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Camera monitoring and automation in sugarcane fire prevention: fundamentals for designing operational procedures and their impacts.

Camera monitoring and automation in sugarcane field fire prevention: foundations for the design of operational procedures and their impacts

Monitoring by cameras and automation in the prevention of fires in caves: fundamentals for the design of operational procedures and their impacts

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SUMMARY

With the gradual elimination of pre-harvest burning of sugarcane in the state of São Paulo, fire has ceased to be a management practice and has become an unplanned event, whose containment depends on early detection and rapid response. The fires recorded in August 2024, which led the state to the highest monthly number of hotspots in the INPE's historical series, reinforced the interest in camera monitoring systems and alarm automation. This article, developed through a narrative review of the scientific, technical, and regulatory literature, discusses the fundamentals that should guide the design and use of operational procedures supported by these technologies, as well as their impacts. The analysis brings together contributions from remote sensing, computer vision, cognitive ergonomics, safety engineering, and emergency management. The results indicate that system performance depends less on equipment specifications and more on the clear definition of automation levels, calibration of operator confidence, handling of false alarms, standardization of steps between alarm and firefighting, and integration with risk management and public policies for integrated fire management.

It can be concluded that well-structured procedures enhance the environmental, health, economic, and governance benefits of technology, provided they are accompanied by indicators and ongoing learning mechanisms.
Keywords: Sugarcane; Agricultural fires; Early detection; Automation; Operational procedures.

ABSTRACT

With the gradual phase-out of pre-harvest sugarcane burning in the state of São Paulo, Brazil, fire ceased to be a management practice and began to occur as an unplanned event, whose containment depends on early detection and rapid response. The fires recorded in August 2024, which brought the state to the highest monthly number of hotspots in the INPE historical series, increased interest in camera-based monitoring systems and alarm automation. This article, based on a narrative review of scientific, technical and regulatory literature, discusses the foundations that should guide the design and use of operational procedures supported by these technologies, as well as their impacts. The analysis draws on contributions from remote sensing, computer vision, cognitive ergonomics, safety engineering and emergency management. The results indicate that system performance depends less on equipment specifications and more on a clear definition of automation levels, the calibration of operator trust, the handling of false alarms, the standardization of the steps between alarm and suppression, and integration with risk management and public policies on integrated fire management. It is concluded that well-structured procedures enhance the environmental, health, economic and governance benefits of the technology, provided they are supported by indicators and permanent learning mechanisms.

Keywords: Sugarcane; Agricultural fires; Early detection; Automation; Operational procedures.

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1 INTRODUCTION

Sugarcane has a significant presence in São Paulo's agriculture and, at the beginning of the 2010s, occupied...
approximately 5 million hectares in the state of São Paulo, equivalent to 21.3% of its territory (Aguiar)
et al., 2011). For decades, fire was part of the production system itself, employed to
eliminate straw before manual cutting and increase the productivity of cutters (Saiani; Perosa,
2016). State Law No. 11.241/2002 established the gradual elimination of this practice, and the Protocol
The Agroenvironmental agreement signed in 2007 between the São Paulo state government and the productive sector brought forward the deadlines, the
which accelerated the mechanization of harvesting (São Paulo, 2002; Aguiar et al., 2011). With the replacement
With the planned burning for the harvesting of raw sugarcane, fire ceased to be a management tool and
It began to occur as an unplanned and unauthorized event. This change altered the nature of
The problem, which ceased to be the control of a programmed operation and became the detection and...
Responding to unpredictable events.

The events of August 2024 made the magnitude of this challenge evident. Program Data
Data from the National Institute for Space Research indicates that the state of São Paulo recorded wildfires.
that month saw the highest number of hotspots in its historical record, which began in 1998, and
Surveys by MapBiomas indicated that sugarcane areas were among the most affected.
affected (INPE, 2024a; MapBiomas, 2024). In this context, monitoring systems by
Cameras, control centers, and alarm automation have come to be seen as solutions.
Promising technologies. The literature on human factors and systems security shows,
However, technology alone does not guarantee performance, as its effects depend on the form.
how the procedures are designed, the way operators interact with the automation.
and integration with the response structure (Bainbridge, 1983; Parasuraman; Riley, 1997).

