“Ouch, that speed hurts”: How cost algorithms in modern autopilots change the aesthetics of flying airplanes

David Crvelin
HEC Paris

Victoria Honsel
University of St. Gallen

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Abstract

In this paper, we draw attention to the so far largely ignored roles of cost saving software in transport and mobility systems. Based on an in-depth qualitative study of modern flying, we examine the ways in which cost management algorithms are increasingly used to bypass human operators for making complex technological architectures work more cost-efficiently. The case studies the implications of this ‘invisibilization’ of accounting by focusing on two types of cost management algorithms that are nowadays an integral part of airplanes’ autopilot: the cost index (CI) and take-off performance calculation (TOP). The study highlights how airlines, over time, have shifted from encouraging pilots to perform manual cost management towards letting the aircraft ‘think’ itself about what makes a flight most cost-efficient. We outline how this strategic change from explicitly fostering pilots’ cost sensibility towards implanting a cost-saving rationale directly into an airplane’s technological ‘brain’ fundamentally redefines how pilots see themselves, how they handle their instruments, what excites them about flying, and how they cope with non-routine situations. By showing the unique ways cost-saving algorithms in transport systems infuse human users, the paper provides scholarship with new insights on how organizations can implement strategic accounting intentions and make non-accounting professionals engage with such an accounting rationale.

Keywords: accounting implementation, cost-saving algorithms, autopilot, embodiment

1. Introduction

> "Of course, it's about the survival of the passengers.
> But it's also about our survival as a company."[1]

On 9th June 2024, the airplane manufacturer Airbus announced plans to equip its airplanes with new and enhanced flight management computers (FMS). Representing the 'brain' of an aircraft, the FMS helps in planning flights and calculating flight paths and increasingly conditions pilots' cost management decisions. Importantly, the FMS is not just a passive information system detached from those technical systems necessary to keep the aircraft flying. Rather, depending upon the inputs, the FMS actively interferes with the technical configurations of the aircraft during a flight, including power setting, climb- or descent rates, bank angle, speed brakes, rudder trim, flap parameters, etc. While the pilots are the ones feeding the FMS with inputs, the ways in which the system interferes with the aircraft's maneuvering during the act of flying are not directly imminent to the operators. The software functions as an intermediary between pilots' control inputs and the aircraft's mechanical execution; it puts each control input in relation to the predefined efficiency criteria of the airplane and can also override commands (unless it would be manually disengaged, of course).

The interesting part of Airbus' announcement is that it explicitly expressed the vision to assign even more power to the FMS in interpreting and adjusting the pilot's commands following cost-efficiency rationales. The new version, advertised as *Integrated Flight Control Computer* (IFCC), is a high-utility software system that optimizes flying by being unprecedently interwoven with the autopilots. More explicitly than ever before, Airbus motivated the increasing authority given to the FMS by improving the potential for cost management and fuel reduction. Thereby, Airbus' announcement marked a new milestone in a long history of struggles to make cost management an integral part of commercial flight operations. While earlier attempts to translate cost-saving rationales into pilots' flying were driven by training-, education- or incentivization initiatives, the FMS allowed infusing the cockpit systems directly with this accounting logic via algorithms and cost indices. Rather than working through pilots, the new systems give the accounting and finance departments of airlines direct access to the airplane's behavior at all stages

[1] Quoted from interviews with a former head of operations at a large European airline.

of a flight. Understanding the significant consequences resulting from the fact that airplanes' increasing 'think' in terms of cost is at the core of this paper.

Analyzing these consequences matters more generally because the trend to equip modern technological systems with 'eco modes' extends well beyond the aviation sector: data-driven models are used to optimize train driving patterns to save up to 7% of CO2 emissions (Global Railway Review, 2024), and automated vehicles on the street provide additional opportunities for fuel-saving (Jungblut et al., 2023). Despite this trend of coupling everyday mobilities with cost-saving rationales, we know very little about this algorithmic form of control. While some research has started to explore the impact of hidden cost algorithms working throughout digital platforms (Kornberger et al., 2017), research on how this 'invisibilization' of accounting and control impacts those operating mobility systems is scarce. Indeed, many calculative practices in high-risk technologies, ranging from nuclear power plants to civil jetliners, "are both opaque to the public gaze and largely neglected by sociologists of accounting" (Downer, 2011, p. 269).

This paper, therefore, contributes to research by investigating the implications of an increasing cost sensitivity in how airplanes are operated. The analysis is based on interviews with pilots and airlines' operating managers, shadowing pilots while flying passenger jets, observations of crew's reaction to abnormal situations in a full-scale flight training simulator of a large airline (Level D certified), and an analysis of approximately 750 incident reports related to both manual and algorithmic cost management. We outline the ways in which the shift from educating pilots in cost sensibility towards making cost reductions an integral part of how airplanes 'think' redefines the ways in which pilots think of themselves, how they handle their machines, what excites them about flying, and how they handle non-routine situations.

Theoretically, we build upon the work of Michael Polanyi and his distinction between tacit- and focal awareness (Polanyi, 1968; Polanyi & Prosch, 1975a) to understand the changing ways in which airplanes are flown in the wake of algorithmic cost management as well as the implications for the crew's performance when flying. The findings highlight that algorithmic control has significantly reconditioned both the *feel* and the *aesthetic* of flying. The pilots' sense of comfort with noise levels, acceleration, visual markers, and turbulence has fundamentally changed as a consequence of cost algorithms' interventions at all stages of the flight. Our case points out how these algorithms have contributed to a new standard of flying that is driven by seduction to get the airplane to its destination with maximum cost efficiency. We observe that pilots tend to feel guilty if their bodies sense that the airplane is running at technical capacity limits. The paper, therefore, shows how a cost-saving intention is not primarily implanted in pilots' minds via training, education, or incentive systems, but instead, the algorithmic control in mobility systems works differently: they tend to implant cost-saving rationales into our bodies rather than our minds. We demonstrate how this not only matters because potential frictions between accounting- and safety concerns become more difficult to separate but also because such algorithms inhabit an invasive nature over human-machine configuration in their entirety. Specifically, the cost saving algorithms tend to also hijack the functioning of other airplane controls through pilots' desire to optimize the airplane's efficiency at all stages. Using cost management programs such as "take-off performance" or "cost index" provokes pilots to further experiment with other controls and procedures which in turn opens new possibilities for re-utilizing the cost-saving software. While most research on aircraft automation has shown how pilots feel discomfort with the increasing authority of autopilots (e.g., Chow et al., 2014; Degani et al., 2013; Elish & Hwang, 2015; Oliver et al., 2017), we illustrate how cost algorithms' redefinition of pilots role in fuel management can also create a form of excitement, triggered by the ambition to outperform oneself (and the machines) in terms of cost-saving.

The remainder of this paper is organized as follows: the next section will provide a literature review of prior work highlighting how digital technologies are transforming everyday accounting practice. This will be followed by a review of what we know about sense-making and cognition in a cockpit, underpinned by our theoretical anchor of Michael Polanyi's different levels of knowledge. After detailing the methodology and data collection, we will introduce two algorithmic cost programs that are integrated into the autopilot of modern airplanes: take-off performance (TOP) and cost index (CI). Here we will demonstrate how these systems have historically gained ever more authority over the aircraft. The second part of the empirical discussion will provide a vignette of an aircraft simulator experiment that we conducted to understand how cost-efficiency algorithms have changed the aesthetic of flying. Lastly, the third part will provide an analysis of crew reactions to abnormal situations caused by an other-than-expected functioning of the cost-saving software. In the discussion and conclusion, we will reflect also more broadly upon the importance and implications of studying the diffusion of costing systems in our everyday transport systems.

2. Non-accounting professionals as calculative agents, digital technologies, and the 'invisibilization' of accounting

Implementing strategic management ideas and an accounting logic necessary to facilitate organizational change therein is an everyday task for any organization. Extensive research has already investigated how such change is brought into the organization, packaged into operational tools and practices, and eventually implemented among organizational members. Employees with professional backgrounds and experience in accounting and finance likely buy into the reasoning behind accounting change rather easily, with new rationales being – at least seemingly – accepted if they appear to increase efficiency, accuracy, or compliance with external requirements (cfr. Briers & Chua, 2001; Clerkin & Quinn, 2021; Major & Hopper, 2005). Next to these "calculative centers", which have been the traditional anchor of accounting's power (cfr. Robson, 1992), research points to the tendency of accounting to become more diffuse and increasingly infuse the everyday actions of users, operators, or workers in an organization's periphery. This decentralization deemphasizes the skillful accountant in corporate headquarters and allows ever more actors to become calculative agents. Hence, organizations must engage also non-accounting professionals with a new accounting rationale to achieve organizational change. But how are non-accounting professionals turned into calculative agents?

