural, or technological. The way procedures and manuals are written, the choice for statistical data collection and use, and the way they are analyzed could be more neutral. There is a consequence for a given option, which might be the inclusion and exclusion of elements, for example (Law, 1999). There are, in this way, distinct realities, multiple realities.

Mol (2002) explores what can be called the denaturalization (entities do not exist autonomously, they are not naturalized) of multiple realities by associating them with politics. Via ANT , politics can be understood as arrangements that include and exclude and refer to heterogeneous, hierarchical distribution (when, for example, actors take certain positions and displace others through connections); it can also be asymmetries that derive from the constitution of the network, which reveal power relations and politics. The notion of political ontology in Mol (1999) concerns mostly the implication of politics in the world and the world in politics. This idea can be explained because the conditions of these connections occur as they are fabricated. There are no conditions of possibilities given beforehand.

This notion of multiple (and not plural - as we work here with the idea of overlapping) realities is constituted from a processual understanding of reality. Considering this notion, we have two concepts that have evolved throughout the different ANT movements: translation and enactment. In the classic texts about ANT, translation was related to arranging and stabilizing, even if temporary, networks and their relations, sequentially displacing different associations, resulting in a mechanical and structured process of composing a network and assigning meaning to it. Such a concept had been revisited in the ANT and movement and from a new understanding that the original idea did not account for keeping up with the dynamism and complexity of the natural world, "deals with the predominant and emphasizes the understanding of how networks of relations and objects become stable" (Camillis & Antonello, 2016, p. 61).

The inclusion of the enactment concept rescues the idea of the production of multiple realities, of an organization as a result and product of processes that continuously happen, "contributing to the study of the processes and practices of organizing," repositioning the emphasis "on the idea of a functional organization" (Camillis & Antonello, 2016, p. 62). Mol (2002) explains that enactment was selected to dissociate the theatrical idea of acting or performativity, tied to other social science concepts. We underline that socio-material actions and relations create realities. In this sense, the image of enactment can be approximated, as Law (2014) explains, to the concept of performance, since it concerns the chronicity with which relationships are formed, characterized by a continuous process of production and reproduction. Entities are reversibly performed through relationships, as there is no fixed attribute for any entities in the network through this lens of understanding. They, therefore, find form in the relationships they establish. Here, relationships can be understood by everything that is transported and moved. The heterogeneity of what circulates was defined by Callon (2008) as a socio-technical agency: "the agencies that exist and can do, think and say from the moment in which they introduce the human body, the procedures, the texts, the materiality, the techniques, the abstract and formal knowledge" to name a few (Callon, 2008, p. 309).

In this way, a reality implies the existence of another/other unavoidably. Such an idea outlines the notion of alterity ("If something exists, is enacted, it is because another (alterity/otherness) is also enacted") (Camillis & Antonello, 2016, p. 62). Therefore, actants and action matter, even if there is predominance or prevalence of something at a given moment. Enacting emerges as a way of crafting the real as it produces, shapes, and remodels the different types of actants (Law, 2009), sustains the process, and constitutes the collective. It also encompasses fluidity, reversibility, and multiplicity in the different versions of competing and overlapping realities, thus dialoguing with the criticisms addressed to the concept of translation, especially with the need for a processual approach that transcends the predominant and stable advocated by the idea of translation. So, Law (2004) summarizes that those entities take on different forms, attributes, and characteristics because they are performed in an uncertain context to achieve some stability, even if momentarily.

THE ACTOR-NETWORK THEORY ASSUMPTIONS FOR METHODOLOGICAL 'OPERATIONALIZATIONS'

Cartography of controversies

Among the ways of conducting research when ANT is the s ANT ting point, we can highlight the cartography and subsequent analysis of controversies. Different actors involved in the action define *debates* (Venturini, 2010). Latour (2005, p.44) explains the importance "of tracing connections between controversies themselves rather than trying to resolve them." We consider, thus, that actors negotiate different interests trying to fix them in a movement understood as translation, a concept already described in the previous section (Camillis & Antonello, 2016). This process occurs when the researcher starts following the actors in the field and begins the cartography of controversies.