Given this, this article aims to discuss, in light of scientific, technical, and regulatory literature,
the fundamentals that should guide the design and use of operational procedures supported by
Camera monitoring and automation for fire prevention and initial firefighting in
sugarcane plantations, as well as the expected impacts of these procedures on the environmental, social, and environmental dimensions.
economic and governance. The aim is to offer a theoretical framework that contributes to the...
Investments in technology should be accompanied by coherent, measurable processes and
sustainable over time, preventing the acquisition of equipment from being confused with the
solution to the problem.

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2 METHODOLOGY

This is a qualitative and exploratory research study, conducted through a review.
The narrative of literature. The choice of this approach is justified by the interdisciplinary nature of the subject.
which involves remote sensing, computer vision, cognitive ergonomics, engineering of
safety, emergency management, environmental health, and public policy. Unlike the review.
systematic, whose focus is to answer a specific question based on a rigid protocol of
In the selection and extraction of data, narrative review allows for the articulation of frameworks from distinct fields and
to construct a theoretical synthesis aimed at understanding an applied problem, which corresponds to
purpose of this study.

The searches were conducted in academic search engines and in journal portals and
publishers such as SciELO, PubMed Central, MDPI, SpringerLink, and CSIRO Publishing, in addition to
Institutional repositories of Brazilian universities, with special attention to periodicals.
specialized in vegetation fires, such as Fire Safety Journal, International Journal of
Wildland Fire and Current Forestry Reports. The search terms combined, in Portuguese and English,
Terms related to fire detection, cameras, computer vision, automation, trust.
in automated systems, false alarms, initial attack, risk management, sugarcane and burning
straw. Regulatory and technical documents were also analyzed, including federal legislation.
and Paulista on the use of fire and integrated management, the doctrine of the incident command system
Adopted in the United States, the ABNT NBR ISO 31000 standard and the bulletins of the Wildfire Program.
from INPE.

The selection prioritized peer-reviewed studies, official documents, and reference works.
widely cited in their fields, without strict time restrictions, since part of
Theoretical foundations regarding automation and human error were formulated in the 1980s and 1990s.
remains current. The quantitative data presented were extracted from public sources, such as the
INPE, MapBiomas, and the reports from the Agroenvironmental Protocol are used only for
To contextualize the problem, the analysis was organized into six thematic axes, which structure the sections.
The following sections discuss the context of fires in sugarcane fields and the impacts of the procedures.
operational. Because it is a review, the study does not empirically test hypotheses, and its conclusions
They should be understood as theoretical propositions to be verified through field research.

3. FIRE IN SUGARCANE FIELDS AFTER THE END OF PRE-HARVEST BURNING

Burning the straw before manual harvesting was, for a long time, a common practice in sugarcane cultivation.

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Brazilian, because it facilitates cutting costs and increases workers' income (Saiani; Perosa, 2016). The Federal Decree No. 2,661/1998 regulated the use of fire in agricultural, livestock, and forestry practices. through controlled burning, and in the state of São Paulo, Law No. 11.241/2002 established a schedule. of gradual elimination, with different deadlines for mechanizable and non-mechanizable areas (Brazil, 1998; São Paulo, 2002). The Agro-environmental Protocol of the Sugar-Energy Sector, signed in 2007, It brought forward these deadlines for the signatory units, and monitoring via satellite imagery.

A study conducted by INPE researchers showed a significant increase in harvesting without burning in the years following, especially in areas of crop expansion (Aguiar et al., 2011). In 2006, approximately 34.7% According to mapping with images from [source], no burning occurred in the mechanizable area harvested in the state. Landsat satellite (Aguiar et al., 2009), and, according to the Protocol reports, harvesting without Burning among signatories reached 72.6% in the 2012/2013 harvest, 83.7% in the 2013/2014 harvest, and 91.3%. in the 2015/2016 harvest (São Paulo, 2014, 2016).

Eliminating burning addressed well-documented environmental and health concerns. Cançado et al. (2006), when analyzing almost a year of data in Piracicaba, found that increases The concentrations of particulate matter associated with sugarcane burning were related to Increases in hospitalizations for respiratory illnesses among children and the elderly, with more intense effects. during the burning season. Ribeiro (2008), in a review of studies published between 1996 and 2006, concluded The elderly, children, and asthmatics are among the most affected groups, which generates additional demand. regarding health services. Arbex et al. (2004) had already gathered evidence on the effects of biomass burning in the respiratory system, and Saiani and Perosa (2016) found, in an analysis of Panel data from municipalities in São Paulo, relationship between the advancement of mechanization and the reduction of respiratory hospitalizations, especially among the elderly. These results indicate that fire in In sugarcane fields, even when accidental, it represents not only a loss of productivity, but also a public health problem.