While this question is relevant for any organization, it received particular attention in certain industries. For instance, given the increasing financial pressure on healthcare organizations, studies have explored how medical professionals are learning to integrate calculative practices into their daily routines (Martin et al., 2020). Extensive training in management and accounting skills was of crucial relevance, for example, when introducing new accounting rationales and public management practices in the Finnish healthcare system (Kurunmäki, 2004) or when developing and selling a balanced scorecard to medical professionals (Qu & Cooper, 2011). Also, beyond the healthcare sector, workshops, training seminars, and various education initiatives are a common approach to introduce non-accounting professionals to cost-saving rationales. For example, Oakes, Townley & Cooper (1998) famously described how staff in a publicly owned museum had to learn to account differently for their work and develop other ways of viewing the organization. Thereby, business planning functioned as a pedagogic practice, in which employees amend their organization's fundamental identities, a "form of learning through discovery and self-reflection" (1998, p. 274). Similarly, in NGOs, it is common practice to familiarize non-accounting staff, like social workers or teachers, with accounting rationales via dedicated training events. But even when changing accounting via training and education, studies refer to organizations and whole industry sectors that have faced resistance among employees (cfr. Girei, 2022; Kurunmäki, 2004; Qu & Cooper, 2011). By targeting employees' reasoning, training initiatives approach non-accounting professionals and their cognitive minds directly with new accounting rationales. Given this direct approach to reasoning, this strategy of implanting an accounting rationale among employees might not be successful, if the intended accounting logic clashes with the motivations, norms, and values of the social workers or medical professionals (e.g. Agyemang et al., 2017; Chenhall et al., 2010, 2017; Hall, 2017; Martin et al., 2020).

Besides the reliance on training and education initiatives, accounting implementation is also often facilitated by incentive and bonus systems (cfr. Dambrin & Robson, 2011). In contrast to the potentially more subversive or subtle influence of pedagogical approaches on employees' minds, incentive systems rather obviously demand employees to prioritize, for example, cost-saving rationales for monetary rewards. Despite this potential of directly conditioning employees' behavior, incentive systems can imply a potential for detrimental psychological effects, such as the triggering of unethical behavior for increasing financial rewards. Unsurprisingly, it is thus no common practice in the aviation industry to reward pilots for saving fuel, as the airlines could not make public a monetary incentive for pilots that might entail their deprioritizing of security concerns.

Today, digital technologies and algorithmic management have fundamentally changed the ways in which cost accounting and control works – and they entail an unprecedented decentralization and "invisibilization" of accounting. Jaecle and Carter (2023) show in a study on mandatory calorie labeling in the UK how these 'simple' counting and ratings allow everyone to engage in the accounting of the body without any effort. Indeed, smartphone apps, quickly accessible coordination software, or more comprehensible programming languages allow everyone to become an accountant of his- or herself. As noted by Humphreys (2018, p. 29), "enumerating activities, events, and experiences can be part of what we do when we engage in media accounting. Enumeration is easy to see in the contemporary social media environment." In organizations, instead of targeting the individual employees' minds directly via training or monetary incentive systems, a cost-saving rationale can now be inscribed into the technological architecture of an operation or process and thereby indirectly condition the behavior of employees.

Digital technologies and algorithmic management thus offer new means for implanting accounting logic into an organization also, particularly among non-accounting professionals.

On the one hand, this implantation of accounting takes place rather hidden from conscious awareness and attention. We thus speak of an "invisibilization" of accounting, as the working of algorithms tends to remain largely obscure to its users, as seen in the examples of platforms like TripAdvisor (Jeacle & Carter, 2011) or eBay (Kornberger et al., 2017). Arguably, algorithms and digital technologies provide seemingly unobtrusive and subtle means of implementing accounting logic in an organization because they make the inherent accounting less visible and its very practice less salient to those practicing it. For example, in Crvelin and Löhlein's (2022) study of collective action networks, it is highlighted that many volunteers do not even realize how their utilization of digital technologies turned them into calculable selves. While constantly engaging in cost-benefit calculations and budgeting, many appeared surprised when being asked about their apparent accounting affinity and daily practice. This invisibilization of accounting enabled through digital technologies *enhances* accounting's power in everyday life by tendentiously escaping explicit awareness and, therewith, reflection. This general phenomenon is thereby also in line with Humphrey's (2018) argument of how modern media and technology enable new but hidden possibilities for everyday accounting. In this paper, we argue that the power of algorithmic management lies exactly in this ability to bypass the human mind – or rather the cognitive awareness of its workings – and instead implant the cost-saving rationale more subtly and indirectly into the bodies of a system's users.

On the other hand, the new digital technologies and means for algorithmic control are also associated with a new dimension of playfulness and enjoyment. Studies have started to explore how human users develop a sense of enjoyment and fun when engaging with gamified reward systems or engaging in playful competition (Chapman et al., 2021). It has also become of increasing interest to understand how users of or workers on platform architectures such as Uber are clearly conditioned in their labor practice by the algorithmic management but nevertheless try to maintain forms of freedom, self-direction, and autonomy (McDaid et al., 2023).

Consequently, digital technologies and algorithmic management change the way organizations implement accounting rationales, particularly among non-accounting professionals. In this study, we contribute to organizational management and accounting scholarship by analyzing how airlines shift the way in which they implant their cost-saving rationales among their cockpit crews. While the above research has provided important starting points for analyzing the expansion of digital technologies and algorithmic management in platform settings or among normal citizens, much less is known about accounting's presence in contexts of more sophisticated technologies and systems, and its operational users. Accounting algorithms diffuse not only through everyday smartphone applications but also as components of machines at the higher end of technological sophistication. Energy-intensive production- and planning systems are increasingly coupled to algorithms as they enable a more efficient operation along given cost structures; similarly, transport infrastructures embody algorithmic cost management as a hidden calibrator of their operations. Today, high-speed trains, buses, vessels, subways, and airplanes are all equipped with programs that ensure the profitability of their operations at optimized cost levels (e.g., Global Railway Review, 2024; Jungblut et al., 2023). Like the 'Eco Mode' button in cars, this software delimits the maximum intensity of operation, thus automatically reducing fuel use and abrasion. While this trend is clearly evident, we know almost nothing about the consequences when accounting logics silently interfere with such complex systems through software programs and algorithms. While organizations seemingly tend to celebrate these developments as contributions to a more sustainable world, we show that these developments can also come with significant implications for us when constructing the intelligibility of a situation or defining ourselves as users of technologies. The next section aims to facilitate that argument by elaborating on sense-making and cognition in complex movable systems.

3. Sense-making and cognition on the flight deck

Historically, flying has been an inherently embodied activity. Technical flight instruments tended to be spare and too inaccurate to be the primary mode of information and basis for pilots' decision-making. Instead, flying was a matter of *feeling* the airplane and its operation, and what DeLyser (2010, p. 146) called the "rhythms of arial mobilities." Indeed, getting a sense of correct speeds and manual calibration was often based on the forces felt through the muscle system of the body (Adey, 2008; Vowles, 2006). While this primacy of embodied cognition is still seen as given in most leisure- and military flying, modern commercial aircraft have little in common with historical models. They are highly technological vehicles in which "the successful completion of a flight is produced by a system that typically includes two or more pilots interacting with each other and with a suite of technological devices" (Hutchins, 1995, p. 265). Indeed, research in engineering and information science has extensively described a trend in aviation and cockpit processes over the past decades that resembles similar developments in automotive, medical, and other high-tech domains. As Degani et al. note:

> "Modern aircrafts are wired with thousands of sensors, sending a multitude of signals about the state of the craft's machinery and the surrounding environment, whereas onboard automatic control systems generate thousands of signals about their internal states, events, and computations. In addition, advancements in data processing and analytical abilities have created massive increases in the amount of data available in almost every avionics system." (Degani et al., 2013, p. 350; see also Srivastava, 2012)

Given the "rapid pace" of development onboard and the awareness that any "technological devices introduced into the cockpit invariably affect the flow of information" (Hutchins, 1995, p. 287), new computational equipment has significantly altered piloting tasks by taking over many responsibilities that were once exclusively managed through human pilots' hand-eye coordination. Nowadays, pilots, for example, no longer need to continuously monitor flight instruments or decide and execute the necessary control inputs to maintain the desired flight parameters such as heading, course, altitude, or speed. Instead, they rely on flight directors who automatically determine the required control inputs and use autopilot and autothrottle systems to adjust the airplane controls accordingly.

Furthermore, cockpit automation systems have advanced to perform various cognitive tasks associated with instrument flight. For example, a flight management computer (FMC) automates navigation by allowing pilots to pre-program waypoints, courses, altitudes, and airspeeds for the entire flight route. The FMC handles all calculations related to bearing, distance, time, and fuel, continuously tracks the airplane's position, and automatically updates its navigation settings as it progresses from one waypoint to the next. Increasingly, pilots are described as "managers of automated systems" (Rankin et al., 2016, p. 623) or "information managers" monitoring and interpreting highly automated systems by typing "commands into a computer as they monitor displays connected to various onboard sensors" (Holford, 2022, p. 148). With pilots taking more and more the role of "hands-off managers" of heavily computerized and automated systems (Schultz, 2018, p. 122), human-computer interaction becomes crucial for the working of the cognitive system called the cockpit. An embodiment-based interaction, such as handling the stick and the rudder to control the airplane, is executed as if those technical tools involved would serve as an extension of the pilot's body and bodily functions (Henriqson et al., 2011). Arguably, embodiment-based interactions become increasingly mediated by technological devices and automated systems. Indeed, as Holford argues, "pilots have become *disembodied* from their surroundings across the blinkering effect of representational technologies—that is, where representational accounts (or frames) impoverish their direct contact with the performative environment of the aircraft across the masking of their phenomenological senses" (2022, p. 148).