Cartography of controversies deals with a descriptive approach that addresses multiple perspectives and actors (Venturini, 2010). This description lends itself to giving voice to the field, illuminating different points of view in a balanced way, and planning the agency of human and non-human actors around negotiations and temporarily stabilizing conflicts. We are particularly interested in situations where different viewpoints need to coexist and socio-material influences that reify these realities. At this point, it is essential to emphasize that this process does not lend itself to closing or resolving the conflicts encountered in the field (Latour, 2005).

ANT 's ontological positioning moves towards accepting that controversies belong to the actors and, therefore, researchers "have no right to impose their solutions" (Venturini, 2010, p. 268). This position does not prevent the researcher from expressing their ideas; however, the technique implies care so that the researcher's opinions do not silence the other actors' voices and ways of acting. At the same time, one should not assume what the actors say as

the metalanguage of description (Latour, 1997). This care is closely related to the critique of essentialism and reductionism present in ANT. Cartography should be analogous to an atlas, allowing the observation of different debates, allowing the actors to explore these negotiations and points of tension broadly, and giving visibility to elements not captured by traditional epistemes (Venturini, 2010).

Broadening perspectives and methodologies in safety sciences

In safety science studies, systems engineering biases or functionalist models that square up units of analysis predominate, dissociating the social (often the human) from the technical (often the operated system) (Dekker, 2014a). The Cartesian-Newtonian bias imposes a dualistic perspective of separation between subject and object and between humans and technical systems. In effect, technical disciplines (e.g., physics, chemistry, engineering, computing) exercise a technical and engineering look to the design and evaluation of systems - taking an average human, typically characterized by anthropometric measurements and a framework of physiological and psychological limitations - as the reference for the development and application of their principles and methods. At the same time, social disciplines (e.g., sociology, anthropology, psychology, and management) typically restrict their analyses to individuals and institute human and organizational phenomena, such as assumed safe behaviors and safety culture, as components of the order of commitment to professional and corporate values. This separation between subject and object, between social and technical, circumscribes the challenges of safety science in researching the social (i.e., humans) or the technical (Haavik, 2014).

In the last 50 years, the systems approach, characterized by the socio-technical movement (Amir & Kant, 2018), the perspective of cognitive systems engineering, and correlated cognitive systems as units of analysis (Hollnagel & Woods, 1983) have sought to overcome the limitations of the human-system dualism in prevention science. More recently, are the contributions of the complexity perspective to prevention science, experimenting with concepts such as locality (Dekker, 2014a), interactions (Righi, Saurin, & Wachs, 2015), and coupling (Perrow, 1984), influencing both the perspective of studying the social - e.g., Turner and Pidgeon's (1997) postulates on the incubation of disasters - and the technical - e.g., Levesson's (2003) STAMP approach of systemic thinking applied to accident investigation and prevention - towards investigating how accidents occur and how they can be prevented.

In this sense, the systemic and complexity perspectives have reinforced the importance of aggregating the elements of a socio-technical system to understand the patterns that emerge from its interactions while recognizing that this aggregation lacks the view of the agency of things. By allowing us to re-aggregate the heterogeneous elements (human and non-human, social and technical) in a sociotechnical perspective that also seeks to understand the agency of things (i.e., discourses, artifacts, machines, leaders, instituted values), ANT offers the possibility of exploring what is being enacted and the actors/actants that perform multiple organizational realities and transformations. The dynamics of safety culture, its meaning enacted by actors

amidst controversies between goals of production, protection, quality, care, and performativity, for example, could benefit from ANT 's perspective and methodological and analytical approaches towards understanding political dimensions of practice in a safety investigation, accident prevention, and management.

We thus argue that empirical studies with ANT can give voice to the silenced ones in the field, capturing other realities silenced by political asymmetries. Identifying essentials for organizational continuity and achieving profitable results with safety for its members can be reconciled into operational and management practices. We understand that certain symbolic truths (such as indicators that can distort the reading of reality and legitimize certain discourses) undermine the understanding of what happens in the negotiated interactions (controversies) in the empirical fact of complex systems, in the political dimension of being with.