With the end of planned burning, the nature of fires in sugarcane fields changes. Before, there was an operation. subject to prior authorization and planning (Brazil, 1998), whereas now the occurrence is, by The harvest of raw sugarcane is a non-scheduled process that can begin outside the producer's control. It maintains a layer of straw on the soil, which has agronomic benefits for soil conservation. Nutrient cycling and moisture retention are widely discussed in the literature (Carvalho et al., 2017). From the point of view of fire risk, however, this layer constitutes material Continuous fuel, whose flammability depends on moisture content, charge and arrangement, variables that classical propagation models, such as the one proposed by Rothermel (1972), They identify factors that determine the speed at which the flames advance. Fire management therefore becomes... requiring vigilance throughout the dry season, not just during the harvest period.

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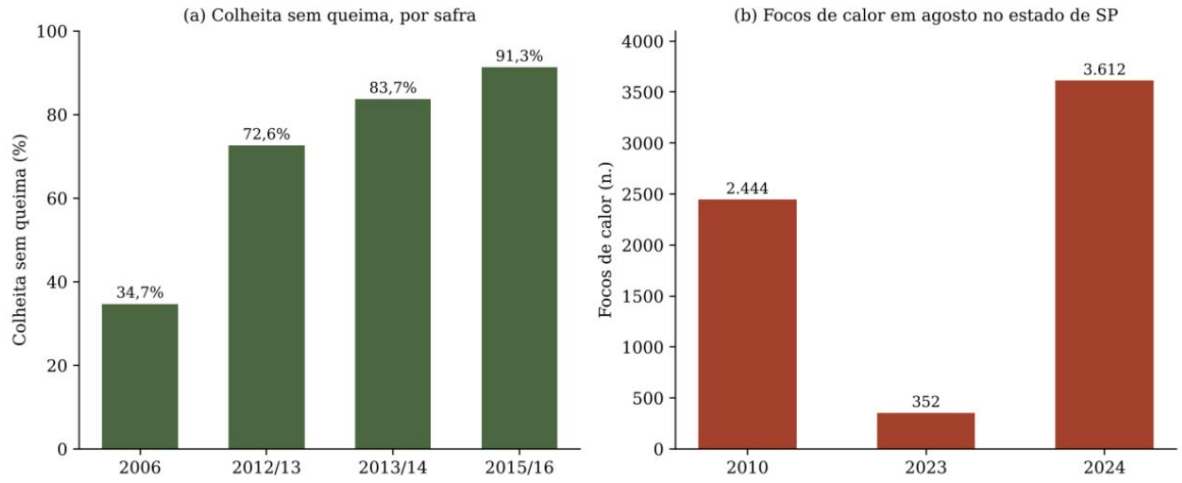
The events of 2024 illustrate the scale that this risk can reach. According to the database
According to the Burnings Program, the state of São Paulo recorded 3,612 hotspots in August of that year.
According to the reference satellite, this is the highest monthly value since the beginning of the historical series, compared to 352 hotspots in...
same month of 2023 and 2,444 in August 2010, until then the most critical August in the series (INPE, 2024a). The MapBiomas Fire Monitor estimated that approximately 430,000 hectares burned in state between January and August 2024, with 86% of the burned area concentrated in August and predominance of agricultural areas, especially sugarcane plantations, which totaled approximately 236 thousand hectares affected during the period (MapBiomas, 2024). Figure 1 summarizes this trajectory, by to contrast the progress of harvesting without burning with the recent behavior of hotspots in the state, and suggests that the planned fire reduction was not accompanied by a proportional reduction in risk.

Figure 1 – Sugarcane harvest without burning in the state of São Paulo (a) and recorded heat spots in August in the state by the reference satellite (b)



Source: Prepared by the author based on Aguiar et al. (2009), São Paulo (2014, 2016) and INPE (2024a). Note: the 2006 value refers to the mechanizable area harvested in the state, and the others to the signatory units of the Agro-environmental Protocol.