Based upon the widespread recognition that information processing has fundamentally changed on the flight deck, studies on how pilots cope with unexpected situations and problems have shifted toward the implications of an increasing amount of information available to crew members. In fact, many studies highlight how the so-called information overload is a major factor in modern commercial aviation incidents. For example, Weick's (1990) study of the collision of two Boeing 747 jets in Tenerife in 1977 highlights how "a loss of cognitive efficiency due to autonomic arousal, and a loss of communication accuracy due to increased hierarchical distortion, created a configuration that encouraged the occurrence and rapid diffusion of multiple small errors" (Weick, 1990, p. 571). Similarly, Oliver, Calvard and Potočnik (2017) study of the Air France 447 disaster focuses on cognition and visual information processing. They suggest that "the same measures that make a system safe and predictable may introduce restrictions on cognition, which over time, inhibit or erode the disturbance-handling capability of the actors involved" (Oliver et al., 2017, p. 729). In these studies, sorting out problems and the limits of human agents to do so becomes a matter of looking at screens and absorbing information. In these instances, the pilot seems to differ only slightly from an investment banker or a plant manager of a nuclear power facility. As both a corrective calibrator and a potential distractor, the body itself does not seem to play a role anymore.

Yet, although the role of the body in the cockpit seems to disappear from consciousness, it is important to note that the role of the body as a form of data for informing decision-making has never really disappeared from actual flying practice. While not often actively reflected upon, many pilots see it as indispensable for getting a holistic sense of situations. For example, it was the sink rate that prompted the captain of AF447 to leave the crew rest area and return to the cockpit – already with an idea in mind what was happening (Oliver et al., 2017, p. 729). Indeed, the chilling CVR transcripts indicate that the commands the captain gave when entering the cockpit were based upon some understanding developed independently of the screens earlier. Likewise, a check captain once admitted during a conversation with one of the authors that sometimes it's better to trust the body than the instruments. He, a New Zealand citizen deployed to Nepal for two years to train local pilots in a new Airbus aircraft, indicated, "in this area (Nepal), reliance on instruments can sometimes distract more than it adds. Before every take-off roll at Tribhuvan, I close my eyes for a couple of seconds to calibrate my body to zero." Not being too quick to deny a strong role in bodily feelings on the flight deck is also important in light of the accounting software investigated in this paper. While most computational equipment was originally developed to decrease the (potentially unreliable) role of the body in flying, we find accounting algorithms such as cost index or take-off performance not to bypass, but interfere with the embodied interactions of the crew.

Thus, despite attempts to rule out the body's influence from the flight deck, it still serves as an important metronome in everyday flying by complementing the visual information displayed on the screens. As noted by Lefebvre (2004, p. 36), "no camera, no image or series of images can show these rhythms." Accordingly, flying and sorting problems during a flight operation thus unfold through an integrated sensory experience that relies on vision just as much as on hearing or feeling the forces through our kinaesthetic systems. At the same time, while the body never really disappeared as a source of data, the above also makes clear that levels of awareness in problem-solving significantly shifted. To make this shift clear, it is useful to build upon Micheal Polanyi's distinction between focal- and subsidiary awareness. Focal awareness is what you are consciously aware of or explicitly aware of, and subsidiary awareness is what you are less aware of or implicitly aware of. All knowledge has "from-to" relations because meaning is brought from the subsidiary to the focal, which is part of the reason why Polanyi notes that all knowledge must begin with an act of commitment, which is *belief*. He writes, "we must now recognize belief as the source of all knowledge" (Polanyi & Prosch, 1975b). Thus, the matter is not so much about what kind of knowledge is more effective but how each kind operates, and the implications drawn from it for active human decision-making. As we continue to argue in the paper, the pilot's reliance on the tacit bodily senses has not only failed to disappear but continuously cages with the nature of automation. Cost algorithms, we will demonstrate, have a major impact in this changing nature.

4. Method and data

4.1. Motivation for this study

This research initially developed out of curiosity about a personal flight event. After having taken seats on a scheduled flight from Cartagena to Amsterdam, the captain announced that they had encountered a rather complicated "socio-technical problem": due to some planned works along the western threshold of the runway in Cartagena, the airplane was required to take off in an easterly direction instead. The pilot explained that reprogramming the flight management computer (FMC) in the cockpit triggered a system alert (i.e., Take-off config disagree) that the new runway length would be insufficient given the plane's maximum take-off weight (MTOW). As a consequence, there was no other option but to offload all cargo and return to Amsterdam with passengers only. The interesting thing here was not the significant delay, the surprising lack of coordination in advance of the take-off, or the eventual outrage among passengers. Rather, it was the fact that modern airplanes account for weight, fuel, engine thrust, runway elevation, and wind in such a precise manner that even little deviances (here: a change in runway heading requiring only a slight change in pitch) would result in a new calculation offsetting all previous plans – and, in this case, requiring to offload all cargo including passengers' checked luggage.

In personal conversations with professional pilots and staff involved in airport operations, a similar picture emerged: The primarily "manual" processes of controlling an airplane in the past have become, in recent years, an almost fully automatized practice. Many decisions are no longer in full control of the humans but essentially guided by automated systems and technological devices. Many of those conversations raised the issue of cost-saving and efficiency. While in the past, efforts to save money would have been at the discretion of the pilot, it emerged that cockpit automation was increasingly entrusted with the execution of airline cost strategies, thereby reducing the roles of the pilot in the cockpit. Given the "current rapid pace of introduction of computation equipment" in the cockpit and the awareness that any "technological devices introduced into the cockpit invariably affect the flow of information" (Hutchins, 1995, p. 287), we became particularly interested in how this flow of information and the interaction of humans and accounting technology influences the balancing of cost and security demands onboard.

4.2. Research approach, data collection and analysis

Recent media attention on global aviation has heightened after several incidents focusing on the security of aircraft manufacturers (e.g., Shepardson, 2024; Sherman, 2024). Following the personal incident described above, these newspaper coverages sparked our interest in the tensions apparent in the global aviation industry between maintaining high-security standards while enhancing efficiency and profitability of their operations. With aviation constituting a security-critical setting, information on security concerns is highly sensitive. The secrecy of involved organizations, such as airlines, pilot unions, or aircraft manufacturers, has thereby two effects on our project. On the one hand, it is difficult to interview actors on the record. Not only will most organizations in the aviation industry not want them to share sensitive information about potential security concerns, but considering their professional ethos, it is also unlikely that they would acknowledge such concerns even to *themselves*. On the other hand, aviation security relies on the extensive collection and publication of data. Accordingly, much information on actual incidents is publicly available.

Therefore, we adopted a qualitative approach with four data-collecting strategies from March to November 2024: (a) analysis of incidents involving human-machine interaction and contextualizing incidents with online accessible databases, experts forums, and air traffic control (ATC) audio transcripts and cockpit voice recordings (CVR); (b) database and documental analysis; (c) conversations with key informants; and (d) participant observation in both real flights as well as simulator trainings. After an in-depth literature review, we gained an overview of the status quo on human-machine interaction, especially from an information and security science research perspective. In particular, we searched for literature reporting on the empirical fields of aviation or other security-critical settings, the use of automated systems and technological devices in accounting practices, and the accounting process in highly technological environments. Thereby, we found surprisingly few insights in accounting and organizational research on the interplay of technological devices and automated systems with human actors and their embodied decision-making processes in security-critical settings. Thus, we decided to commence the research project with this broad interest in mind.