The political orientation of models and theories

ANT invites (and teaches) researchers and practitioners of safety science to leave their comfort zone, surrounded by regulatory elements of compliance, reports, and approvals, and to walk through their field of practice seeking understanding about what happens and, even more, what they do. An essential contribution via ANT can be related to the agency's analysis of non-human elements and the ability to analyze between the lines of how procedures, goals, and metrics end up pushing the local operation and objectives into unexpected paths.

In this sense, examples are brought by Hopkins and Maslen (2015) and Dekker (2018). The former discusses how rewards for good contractualized or field-negotiated safety numbers end up exerting distorted agency on operations, encouraging the mischaracterization of reality in favor of pre-set goals. Both researchers exemplify such implications with a comprehensive discussion of how contractual bonus ANT gets for top executives, advocating low accident numbers in industrial plants, lead to manipulating statistical data and mischaracterizing accidents to preserve perks or financial compensation. These practices tend to objectify the operators since they are conditioned to beat goals to be held. This non-neutrality, especially when we consider non-human actors, needs to be discussed or even considered in other approaches commonly used in organizational studies (Law & Urry, 2004).

Dekker (2018) highlights several aspects, such as the creation of operational procedures thought exclusively about the legal protection of organizations, leaving out the peculiarities of the operation, toxic cultures of punishment, and the organizational castration of technicians and specialists who are relegated to blindly execute the prescriptions of those who do not understand the constraints and needs of the operation - which gaps organizational learning. We can notice a strong tendency for self-reference and hyper-bureaucratization experienced in complex socio-technical systems - something that keeps safety managers away from the problems in the field but stuck in their rooms producing reports and indicators for audits legal protection of their companies. ANT allows us to give voice to the actors through compliance tools like training and mandatory reporting and through their actions and inactions, attitudes, and constraints.

In proposing that safety science should be reoriented politically, Haavik (2021) seeks the possibility of dialogue with the perspective of political ontologies. In environments of continuous negotiations and provisional stabilizations, different realities enacted by other actors compete for the imposition of their diagnoses and solutions amidst translations that constantly occur in a network. Examples can be found in the competing explanations of the Macondo accidents (Hopkins, 2012), the Mariana disaster (Bussular et al., 2019), and even in widely studied cases such as Chernobyl (Walker, 2004) and Challenger (Vaughan, 1996).

Multiple interpretations of reality compete for the implementation of actions that consider one path or another and completely discard an entire associative network that would lead to a course and sequence of activities, which can be opposite, diagonal, or transversal, for example. The object of interest of ANT is the study of how these associations are consolidated and mobilized (how actors gain identity and voice by enacting realities) to define courses of action. Using the cartography of controversies method can lead organizations to visualize the formation and operation of these socio-material networks in everyday life, regardless of the occurrence of an accident, which can add to the restrictive logic of accident investigation in retrospective analysis in the way of organizational learning.

That said, the subsection that follows departs from the work of Venturini (2010) and the contributions of Tureta et al. (2021) as a gateway for us to move through the heterogeneities characteristic of complex socio-technical systems. In this way, we present the cartography of controversies as a resource to researchers in safety science, and organizational studies, for more emphasis on relational aspects. From this possibility, we can associate the social and the technical for a better understanding of why things happen as they do in the practical realities of these systems. It is not, therefore, a ready-made methodology to be applied in a given empirical field (Venturini, 2010). This distinction is quite important in the scope of the debate on Actor-Network Theory, mainly because the stimulus to follow the actors in the field (Latour, 2005) refers to the relevance of displacement, of flow, of the importance of paying attention to "the process, the unfolding of actions, practices, and controversies present there" (De Camillis, Bussular, Antonello, 2016, p. 78).