The comparison suggests an important lesson for management. The reduction in planned burning does not It eliminated the risk of fires in sugarcane fields, but shifted it to another category, in which the The combination of extreme weather, accumulated combustible material, and scattered ignition sources can to produce simultaneous events of great magnitude. In such situations, the ability to detect Quickly starting a fire and activating the appropriate response becomes one of the factors under control. Directly from the producer, since the response time and the size of the fire at the start of combat influence the probability of success of the initial attack (Arienti; Cumming; Boutin, 2006). It is in this This is where camera monitoring and automation gain relevance, provided they are accompanied by... of procedures capable of transforming information into effective action, which constitutes the object of

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subsequent sections.

4 TECHNICAL FUNDAMENTALS OF EARLY DETECTION

Fire detection in open areas can be carried out by different means, each with...
scope, resolution, and inherent limitations. Alkhatib (2014), in a review of available techniques, groups
solutions in human observation, satellite-based systems, optical cameras and networks of
wireless sensors, and highlights that none of them is superior in all criteria, which makes it common to
combination of methods. Barmpoutis et al. (2020) organize optical sensing systems into
terrestrial, aerial and orbital, and show that the choice depends on the trade-off between area covered,
Frequency of observation, minimum detectable fire size, and cost. For sugarcane field management,
This distinction is relevant because each detection layer answers a different question about
Fire, whether it be the existence of a fire outbreak in a specific region, its precise location, or its evolution.
over time.

The orbital systems offer broad and standardized coverage. The contextual algorithm developed
The MODIS sensor identifies pixels with thermal anomalies relative to their surroundings and has become...
Reference for global active fire monitoring (Giglio et al., 2003). The product of 375 meters
The VIIRS sensor has expanded the ability to detect smaller fires compared to previous products.
coarser resolution (Schroeder et al., 2014). In Brazil, the INPE's Wildfire Program
It processes approximately two hundred images received daily from eleven different satellites and adopts a
Reference satellite to ensure consistent temporal comparisons (INPE, 2024b). The limitation
The operational response of these platforms depends on the frequency of passage and spatial resolution.
and in the interference of clouds and smoke, which makes orbital data more useful for regional surveillance.
and the historical analysis of what is needed for the immediate deployment of teams in a specific plot.

Cameras installed on towers fill part of this gap by allowing continuous observation of
a defined area. Barmpoutis et al. (2020) describe terrestrial systems composed of cameras.
fixed cameras, cameras with rotation and zoom control, or panoramic view cameras, equipped with
sensors in the visible spectrum, in the infrared, or both, and highlight that the positioning
It needs to ensure adequate visibility of the terrain. Video detection algorithms combine
color, movement, texture and temporal variation characteristics of flames and smoke (Çetin et al.,
(2013). In vegetation fires, smoke tends to become visible before the flames, which is why
whose detection receives prominence in surveillance applications (Çetin et al., 2013). In sugarcane fields, the
São Paulo state legislation considers areas with a slope of up to 12% suitable for mechanization (São Paulo, 2002).
topographical conditions that tend to favor long-range vision, although the extent of the crops

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Require networks with multiple towers for continuous coverage.

The advancement of convolutional neural networks has brought performance gains to detection systems.
in video. Muhammad et al. (2018) proposed a convolutional neural network architecture of
Reduced computational cost for detecting fire in surveillance camera videos, and they reported, in
Reference databases, superior performance compared to state-of-the-art methods. Barmpoutis et
al. (2020) note, however, that false alarms remain among the limitations of the systems.
terrestrial optics, which led several researchers to employ infrared cameras to
reduce them. In the agricultural environment, it is plausible that the dust raised by machines, the smoke from
Boilers and the harvesting activity itself produce visual patterns similar to those of a fire.
This initial hypothesis reinforces the need to calibrate systems to local conditions and to predict...
Confirmation steps in operational procedures.

Field evidence reinforces the need for caution regarding the expected performance of these
technologies. Matthews et al. (2012) evaluated two image-based detection systems in
Operating conditions in southeastern Australia, in forest and grassland areas. The systems
They detected and located the fires and performed well on larger fires, but
They showed poor results for small fires located at moderate distances, between 10 and 20 meters.
kilometers. In a subset of occurrences compared with the performance of an observer.
The human test showed a higher detection rate and shorter communication time, leading the authors to conclude...
that image detection can serve as a useful complement to existing methods. For the
In sugarcane fields, the lesson is that actual performance depends on the size of the focus, the distance, and the conditions.
atmospheric conditions and integration with other sources of information, and not just technical specifications.
of the equipment.