We started our empirical research with the analysis of publicly available information. The main source constituted "The Aviation Safety Reporting System" (ASRS), which contains "voluntarily submitted incidents reports from pilots, air traffic controllers, dispatchers, cabin crew, maintenance technicians, UAS crew an others" (NASA, 2024, p. 4). In order to share "vital information to the aviation community", the project run by NASA captures those reports, analyzes and cross-checks them, and makes them public. Receiving an average of 408 a day, ASRS has recorded and analyzed more than two million reports since its establishment in 1976. In their database, the ASRS today provides data points on around 200.000 of those incidents, which already have been digitized. Some reports contain only the bare minimum of technical details for an expert to understand the case; others are complemented by detailed narrations and contextual information provided by involved parties. Supported by a research assistant, we downloaded all recorded data points and started sorting. Given the broadly set research interest above, we commenced by cutting out (for our research purpose) irrelevant incidents concerning, for example, defective material, garbage on the runaway or pilots taking the wrong turn on their taxi route on the runaway. We also cut out duplicates, incidents from non-commercial settings, such as military, agricultural or private purposes, and incidents without narrated supplementary information. Eventually, the data set compiled more than 60.000 incidents. After simultaneously generating insights from other data sources, we further narrowed our interest to human-machine interaction within the cognitive system of the cockpit and the question of how the interaction affects an airplane's fuel efficiency management. This focus allowed us to particularly filter for incidents mentioning in their keyword section the Electronic flight (EFB), the Flight Management System (FMS) / Flight Management Computer (FMC), and the fly-by-wire function. While the costs of commercial aviation depend naturally on a variety of factors, the cost of fuel is among the most significant items on an airline's budget, and it entails some leeway for the pilot. Depending on the flight path, the altitude, the take-off-weight and other variables, an airplane can either shorten the flight time or reduce fuel consumption. Nevertheless, the notion of fuel efficiency management rarely appeared in any of those thousands of incident reports directly – despite some failures and occurrences in the relevant technologies pointing out a connection.

Hence, we analyzed fuel efficiency management further by studying expert forums like the "Aviation Herald". In contrast to the NASA-run ASRS data base, this webpage has been initiated by the aviation enthusiast Simon Hradrecky, who also claims to follow similar purposes as the ASRS: share counter-checked, credible information on aviation incidents to improve aviation safety and calm public concerns. For an incident to appear as an article summary on this privately-run webpage, it must be reported twice from independent agreeing information flows. Interestingly, the community actively engages with the shared information on this page. Below every incident, registered community members comment and discuss it anonymously – sometimes they were involved as passengers or crew members; in most cases, they are just interested and try to make sense of the information together or find solutions for similar issues from their experience. Thereby, the community helped us spot particularly interesting and relevant incidents for our research as they tend to spark more debates among aviation experts. Once our interest was focused on selected incidents, the internet provided another valuable source of information. On webpages like liveatc.net or youtube.com, one can access audio transcripts of ATC communication for some incidents. For some incidents, the CVR records are also accessible. The CVR records and stores all audio sounds in the cockpit for potential incident investigations via the crew's microphones, earphones, and an area microphone in the cockpit. Together, this verbal information helped contextualize the data points available in the often very technically written reports, also enabling non-aviation experts to make sense of the situation in the cockpit.

During this exploratory phase of the research project, we shared our understanding with experts in the field. Informal and anonymized conversations with five key informants allowed us to check our knowledge for accuracy and explore our propositions from a technical perspective. Two of these informants are experienced pilots with decades of experience flying commercial aircraft in passenger- and cargo transportation. Another informant works as part of the crew but not in a role involved in the cockpit to counter-check our impressions of cockpit operations from an "outsider" position. The fourth informant works as a fly-by-wire engineer who consults aircraft manufacturers on optimizing their operational infrastructures onboard. The fifth informant is a retired head of ground operations who has decades of experience running crew management in a large airline. The conversations were used to identify human actors' engagement with the technological devices and automated systems on board and to discuss the preliminary findings from our initial analysis.

Most recently, one author was also able to collect primary material from simulator sessions. Flight simulators have been shown to help reduce the complexity of flying because they enable training under safe conditions (Auer et al., 2023). Joining in the training session of a pilot or re-constructing specific incidents in the simulator allows collecting first-hand evidence about the processes and interactions in the cockpit. This experience especially pointed us towards the study of distributed, embodied cognition and the role of tacit knowledge in the pilot's performance onboard.

To answer the question of how technological devices, automated systems, and human pilots come together to account for decision-making related to fuel efficiency on board, the following empirical section is divided into four parts. First, we provide a brief history of cost-efficiency measures in the context of operating commercial airplanes. Particular attention here is paid to how the emphasis on cost reduction shifted from having the pilot as a target towards bypassing the human in the front seat and instead applying a "hidden hand" of the system. The second section then provides a vignette exemplifying how troubleshooting associated with the *manual* fuel management of pilots is sorted along with what we would define as "cockpit politics." The third section contrasts incidents related to manual fuel management to those caused by cost algorithms linked to the autopilot. Lastly, the fourth section elaborates on how unexpected inconsistencies in cost reduction programs in the aviation sector generally tend to distort the bodily ways of sorting problems. In what follows, we will present the findings derived from this extensive data collection.

5. Empirical analysis

Our empirical analysis will be organized into three principal parts. First, we will demonstrate how two cost-saving algorithms (cost index (CI) and take-off performance (TOP) calculation) have historically expanded their authority over aircraft controls. The second part of the empirical discussion will provide a vignette of an aircraft simulator experiment that we conducted to understand how cost-efficiency algorithms have changed the aesthetic of flying. Lastly, the third part will provide an analysis of crew reactions in abnormal situations caused by an other-than-expected functioning of the costing software. We will point to the paradoxical political effect that while the number of incidents increases with the power of algorithms, it is primarily the pilots who are blamed for such occurrences.

5.1. From pilot to system: The history of cost- and fuel management on the flight deck

Cost and fuel management has always been an important component of everyday flight planning operations. Historically, however, seeking the best prices and most efficient operational processes was the responsibility of accounting and finance staff. Even though there was an increasing trend towards automation already in the 1980s, the pilots' involvement in active fuel management was minimal. At best, it was restricted to the interaction between the dispatcher and captain regarding the amount of fuel to be taken on board. Towards the end of the 1980s, there were increasing attempts to educate flight crews more seriously in managing costs during the flight. This involved a sensibilization of how fuel can be saved when taxing, thrust used at take-off on long runways or APU utilization. Also, efficient flight planning was increasingly seen as part of pilots' activities rather than exclusively those of the operations team. Note how a former captain described this shift towards the end of the decade:

> About 30 years ago we began making "reduced thrust" take-offs as this extended engine life. Lower take-off thrust equals lower tail pipe exhaust temperatures, which equals extended engine life. Engines are expensive.

At the same time, the real implications for everyday flying operations remained insignificant. While pilots increased their cost consciousness, those accounting considerations still resided rather in the background while giving utmost priority to their manual flying skills.

However, the early 1990s were marked by significant technological developments both on the flight deck and the accounting departments of airlines. On the side of the airplane, there was tremendous progress in the so-called *fly-by-wire systems (FBW)*. This system entails that pilots' control inputs are no longer directly translated into the aircraft's mechanical steering components. While in the past, the metal wire connected the pilot's control column with the aileron; FBW systems introduced the translation of control inputs by a computer into an independent motor system. State-of-the-art FBW systems interpret the pilot's control inputs as a desired outcome and calculate the control surface positions required to achieve that outcome; this results in various combinations of rudder, elevator, aileron, flaps, and engine controls in different situations using a closed feedback loop. The pilot may not be fully aware of all the control outputs acting to affect the outcome, only that the aircraft is reacting as expected. The FBW computers act to stabilize the aircraft and adjust the flying characteristics without the pilot's involvement and to prevent the pilot from operating outside of the aircraft's safe performance envelope.

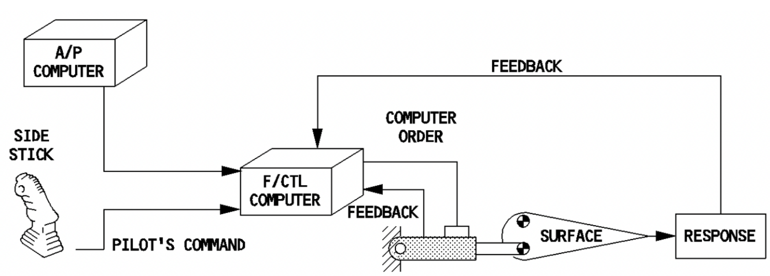

Figure 1: *The Airbus fly-by-wire schematic (Airbus A320 FCOM)*

Moreover, also the accounting and finance departments began to move beyond their manual calculations and cost reduction programs. A breakthrough constituted the development of flight planning software to match capacity with demand, accurate forecasting, slot portfolio management, and scheduling more generally. Developed by companies such as Sabre, these software systems enabled flight planners to include an unprecedented number of variables in their calculations, including different fuel prices at different destinations to manage refuelling, weather conditions for ideal altitude settings, traffic parameters, costs of diversion, etc. One of our interviewees, a senior flight planning manager at a large German airline vividly explained how this software fundamentally changed the ways in which they were working. In fact, it even gave rise to a new kind of prestige associated with the image of the flight planner, as the following quote indicates:

> So, we had this rule. When the plane is on the ground, it belongs to the ground. But what really changed everything was the introduction of flight planning software in the 1990s. I remember when I travelled to Dallas to see the workings of Sabre systems. And I thought this is what we need. We could now monitor every second of an aircraft's flight path. We could always communicate with the pilot through telex. This was not possible before. I mean, I could have tried to use a relay hookup, but this was really cumbersome.