Analysis of Controversies: ANT research "stages"

The systematization of the stages proposed here should not be taken as a linear and definitive proceduralization of the theory. It is a suggested path, which the study's objectives and the fieldwork's development should always guide. In this sense, we rely on the literature on the subject, especially in the works of Tureta et al. (2021) and Venturini (2010), from interlocution with seminal authors of ANT as Mol (1999, 2002), Law (1999) and, Latour (2005). The steps identified in Table 1 are based on the systematization of Tureta et al. (2021, p 7-10) for the anti-history of the cartography of controversies. In this work, the authors proposed a method for anti-historians, s ANT ting from the analysis of controversies.

Table 1. Steps that can be followed for the analysis of controversies

Step identification	Description
Identify the controversy	These steps concern the phenomenon that is being analyzed. Even though we must identify live and emerging controversies, researchers should pay attention to what is being repressed and hidden (that which is or is somehow silent in the discourse). The heterogeneity of the association tends to emerge more clearly for description to the extent that the actors' debate and present their positions about a controversial theme/object. Such places tend to mobilize past issues, which enter into tension with the mobilizations of the present in negotiation.
Mapping the network of actors	It is related to the actors involved in the controversy over time. Notably, the 'actors' identity emerges around a discussion within the renegotiation between old and new networks. From the principle of symmetry, the researcher must be aware of different actors' perspectives, be they human, or non-human, without opting prematurely for the primacy of one world understanding over the other—all associated voices and all that exerts agency matter.
Tracing the practice of translation	At this point, the 'tracing' concerns how actors connect, disconnect, transform, and update meanings and repertoires from this continuous flow of information, contestations, and ideas, that circulate among the network's connections. In this relationship, actors gain 'identity' and mobilize 'allies' around new interests. Here we suggest the idea of enactment from the perspective of flow and more latent continuity.
Identifying the politics of actor networks	Given the exercise of power present in networks, it is essential to note that the controversies under debate are 'shaped' by the strength of different actors. Some may favor the adopted version by relating past and present, while others may resist. Therefore, the researcher must identify the movement of each actor, recognizing what makes them accept or resist a specific role and stable versions to the detriment of others that are silenced or not.
Describing the multiple realities	One should describe the multiple realities of what is being done in practice, bringing to the debate a descriptive scene of what may have been hidden in the past, considering the perspective of multiple realities. As the status of controversy is never definitive, we can unveil practices and compromises that arise from these negotiations. Here we can reveal new actors and understandings about other realities that still need to be prioritized.

Source: Tureta et al. 2021, p. 7–10 (adapted)

Step identification description identify the controversy.

Controversies are not the objects of study of ANT research. The constant interest in the theory is directed toward the relationships between the heterogeneous elements of networks. The path, via the analysis of controversies, is only possible from what is enacted in the associations between technical and social factors that need to be regrouped in complex socio-technical systems.

DISCUSSION: ANT AND SAFETY SCIENCE

Based on what has been presented and avoiding the relativization of complexity and its unfolding in complex socio-technical systems, ANT provides us the basis to shift knowledge to practice. We understand that functionalist and positivist methodologies with pre-defined frames do not account for this complexity. Guided by the question: *What invites [the actors] to act?* we advocate an associative view, in which organizations and their systems are seen as dynamic processes (and not as final and substantive sets of artifacts and individuals able to perform circumscribed by rules and regulations). Based on ANT, 'static' elements also have agency to the extent that, in relation with human actors, they influence the doings and organizational processes of practice and control human agency in a given network. This expanded dimension of perceiving realities allows us to access overlapping realities. An example is the views on safety problems seen by the top management, which often reflect cold numbers in spreadsheets and matrixes dissociated from the processes and factors that led to those constructions. On the front line, the meanings of the same data are often different. Often, these realities are obscured by ANT gets, deadlines, and contracts (e.g. Dekker, 2018; Hopkins & Maslen, 2015).