5. Automation and the Role of the Human Operator

Introducing smart cameras into an operations center does not eliminate the need for a human operator.
but redefines its role. Parasuraman, Sheridan and Wickens (2000) proposed a model in which the
Automation can operate in four functions: information acquisition, information analysis, and...
selection of decisions and implementation of actions, each with varying levels of autonomy.
Applied to sugarcane field monitoring, the model helps to separate what is expected from the technology into
each step. The camera and algorithm can acquire and analyze images with a high degree of automation.
while the decision to mobilize brigades, water trucks or external support may remain with the
operator or field leadership. Explicitly defining these levels is the first step towards
Designing coherent procedures avoids gaps in responsibility and overlaps.

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They delay the response.

Bainbridge (1983) described the so-called ironies of automation by observing that the more one
The system is automated, but the operator is responsible for the difficult tasks, such as
To monitor rare events over long periods and take control in abnormal situations. The author
He pointed out that prolonged surveillance of systems that rarely experience incidents is a task.
for which humans have limited performance, and loss of practice reduces the ability to
Intervention occurs when it becomes necessary. This is done in a control center that monitors dozens of cameras.
During the dry season months, with most hours devoid of significant events, this paradox arises.
This manifests itself in a concrete way. The procedures therefore need to provide for job rotation, breaks,
simulated exercises and attention-maintenance mechanisms, and not just instructions on what
Do this when the alarm sounds.

Parasuraman and Riley (1997) distinguished four forms of relationship with automation, which are the use
proper use, misuse, characterized by overconfidence, and disuse, which occurs when the operator
Ignoring or shutting down the system, and abuse, when automation is deployed without considering its...
consequences for human performance. Lee and See (2004) argue that the goal is not
Maximize confidence in automation, but calibrate it so that it matches the actual capacity.
of the system in each context. In fire monitoring, overconfidence leads the operator
to stop visually inspecting areas where the algorithm did not issue an alert, while the
Distrust leads to the dismissal of genuine alarms. Both deviations have a cost, and calibration...
It depends on transparent information about the system's success and failure rates across different systems.
operating conditions.

The issue of false alarms deserves particular attention. Breznitz (1984) analyzed the phenomenon.
known as the false alarm effect, in which repeatedly unfounded alerts reduce the
The credibility of the following warnings. Dixon, Wickens and McCarley (2007) showed
Experimental research has shown that automation prone to false alarms negatively impacts overall performance.
more than an automation prone to omissions, it affected the operator's willingness to follow the rules.
alerts regarding your confidence in the system when it remained silent. For control centers
Agricultural monitoring, where dust, industrial smoke, and management activities can generate
stimuli similar to fire, this evidence implies that the sensitivity of the algorithm cannot be
adjusted solely for the purpose of not losing any focus. The alarm threshold should consider the
The cost of each type of error should be considered, and procedures should include a quick and standardized step for...
verification.

Endsley (1995) defined situational awareness at three levels, which correspond to the perception of
elements of the environment, to understanding their meaning and projecting their future state. One

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The camera alarm responds, at most, to the first level. For the operator to understand what is happening...
As the fire progresses and projects its evolution, it needs additional information, such as direction.
and wind intensity, relative air humidity, sugarcane stage and straw condition, proximity
sensitive areas and location of available teams. The integration of these layers into a single
The interface, with georeferenced maps and meteorological indicators, is what differentiates a control center.
capable of supporting decisions from a simple video room. The procedure design should start from
decisions that the operator needs to make, and only then define which data should be presented and in what context.
What format?