It was only a matter of time before these initially parallel developments (advancements in FBW and flight planning software) started to become linked at different systems levels. While until the mid-1990s, the intelligent FBW systems were primarily aimed at assisting the pilot's intention, they now also formed a point of entry for introducing different logics into the FMC system. These software linkages began to allow a translation of accounting logics right into the computer of an airplane and thereby attribute them permanent control over certain parameters also during the flight. The power of the accounting divisions thus significantly extended from the ground to the air. Today, in particular, two powerful accounting systems on modern airliners are directly linked to autopilot controls: the cost index (CI) and the take-off performance (TOP).

The cost index can be summarized as the ratio of fuel costs to all other costs, and it considers the relationship between fuel-related costs and time-related costs. With regards to time-related costs, the faster the aircraft is flown, the more money is saved in time costs. It also means larger distances between inspections can be flown when considering maintenance costs. However, if the aircraft is flown at such a high speed, the fuel burn increases and total fuel cost for the trip increases. The CI is calculated by the accounting and finance department of an airline individually. It is bases on the cost structure of each airline and thus cannot be generalized. Importantly, the CI is not just a management KPI but is inserted into the FMC by the pilots at the beginning of each flight. Depending upon its value, the autopilot then manage parameters such as thrust, climb rates, or speed. What is critical is that, once inserted, there is no direct information available to the pilots on how exactly the CI interferes with flight control. This interference, at the same time, can be manifold. The CI cannot only calculate thrust settings and speed but also more hidden configurations, such as the shift from Mach speed to IAS during descent. In fact, unless pilots deliberately check in the FMC, the configurations and technical decisions remain largely invisible during the flight. See Figure 2 to get a sense of how the CI works in the system.

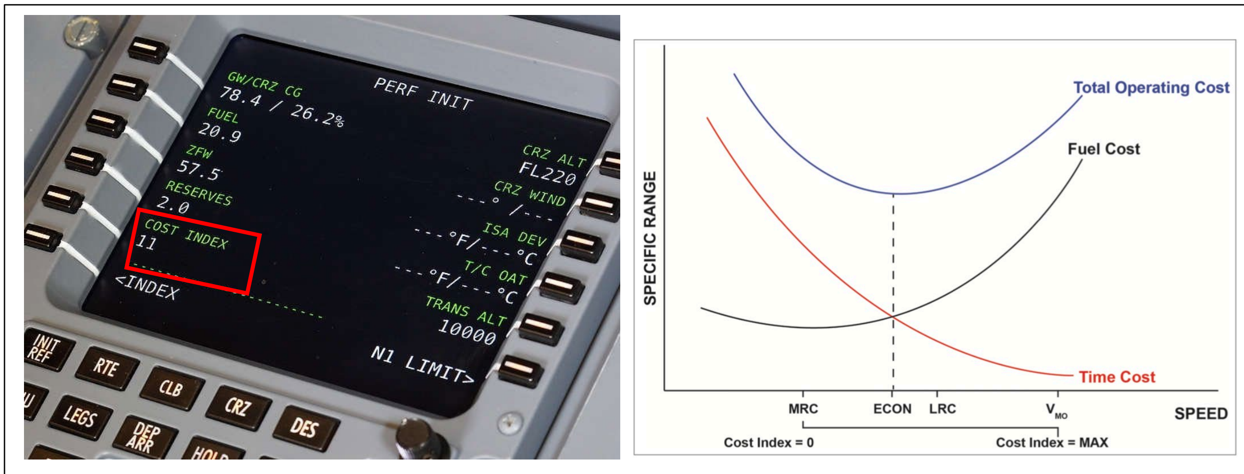

***Figure 2**: The workings of the cost index (right image) and how it is used on the flight deck as an input into the FMS (source: Airbus)*

A second important cost algorithm on flightdecks is called take-off performance (TOP). While the CI is mostly used during the flight and descent, the TOP system is intended to assist cost management at one of the most intense stages of the flight – the take-off and climb to cruise altitude. Unlike the CI, the TOP is not a single index but is calculated based upon diverse inputs such as weight, configuration, runway length, heading, weather condition, etc. (see Figure 3 for some parameters on how it is calculated). Based upon these inputs the autopilot selects a thrust setting for take-off and climb. This is because on runways with significant length there is no need to set engine thrust at 100 percent and needlessly increase engine abrasion. Based upon the take-off inputs of the crew, the FMC will show a take-off thrust setting and indicate at which altitude thrust can be reduced further. For example, in the left image of Figure 3, the thrust reduction altitude (THR) shows 3370ft, meaning that thrust can be further reduced after passing that ceiling while ensuring a safe climb.

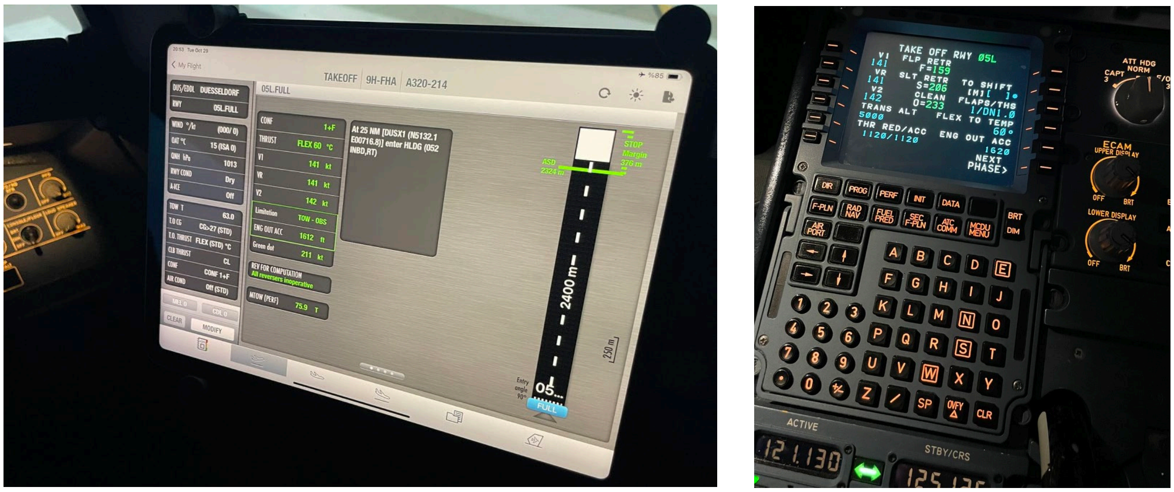

Figure 3: *Calculation of the tack-off performance (TOP) in an Airbus A320-214: Left image shows how different performances are simulated based upon different inputs on an iPad. Right image shows the FMS into which the calculations are being copied. (source: own images)*

The increasing attempt to induce cost- and fuel management into the cockpit has been quite effective and airlines celebrate these advances as important milestones for greater sustainability. Not only has the average life cycle of engines increased by roughly 40 percent between the 1970s and 2010s, but also airplanes themselves became 70 percent more fuel efficient due to better construction. While this has caused excitement from the perspective of airline management and aircraft manufacturers, it is important to note that the number of incidents has increased alongside this seemingly positive technological development. In what follows, we outline how cost management has contributed to an emerging incident category and also how the nature of those incidents differs between earlier manual fuel management and more recent algorithmic interference.

5.2. The changing aesthetics of flying: an observation vignette of a simulator scenario

The ways in which cost savings algorithms have changed the aesthetics of flying, as well as how they changed how pilots understand themselves, can be illustrated well based on some scenarios that we observed in simulator training (aircraft type: Airbus A320-214). In one of these settings, we asked two different crews to fly the same route two times: first, they should try to arrive at the destinations as *quickly* as possible with no need to pay attention to any cost savings rationale. Within the limits of the given operating procedures of the aircraft, they were free to choose whatever measure they saw as appropriate to get the aircraft to fly as fast as it could (e.g., thrust settings, altitude, speeds, etc.). Second, both crews were instructed to fly the same route as *efficiently* as possible. Here, they were given the authority to make full use not only of the possibilities provided by the cost-saving program but also of all other controls of the aircraft. No ATC restrictions were made, and the crews could select both routing and taxiing at their own discretion. Of course, all legal regulations related to air traffic procedures needed to be followed (e.g., pilots could not choose to fly through corridors or at altitudes that are closed to passenger traffic by federal regulations). Also, the pilots were not allowed to put the aircraft under a level of stress that would exceed the manufacturer's certified technical limits.

Observing these scenarios provided crucial insights into the reasoning of pilots when they attempt to get the aircraft to its destination as efficiently as possible. Interestingly and somewhat unexpectedly, the scenario in which the pilots were told to fly as fast as possible turned out to be not nearly as interesting for them as the ones asking them to maneuver as efficiently as possible. Communication in the fast-fly scenario was reduced to a minimum as it was obvious to two pilots that everything would be operated at maximum capacity. Hence, there was no need to discuss different altitudes or speeds: everything was set at maximum. This is well reflected in the left image of Figure 4, which was taken during the scenario observations. The grey column on the left side of the primary flight display indicates the airspeed and the little red bar in the upper half of the column shows the degree to which the airplane operates at maximum speed. If the green arrow in the middle of the column had moved up just a little bit, the system would have called out an overspeed warning. Also, the altimeter in the gray column on the right side of the PFD shows that the plane is flying at a relatively low altitude in order to minimize the time lost through climb and descent.