This corporate vision is illustrated by the Macondo accident in the oil and gas industry: the celebration of superior numbers achieved in safety indicators on the eve of the disaster constitutes a reality dichotomously opposed to the reports produced in retrospect, with high pressure for production, decision-making based on dubious data, and systemic complacency (Hopkins, 2012). Another case occurred at the Samarco dam in Mariana, in the state of Minas Gerais, with technical reports attesting to the safety of the assembly that collapsed (Bussular et al., 2019). There is no wrong or right side here: these realities were legitimately created, overlapped, and only contrasted in retrospect. Law (2004) takes up this discussion. It clarifies that reports of this kind are not about malpractice/unfairness but, as initially proposed by Latour and Woolgar (1979), "different practices, enacted in peculiar ways and through the associations of distinct elements, end up producing different objects, which overlap and engender consequences" (p.54). In short, realities are not explained by practices and cultures but produced by them (Mol, 2002, pp. 53-54).

The non-relativization of complexity refers to the reality of operational safety and quality management systems (Álvarez-Santos, Miguel-Dávila, Herrera, & Nieto, 2018; Grote, 2012). In this scenario, the agency is constantly negotiating new networks that form and deform, from translations and new identities for actors. It is these meanings, repertoires, it is the openness to the continuous flow of information, contestations, and ideas that circulate among the network connections that, we argue, will allow us to access somehow the complexity and variability present in the realities that are being performed (Mol, 2003; Law, 1999, 2004).

The cartography of the controversies in a given fact, thus, may contribute to cracking the dominant logic of analytical linearity present in the models that orbit the debate on operational safety, providing other explanations of why things are the way they are. In practice, replicating standard solutions for multiple domains and diverse operational realities forces the use of

management tools that can achieve more fruitful results in loosely coupled systems (production lines, for example). However, this is not true in overly complex systems and coupling (oil and gas industry).

Other works, such as (Grote, 2012; Haavik 2014; Le Coze, 2012, 2013, 2014), also criticize the functionalist use of the working tooling of models and methodologies (such as risk matrices, root cause analysis, behavioral audits, and standardized courses and concepts imported and distributed across multiple industries) traditionally used to conduct research and work involving operational safety. Importantly, this gap is not fit in a specific model but in its use for statistical reduction and complexity metrics in the field that grow in scale but need to be revised in depth in their domains.

Circumscribing the socio-technical complexity of industries to numbers and graphs on a spreadsheet or to goals and indicators to be beaten, we deny all the plot and peculiarities that make the system behave this way. This understanding of the *hows and whys* beyond the *what* is where ANT can contribute more forcefully, complementing the practices in the field and potentially narrowing the gap between the understandings of top management and frontline. As such, safety science evolution is independent of management models and tools but on complementing approaches that highlight hidden aspects of current methodologies that have failed to incorporate management processes into operational safety. In particular, the social dimension of complex socio-technical systems.

CONCLUSION

Safety sciences are broadly marked by the dichotomy between humans and not humans: machines and processes or behaviors and deviance. Relationally treating complexity is a challenge for the research agenda of this field. As for complex safety sciences, we need to equally account for the relationship between human actors from different fields - psychologists, geologists, frontline operators, philosophers, sociologists, engineers, divers, and welders - and non-human actors - sciences, disciplines, laws, regulations, techniques, unpublished indicators, audits, vessels, technologies, policies, practices. To this end, ANT contributes to new research connections to be produced in light of shifts that reach this socio-technical hybridity. To translate goals, interests, devices, and human beings (Latour, 2000), we must revive possible controversies connected with solution-oriented research based on conformed, ready, and unquestionable objects. Such processes can contribute to accessing the political tensions in realities provoked by the different actors associating themselves with the networks formed in complex socio-technical systems. We explore part of this epistemic trajectory of safety science research, which exposes essential gaps concerning the political dimension of this field, the relativization of complexity, and the simplification of heterogeneous relations. From this displacement by safety science, we identify possible collaborations of ANT to broaden the analytical potential of these networks. We are especially concerned about their heterogeneity and complexity since the problematization

of possible controversies (past, hidden, cold, limited) can highlight the different overlapping realities (multiplicity and political ontologies) that sustain and create, at least temporarily, the reality of the field.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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