6. DESIGN OF OPERATIONAL PROCEDURES FROM ALARM TO RESPONSE

Effective detection only translates into harm reduction when it is followed by a rapid response and
appropriate. The literature on vegetation fires treats this stage as an initial attack, and Arienti,
Cumming and Boutin (2006) differentiate between failure to respond, when combat does not begin before
a given time or fire size limit, or a containment failure, when the team arrives
They arrived at the scene but were unable to control the fire. The authorities identified that the fuels...
Weather conditions, the presence of roads, and management variables influence the probability of
success. This distinction is useful for sugarcane fields because it shows that reducing detection time is
necessary, but insufficient, if the teams' travel time, the availability of water and the
accessibility of the plots is not addressed in the same procedure.
Plucinski (2019) shows that the effectiveness of suppression can be evaluated on different scales, from
the flames and the fire line, all the way to the full incident and the landscape, and that each scale requires indicators.
own. This perspective helps to structure the procedure into measurable steps. It is proposed, in this
The study should include signal detection, operator verification, and classification of the signal.
The event, the dispatch of resources, the arrival of the first team, the start of the combat, the containment.
and the aftermath. Each transition can be recorded with the time and person responsible, which allows for identification.
where time is wasted and where decisions fail. Without this record, the organization only knows if the
The fire was controlled or not, but he doesn't understand why, and he misses the main source of learning.
for the following harvests.
Standardization of the response is referenced in the Incident Command System, incorporated
to the U.S. National Incident Management System. The document establishes principles such as
common terminology, modular organization, defined chain of command, span of control
manageable and unified command when multiple institutions work together (FEMA, 2017).
Although designed for larger-scale emergencies, this framework offers applicable logic.

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to agricultural operations, especially when a fire crosses the property boundaries and becomes
Involve neighbors, fire department, civil defense, and highway concessionaires. Procedures
Internal procedures that already adopt clear roles, standardized language, and escalation criteria facilitate this.
Integration with public bodies prevents coordination from being improvised, precisely in the context of...
most critical moment of the event.

A central aspect of the design is the definition of classification and scaling criteria. Martell
(2015) analyzes fire management from a supply chain perspective and reviews support systems.
decision-making based on operational research focused on planning and resource allocation.
suppression. In practical terms, it is proposed that the procedure indicate, for each risk combination
Given the meteorological factors, the initial location and size of the fire, which resources should be activated and within what timeframe.
Hollnagel (2014) warns, however, that there is a difference between work as imagined by
designers and the work as it is actually performed, and the variability in people's performance.
It is also a source of successful adaptation. Therefore, the criteria must be clear enough to
to guide quick decisions, but not so rigid as to prevent adjustments in the face of unforeseen situations.
planned.

Operational procedures also need ongoing review mechanisms. Leveson
(2011) proposes understanding safety as a control problem, in which accidents
result from inadequate or unapplied restrictions on the system's behavior, and not only from
component failures. From this perspective, each fire occurrence, including false alarms and...
Near misses reveal something about the adequacy of existing constraints and feedback loops.
The systematic analysis of these occurrences, combined with periodic simulations carried out before the start of the
During the dry season, it allows you to update access routes, water collection points, contact lists, and...
assignment of responsibilities. A procedure that is not practiced tends to become detached from...
operational reality and a loss of credibility with the teams that should be implementing it.

7. Integration with Risk Management and Prevention

Detection and response are only part of a broader fire risk management strategy.
The ABNT NBR ISO 31000 standard describes a process that involves establishing the context,
The identification, analysis, evaluation, and treatment of risks, accompanied by monitoring.
Critical analysis, communication, and continuous consultation (ABNT, 2018). Applied to sugarcane fields, this
The structure allows mapping ignition sources, such as highways, railways, transmission lines, and areas.
urban and mechanized operations, and cross-reference them with the vulnerability of the plots and the importance
of the exposed assets. The result guides both the location of the cameras and the measurements

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Preventive measures, such as the construction and maintenance of firebreaks and access roads, and the restriction of activities. of greater risk on critical days.

The risk of fire varies daily depending on weather conditions, and this Behavior can be incorporated into procedures through hazard indices. The system The Canadian meteorological fire hazard index, described by Van Wagner (1987), uses Temperature, relative humidity, wind speed, and precipitation are used to estimate fuel moisture content and potential fire behavior. Such indices, adapted to local conditions, They can define readiness levels that alter the intensity of monitoring, the availability of teams and the restriction of operations. In this way, the procedure ceases to be static and becomes... Responding to the risk of the day, concentrating resources when the probability of ignition and spread is highest. It is larger, without maintaining operations on high alert throughout the entire season.