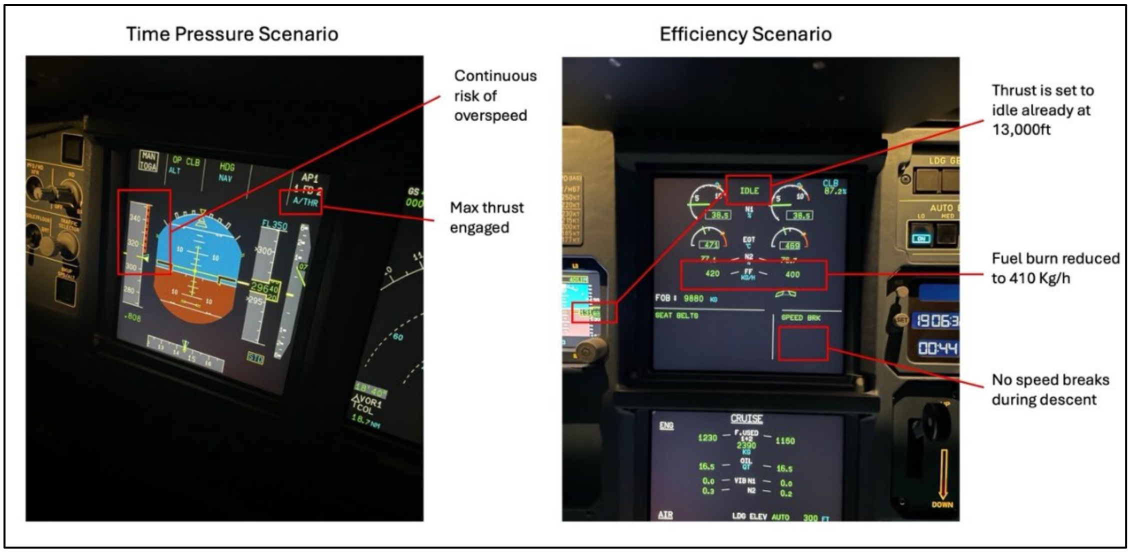

Figure 4*: Images show instrument indications during the two scenarios that were observed by the researcher in a simulator (Source: own images)*

What was interesting to observe in the fast-fly scenario was how the pilots showed obvious signs of discomfort with the ways in which they were flying the plane. Importantly, this was not attributed to any safety concerns but to the ways in which the speed jeopardized what they considered the aesthetics of flying. To make this clear, it is important to note that simulators like the one we used (i.e., Level-D certified) replicate reality very accurately, so much so that pilots often report that "they forget sitting in a simulator after 10 minutes." It is not only that the cockpit is an exact replica of a real one but also that the simulator copies the exact movements and noises of a real airplane when doing things. Also, the view out of the windows quite realistically reflects reality. This means that the crew felt the speed, acceleration, climb, or descent rates during the different scenarios quite heavily – as they would onboard a real aircraft. Without asking any questions or pushing the crew to explain what they were doing, both the captain and the first officer began to discuss how uncomfortable they felt when their body indicated that the airplane was operating at speed limits. Indeed, precursors of light sound waves were clearly noticeable in terms of little repetitive shocks also for the researchers. While none of this is in any case security-relevant, you can note in the following snapshot of a quick chat between the captain (Cpt) and first officer (F/O) how the discomfort of flying was rooted in the ways in which a high-cost level was experienced through the body:

Cpt: In real life I would never do this… even if I could.

F/O: Yes it's really really sporty. Like a maniac on the highway.

Cpt: That speed really hurts.

F/O: Really uptight… another deficit for the company.

Note that the above conversation was triggered by the bumps and noises which altered the crew of the aircraft operating at high-cost levels. Only getting a sense of this from looking at the instruments would be difficult to detect, as another pilot explained to us in a later interview:

> Actually it (limits of the airplane) is very difficult to realize from looking at the instruments only. You have little possibilities to detect this. Speed may be an indication but then you also have winds that could bring you close to maximum speed without full engine power. It is really everything in combination. Fuel burn, speed, altitude… and… *feeling the aircraft*.

Interestingly, the dynamics of flying changed considerably when switching to the efficiency scenario. Both crews seemed to be enjoying this kind of flying much more than the high-speed scenario. To one extent, this was because they started to actively discuss how they would use the different cost-saving software during the flight. On their iPads (see Figure 3), they were running multiple simulations on how the aircraft would perform by using different cost indices or take-off performance calculations. It almost turned into a competition between the captain and the first officer as to who had the best ideas for planning the flight as efficiently as possible. Both crews appeared really excited when searching for cost-saving potential throughout the entire flight. This was important because the initial inputs to the cost savings programs now also started to influence how the crews were operating the more "ordinary" aircraft controls. Conversations such as "so we selected a cost index 25, but this now enables us to do this…" were frequently used. The cost awareness prompted the crews to become creative at all stages of the flight about what they could do to make their operation more cost-efficient. This again encouraged them to take a look back into their iPads to simulate new scenarios for being more cost effective. Thus, there was a mutual encouragement between the possibility of the costing software and those of the 'normal' aircraft controls. For example, the right image in Figure 4 shows the engine monitor (ECAM) during the descent of one of the flights. Note how the engines were already set at idle by the pilots at around 13,000 feet. This action was provoked by the ways in which the cost index calculates the optimal point of descent.

Importantly, it became evident to us that there was a significant degree of enjoyment only during the low-cost scenario. Pilots liked experimenting, planning, and trying out new things. Conversely, this flipped into high degrees of disappointment when their cost-savings plans did not work out. For example, for one of the crews, the descent at idle thrust at some point resulted in a too-quick descent, which triggered the system to call out a "sink rate" warning. The pilots had no option but to use the speed breaks, which would ultimately result in a loss of energy and the requirement to reengage thrust at later stages. Pulling the speed brakes, the captain stated upon feeling the vibrations of their working, "500 Euros". Indeed, during the low-cost scenario, "being" on the airplane felt significantly smoother, and it was filled with less noise. Moreover, the smoother the flight felt, the more comfortable pilots appeared to be with their chosen action. A smooth and little-noisy flight was associated with fuel efficiency. It is here where we argue that cost management programs have significantly changed the aesthetic of flying through a (re)sensibilization of our bodies. This was also echoed by a pilot during an interview after the simulator experiment:

> There is a new aesthetic of flying. You really see this with the older colleagues. They are conservative and always take the same amount of extra fuel, always use TOGA (full take-off thrust), always use speed breaks, always fly faster than necessary, and so on and so forth. But this is changing with the younger crews… for example, *we call speed breaks today bad planning levers"*. If I plan my descents correctly, I never need the speed brake.

Our data further indicates that cost savings algorithms inhabit some excitement for pilots because they equip them with room for maneuvering which they do not have in terms of the more "ordinary" aircraft controls. Through algorithms such as the cost index or the take-off performance, new areas of intervention were created for pilots. During our interviews, some referred to this as a "welcome challenge" or "a kind of competition". Indeed, as one of our interviewees so aptly put it, "yes, we have indeed become kind of active cost managers" – but without expressing a sense of discomfort or resistance. When expressing this change, the interviewee's facial expressions did not indicate that the new responsibility creates an additional burden. Rather, there was a sense of pride in his words.

5.3. New anatomy of cost-management related incidents

Automation-related incidents are different from those that occur due to issues arising from manual fuel management. The reason is simple: As the cost algorithms interfere with airplane controls by largely bypassing the pilot's commands, they act without humans' being consciously aware of them. Thus, related incidents often surface in awareness at the last minute. Moreover, the cost algorithms are particularly active during very intense phases of the flight, such as take-off and landing. As these phases put the highest stress on materials, control inventions at that stage are most effective for cost management. This makes these algorithmic-induced incidents even more precarious. Not only do they materialize suddenly and unexpectedly, but they also occur during phases in which complexity is high. Thus, unlike manual fuel management incidents, there is often no time to discuss the occurring problem. Sense-making in the way of deliberately attempting to create meaning is largely impossible. In these cases, pilots tend to act according to reflexes largely driven by an embodied 'feel' for the aircraft. Sorting is thereby not a matter of psychological- but rather of *physiological* variables. As one pilot commented in a professional web forum on an algorithm-induced incident:

> You don't have to worry about your hypothetical 737 or A300 captain yanking the controls to the stops in a split second while at 350kias. Flight controls fight back against pilots trying to do stupid things.