Reason (1997) showed that organizational accidents rarely result from a single failure and These generally result from the alignment of weaknesses in various defense barriers, many of which latent and originating from managerial decisions distant from the event. In the context of the fires in sugarcane fields, cameras, firebreaks, brigades, water trucks, and communication protocols make up successive layers of defense, and the effectiveness of the whole depends on none of them being... neglected due to the trust placed in others. Rasmussen (1997) adds that, under Under pressure for efficiency and reduced workload, organizations tend to gradually migrate towards the limits of safe performance. In light of this model, the introduction of Monitoring technology could, paradoxically, fuel this migration if it were used. as justification for reducing the maintenance of firebreaks or the number of brigades.

The regulatory environment also reinforces the need for integration. Federal Law No. 14.944/2024 established the National Integrated Fire Management Policy, with instruments such as plans for integrated fire management, fire brigade programs and the National Fire Information System Fire, and established as a principle the shared responsibility of the federative entities in coordination. with civil society and the productive sectors (Brazil, 2024). In the state of São Paulo, Law No. Law 17.460/2021 had already established the state policy on the subject (São Paulo, 2021). In defining the Integrated fire management as a planning and management model; this framework shifts management... from a purely reactive logic of fire prevention to a planning logic, in which prevention, Preparation, response, and recovery are handled in a coordinated manner. Business procedures Those aligned with this model can facilitate cooperation with public bodies, in accordance with the participatory and shared management guideline foreseen in the law, which includes the private sector (Brazil, 2024).

Prevention in sugarcane fields also has a territorial dimension that goes beyond the limits of each individual area.

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property. Between August 22 and 24, 2024, the state recorded 2,621 hotspots, distributed by different regions (INPE, 2024a), a situation in which an individual structure is unlikely. would be able to respond to all occurrences at the same time. The sharing of images and Alerts between neighboring mills, sugarcane suppliers, municipalities, and fire departments could increase the risk. Effective coverage and reduced redundancies. For this to work, the procedures need to provide for... communication protocols, responsibilities in border areas, and rules for shared use of resources, issues that depend on both institutional agreements and technological solutions. compatible with each other.

8 ENVIRONMENTAL, SOCIAL, ECONOMIC AND GOVERNANCE IMPACTS

Well-designed detection and response procedures produce impacts that go beyond protection. In agriculture, containing fires in their early stages reduces the burned area. and consequently, emissions of gases and particles, loss of surface organic matter and the damage to fragments of native vegetation, permanent preservation areas and legal reserves that They may be interspersed among the sugarcane fields. The preserved straw continues to perform the functions of soil protection and nutrient cycling discussed by Carvalho et al. (2017). In addition, the Reducing the recurrence of fire in the same area tends to benefit the conservation of these [areas]. fragments and the biodiversity associated with them.

In the fields of health and society, studies conducted in the interior of São Paulo state allow us to measure... The importance of prevention. If smoke from planned burning was associated with an increase in Given the high number of respiratory hospitalizations in children and the elderly (Cançado et al., 2006; Ribeiro, 2008), it is reasonable to assume that large-scale accidental fires produce similar effects on populations. exposed, with the aggravating factor that they occur without prior notice and often during low periods. Air humidity. Reducing the burned area through rapid detection and response contributes to this. Therefore, to protect the health of neighboring communities and the workers themselves. As noted Ribeiro (2008) states that these effects also translate into additional demand on health services. which broadens the social scope of the problem beyond the boundaries of property.

From an economic standpoint, the procedures need to be evaluated based on a broad perspective. Cost-benefit analysis. Costs include cameras, towers, connectivity, software, and staff. Monitoring, maintenance, and training. The benefits include reducing sugarcane losses, damage to the stubble and infrastructure, costs of firefighting and environmental and legal liabilities, in addition to Preserving relationships with communities and public bodies. The literature on initial attack. This indicates that fires that escape this phase tend to grow and require more resources, and that

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Longer response times increase the probability of failure (Arienti; Cumming; Boutin,
(2006). Measuring these benefits, however, requires reliable historical series of occurrences.
Response times and affected areas, which again highlights the importance of systematic record-keeping.
of each step of the procedure.

The expansion of camera surveillance also raises data governance issues. Cameras
Long-range cameras installed near highways, villages, and urban areas can capture
Images of people and vehicles, which requires compliance with the General Data Protection Law.
which establishes principles such as purpose, suitability, necessity, transparency and safety in
data processing (Brazil, 2018). The procedures must define who accesses the images, by
How long are they stored, and under what situations can they be shared with authorities?
and how they are protected against unauthorized access. On the other hand, well-managed records
They can support investigations into the origin of the fires and strengthen the company's position in
administrative or judicial proceedings, provided that the integrity and traceability of the images are
preserved.

The impacts of the procedures can only be demonstrated if there are adequate indicators.
Plucinski (2019) highlights the difficulty in measuring the effectiveness of suppression, due to the influence
simultaneous analysis of multiple variables, and shows that the results depend on the scale at which they are analyzed.
evaluated. For sugarcane fields, indicators such as the time between estimated ignition and detection, the time
between detection and dispatch, the time until the arrival of the first team, the proportion of fires
contained in the initial attack, the average area per occurrence and the false alarm rate allow
To monitor performance across harvests. Associated with the analysis of occurrences and review.
Periodic procedures, these indicators transform monitoring into an instrument of
Organizational learning, and not just as a surveillance tool.

CONCLUSION

The elimination of pre-harvest burning represented a significant environmental and health advancement for the
The sugarcane and energy sector in São Paulo has changed, but it hasn't eliminated the burning of sugarcane fields. What has changed is the nature of the environment.
of the risk, which went from a planned and controlled operation to unexpected events, of origin
diverse and potentially simultaneous. In this new condition, the ability to detect early and
Responding quickly has become a crucial factor in management's reach, as demonstrated by...
Episodes from 2024 in the state of São Paulo.

The review showed that the detection technologies are complementary and that none of them solves the problem.
the problem in isolation. Satellites offer regional and historical views, while cameras in

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Towers allow for continuous observation of specific areas. Field evidence indicates, however,
The actual performance of cameras varies depending on focus size, distance, and conditions.
atmospheric factors, which suggests treating them as part of a broader system, and not as a solution.
self-sufficient.

Automation redefines the operator's job, without eliminating it. The fundamentals of ergonomics.
Cognitive studies show that prolonged vigilance of rare events is a difficult task for humans.
...and that confidence in automation needs to be calibrated, not maximized. Therefore, procedures...
Effective strategies begin with explicitly defining what is the machine's responsibility and what is the people's responsibility in each task.
This stage, from acquiring the image to deciding to mobilize resources for combating the virus, is crucial.
False alarms are a critical point for the sustainability of these systems. When
Frequent occurrences reduce the credibility of alerts and compromise the response to events.
true. The definition of alarm thresholds must consider the cost of each type of error, and the
Procedures should include a quick and standardized verification step, especially in
agricultural environments in which dust, industrial fumes, and mechanized operations produce signals
similar to those of an initial fire.

The procedure design should cover the entire chain from alarm to fire control, with steps...
Measurable, with clearly defined responsibilities and clear criteria for classification and scaling. Benchmarks
How does the incident command system offer useful principles of standardization and integration?
with public bodies. At the same time, the criteria need to leave room for judgment of
teams are faced with unforeseen situations, since the actual work rarely coincides completely with...
the prescribed work.
Monitoring technology should be integrated into risk management and hazard indices.
meteorological and other defense barriers, such as firebreaks, brigades, and firefighting resources. There is the
risk that the adoption of cameras will be used to justify the reduction of these other layers, which
This goes against the fundamentals of system security and can increase the vulnerability of the operation.
The National Integrated Fire Management Policy reinforces this integrated vision by valuing the
planning, prevention and cooperation among the various actors.
The impacts of well-structured procedures reach several dimensions. In the environmental sphere,
They tend to reduce the burned area and emissions. On a social level, they contribute to protecting health.
of neighboring populations and to contain the demand on health services. On the economic front,
They reduce losses and liabilities, and in terms of governance, they require attention to data handling.
Personal information captured by the cameras. In all these cases, proof of benefits depends on...
The existence of consistent indicators and systematic records of each occurrence.
As this is a narrative review, this study has limitations, including the absence of verification.

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empirical evidence of the propositions and the predominance of evidence produced in forest contexts of other countries. It is recommended that future research evaluate the performance in Brazilian sugarcane fields. of different detection systems, the effective times of each response step, the alarm rates falsehoods in real-world conditions and the cost-benefit relationship of investments, in order to consolidate a proprietary evidence base for the sector.

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