This changed significantly with the automation, however. A good example of an incident related to TOP is an EasyJet incident. The aircraft, an Airbus A319-111 bound for Newcastle from Nice, was accelerating on the runway when the pilots felt that something was not `feeling` right. While the acceleration did not feel right, the pilots still sensed that the remaining runway would be sufficient and continued for a safe take-off and climb. The investigation by British authorities revealed that the aircraft took off with significantly lower thrust than normally required. What actually happened was a simple mistake regarding the taxiway used to enter the runway. Figure 4 below is taken from the incident report and illustrates what happened. The performance calculation was made in anticipation of entering the runway from taxiway B3 (right image). However, the tower advised the crew to use an earlier intersection as a shortcut (Q3) since the entire length would not be needed for an aircraft of this size. In this instance, the pilots failed to correct this change in the system, and thus, the thrust was set as if departing from intersection B3. Note how the required speeds (V1, VR, and V2) differ due to the difference in available runway length. Again, the example highlights how cost-algorithm incidents surface abruptly and, rather than through talk, they are sorted by a `feeling` for the aircraft.

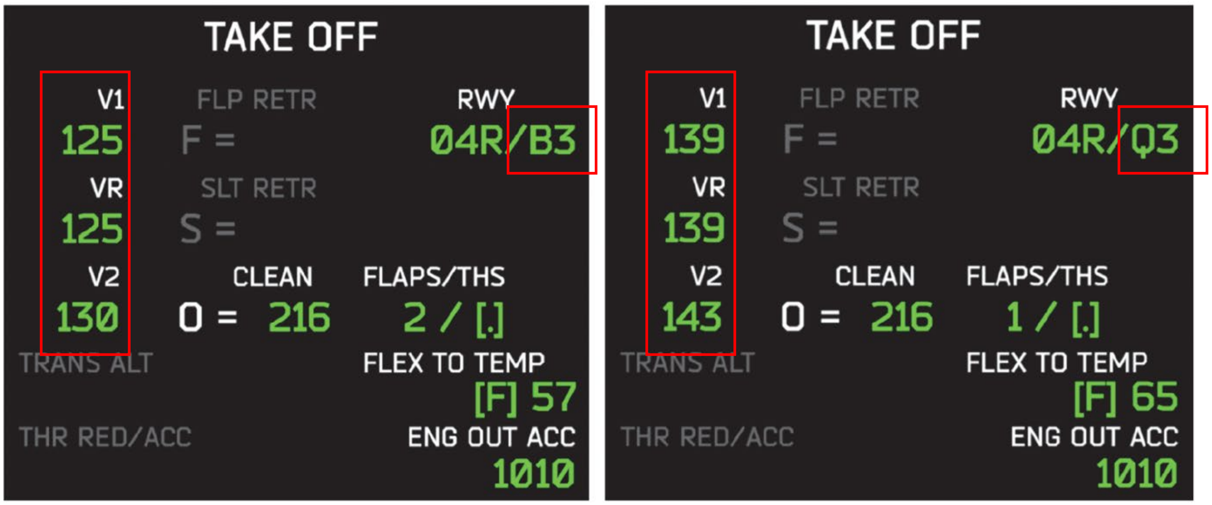

Figure 5: *The difference in take-off performance (TOP)*

The final report concluded that the pilots became significantly confused by the ways in which their bodies detected some abnormality while the instruments at the same time seemed to work quite accurately. Consider the following excerpt from the report:

> Both pilots reported that something was not right during the take-off but, at the time, neither could resolve what was wrong. They felt the acceleration and the cadence of the take-off was slightly slow but thought this might be due to the runway contamination. The feeling was not compelling enough for them to abort the take-off.

This and many other interruptions highlight the centrality of the body in sorting problems in high-intensity manoeuvring. While this bodily sorting is also important in non-cost related problem solving, it is important to note that incidents related to frictions in the human-machine configurations have increased significantly since the coupling of the autopilot with cost management systems. Annually, around ten TOP-related incidents and about two CI-related incidents are classified as serious. Additionally, the number of unreported cases is estimated to be quite high. In fact, there is also an increasing recognition among authorities and accident investigation teams regarding the hazards associated with cost algorithms. For example, the British

Aircraft Accident Investigation Board (AAIB) concluded in an investigation of a similar incident in 2019:

> The AAIB has investigated numerous serious incidents where aircraft have taken off using performance information calculated from a different start point. Worldwide, similar events present a significant hazard to civil aviation despite SOPs containing measures designed to prevent them, such as cross-checks and independent calculations. Pilots performing cross-checks often fail to notice errors or differences when the figures are unexpected, and incorrect calculations can lead to insufficient thrust, and therefore acceleration, during take-off.

Interestingly, despite the increasing alerts made by regulators, pilots during our interviews repeatedly confirmed that there is no problem with using the *body* as data per se. While not as scientific or technically fancy, bodily senses are considered a legitimate source of information. In fact, pilots did not seem to consider it problematic whether a problem is analyzed by deliberate sense-making or by the more reflex intuition of the body. In particular, the more experienced pilots indicate that problems rooted in the control inputs of the autopilot can be effectively understood through the body. For example, a captain who tends to often adjust the CI during the cruise, described in an interview:

> If you change the cost index you feel it. You fly higher and at the limits. To recognize you do not need to look at the instruments. It's in the vibrations of the airplane. Even without checking the cost index I can always give an indication about where it is set.

What is also interesting is that even passengers might sometimes recognize dysfunctionalities in an aircraft`s behavior through their bodily senses. Particularly frequent travelers report to investigators or in online aviation forms how they can feel that something was not right during, let's say, a take-off role. For example, during one take-off incident in Melbourne, Australia, a passenger, himself by training a cabin crew member but off-duty, reported:

> I was on that flight [XXXX] sitting down the back, last row 41E middle seat. The speed of the aircraft to me as if we were were going to slow down the runway, and thats when i started to panic. Being cabin crew myself, i had a gut feeling this aircraft wasnt going to get airborne.

Thus, even though cost-algorithmic incidents tend to surface abruptly and do not allow for conversational sorting, this does not seem so much of an issue for pilots under specific conditions. While many emphasized the importance of thoroughness during flight preparations and the necessity of continuous cross-checks, they also indicated that, even if mistakes happen, experience and the feel for the aircraft will detect and sort them.

What makes these cost-algorithm induced incidents more precarious is a parallel cost-savings strategy of aircraft manufacturers, which evolved largely independent of software development. For quite some time, aircraft manufacturers have been experimenting with composite materials to reduce the weight of airplanes. The traditional material aluminum, which used to be the primary mode of construction, is now giving way to carbon fiber structures – particularly for modern aircraft such as the Boeing 787 and the Airbus A350. While these composite materials were initially intended to reduce weight, they had a pleasant side effect: their flexibility makes the aircraft ride much smoother with less violent reactions to turbulence or control inputs. Manufacturers have also made great advances in reducing the noise of airplanes. This is due to engine refinements, allowing for steadier acceleration and significantly reducing noise levels. Furthermore, better insulation of the cabin has reduced the inside cabin noise caused by the airflow at high altitudes. These and many other advancements have influenced the experience of flying and reduced the sense of actually sitting in a moving object.

While these developments are often met with enthusiasm by passengers, they also have direct implications on flying operations as they limit how pilots can use their bodies to detect problems with aircraft behavior. Many advances in materials and construction significantly reduce the possibility of pilots "getting a feel" of the aircraft. Interestingly, this tendency and associated issues are increasingly coming to the attention of regulators worldwide. Many incidents, particularly those related to TOP issues, are described as having originated in the more general tendency of pilots` losing a `feel` for the aircraft. For example, following a take-off performance incident in Finland, the local authorities reported:

> Humans are poorly adapted physiologically to discriminate between slightly different acceleration rates, and many years of training have made pilots reluctant to move the throttles once take-off power is set. In recognition of this, the AAIB has previously made

safety recommendations that a technical barrier should be developed which would recognise events where the take-off acceleration is lower than expected.

Similarly, the British authorities concluded after a similar incident in Lisbon:

> Pilots are unlikely to recognise abnormal acceleration for the following reasons: (1) Acceleration is not explicitly monitored during take-off. (2) Pilots become accustomed to different rates of acceleration. (2) Perception of motion is primarily governed by visual rather than vestibular cues, and the visual system has a high detection threshold and general insensitivity to acceleration. (3) The visual cues in slower acceleration do not differ enough for pilots to detect until presented with an atypical visual scene (such as the end of the runway approaching).

Thus, there is an increasing recognition of the potentially threatening consequences of invalid take-off performance. One incident that caused quite some attention and has been well-analyzed and discussed was an almost crash of an Emirates A340-500 in Melbourne on March 20th, 2009. The accident was caused by the crew getting confused with the inputs made in the FMC before the flight. Based on mixing up numbers regarding the weight of the aircraft, the aircraft calculated a speed based on a weight of almost 100 tons less than the actual weight. As take-off thrust was now significantly lower than required, the aircraft did not get airborne in time, thus damaging the runway localizer when finally getting airborne (see the image on the right). This flight was indeed a close call and resulted in worldwide discussions on how human-machine

What is interesting here is the pilot communication that occurred during the take-off role (*source: ATSB*). It vividly illustrates the confusion that arose while the aircraft was accelerating on the runway. Remarkably, it shows that the pilots seemed to realize only at the last minute that something was going wrong. Their bodily senses seemed not to kick in to detect the low acceleration rate. Likewise, the confusion and loss of situational awareness are clearly evident in how long it took the pilots to enact countermeasures after the airplane failed to rotate. The transcript has been published in the ATSB report reads as follows:

22:30:55 The thrust levers were moved to the FLX/MCT position.

22:31:30 CPT: “100 knots”

22:31:30.5 F/O: “Check”

22:31:52 Automated announcement of “V1” (the decision speed)

22:31:53 CPT: “rotate”

22:31:56 CPT: “rotate!!!” (Impulsive repeat).

22:31:58 F/O: “rotating!!!” (F/O applied further back pressure on the sidestick)

22:32:03 CPT: “Something`s not right. TOGA!” (selecting “priority left” mode)

Note how nearly 5 seconds passed between the failure of the airplane to lift off from the ground and the captain’s decision to call out TOGA (take-off/go-around speed). The accident has not only received worldwide attention among regulators and manufacturers. It was also widely discussed among pilots in aviation forums. For example, a captain in the forum responded:

> I must have missed something here: If this is a regular flown route, and the pilots were so competent, then why did they miss 100 tons during their calculations? That number equates to around 770 people and their baggage! They regularly fly this route so they know that they take a given number of PAX +/- 8%, so surely, a reality check would have concluded that something was amiss after the calculation showed that they were 100 T lighter than usual. Surely the Captain and the FO would have a *visual contact with the ground and see the fence getting bigger in their window*, so why would you NOT apply full power under these conditions?

Arguably, the tendency to reduce the role of the body in sense-making started much earlier with the introduction of the earlier mentioned fly-by-wire systems. The fact that there is no more cable winch directly connecting the mechanical components of the aircraft to the rudder or control column in the cockpit is known to create such distortions. This is because pilots cannot feel the immediate reactions of the airplane through the controls anymore when connected only via wire. Regulators and manufacturers were soon aware of the potentially dysfunctional effects of this disembodiment. For example, a cable winch would indicate a stall situation to the pilot through vibrations in the control column. This was initially not the case with fly-by-wire systems. Because of how risky this loss of bodily senses was, manufacturers introduced artificial vibration motors to the control components to return this sense to pilots. While even in modern airplanes control columns and rudders apply resistance to the pilot`s input depending upon the flight situation, this resistance is only artificial. One pilot explains:

> Because fly by wire is fly by computer. There is no mechanical connection between the controls the pilot manipulates and the aircraft control surfaces. Early Fly by Wire systems did not provide any feedback (resistance) or "feel" to the pilot. More modern systems do provide the feel pilots expect.

At the same, there is also a recognition that these artificial vibrations never fully simulate the actual forces of older aircraft. Another pilot comments:

> Despite what the engineers will tell you, fly by wire systems do not give you the same feeling as flying with traditional controls. They (engineers) build in artificial feel. Newer versions are pretty fancy, but it is still artificial.

But while the friction caused by the loss of bodily feel for the airplane has always been an issue in the field, it is important to note that the introduction of cost management software has made these problems even more severe. This is due to several reasons: on the one hand, cost management has introduced another way in which the autopilot interferes with flight maneuvering. On the other hand, these movements are themselves weakened by using new materials for constructing the aircraft. What may look like two costing developments canceling out each other does not hold upon closer examination. The new designs of aircraft only *partially* off-set the additional movements created by costing software. Rather, they reduce these movements to a precarious degree in which the body may still sense certain forces but a degree at which the explicit realization of these movements is absent. A lack of acceleration may be sensed. But it appears not as severe in order to trigger some alarm in pilots' minds. In the concluding discussion, we will reflect upon how different strings of an overarching cost-savings logic in an institutional space can combine in unforeseen ways to create outcomes beyond intention and deliberate planning.

6. Concluding discussion: Feeling cost through the body

This paper started with the endeavor of tracing the increasing trend of directly integrating cost functions into the computational systems of aviation operations and the implications of these algorithmic cost interferences on cockpit performance. For this purpose, we analyzed incident reports related both to manual and algorithmic fuel management onboard, we observed the reaction of crew members to abnormal and potentially threatening situations in full-scale flight training simulators of an airline, we joined commercial flights of the cockpit's jump seat, and conducted formal and informal interviews with key informants from airlines and operators. In this concluding discussion following our empirical analysis, we will now reflect more broadly upon the importance of studying the diffusion of costing systems in our everyday transport systems and beyond.

The first section of the empirical analysis demonstrated how airlines and their operators shift responsibility for cost reductions from human pilots to implanting the accounting rationale and cost sensibility into the aircraft's 'thinking'. While this primacy of embodied cognition is still seen as given in most leisure- and military flying, modern commercial aircraft have become highly technological vehicles in which "the successful completion of a flight is produced by a system that typically includes two or more pilots interacting with each other and with a suite of technological devices" (Hutchins, 1995, p. 265). The study of the technical functioning of the accounting logic and automated systems onboard showed that in the past, pilots were at the center of trust, or in Giddens' expert system (1990), the personified expert of the cockpit and the cost reduction efforts; but it appears aircraft manufacturers and airlines increasingly attribute more trust to the ability of automated cost algorithms, whose output is seemingly treated as a symbolic token of security, profitability, and efficiency.

While eco-modes of flying can significantly reduce costs and emissions, there are also dysfunctional effects that remain unresolved. Having the body of pilots trimmed to feel the cost of the airplane also leads to a normalization of flying situations, which would have historically triggered states of alarm. While procedures such as rotating at the far end of runways, flying at the lowest possible airspeeds, or descending with engines set at idle would have created states of distress in the earlier days of flying, our study suggests that these situations now constitute the norm. Our study reveals further that this can create problems as it reduces the time span between the recognition of an abnormality and the initiation of countermeasures. Indeed, there is a growing number of serious incidences related to this reduced reaction time and the ability to assess the situation appropriately – something which has also sparked increasing attention on the side of regulators. Our analysis of incident reports and the cockpit-voice-recorder (CVR) transcripts revealed that cost algorithms can create significant sense-making distortions in high-intensity situations. Somewhat paradoxically, we also demonstrate that in many of these incidents, it is not the FMS that is blamed for the occurrence. Instead, we point out a political dimension: the increasing reliance on cost-saving programs makes it easier to put the blame for incidents on pilots.

While we know from existing research that pilots are not always comfortable with the growing autonomy of their aircraft's 'brain' and the ability of their autopilots (e.g., Chow et al., 2014; Elish & Hwang, 2015; Oliver et al., 2017), the analyzed incidents exemplified that the shift towards cost-induced autonomy ultimately redefines how pilots handle non-routine situations and incidences in their flying operations. Arguably, the industry is already aware that "automation distances the operator from the system itself, and from cues in the operational environment" (Degani et al., 2013, p. 336f). There have been instances where apparent "computer errors" and the flawed human response to such are later described as the crew having had "inaccurate mental models of the situation" (ibid.). In our analysis, we refer to this observation as an apparent *mind-body distortion*: The perceived feelings of the crew and their subsequent sense-making of a lived situation occasionally differ from the real context, requiring a certain technical response from the pilots. While such distortions tend to remain undetected in routine settings when accounting devices and humans interact seemingly smoothly, they become particularly visible in moments of crisis and conflict – just as the analyzed incidents in Section 5.2. have illustrated.

The findings further indicate that handling such critical events broadly associated with fuel management differs significantly between those caused by the pilot's manual accounting decisions and the algorithmic cost saving of the flight management system (FMS). While incidents related to pilots' own calculations are sorted along what we describe as cockpit politics, those caused by system inconsistencies are sorted at the much less articulate level of embodied experience. This is because the pilot's own miscalculations unfold within prolonged periods of time, whereas those caused by the system tend to manifest in sudden events often during flight periods of high intensity (e.g., during take-off roll). While it would be easy to fall into a narrative of condemning the implications of algorithmic control and a loss of human autonomy in decision-making, our case, in fact, points to the fact that these different ways of sorting are not a problem *per se*; our data concludes that both ways of making sense and sorting information can be quite effective but entail distinctive implications and challenges. While pilot-induced errors associated with cost management techniques are made sense of through speech acts, the FMS-related incidents tend to be sorted through our more tacit bodily senses and reflexes therein.

However, what becomes apparent from our analysis is that the construction of modern aircraft, to a certain extent, *inhibits* this human ability to subsidiary problem-solving. While the more embodied way of sorting problems on the flight deck – based upon our cultural muscle memory and its reflexes to counterintuitive physical forces working on our bodies – is certainly effective, it is increasingly distorted through the parallel strategy of aircraft manufacturers to make airplanes more comfortable for passengers. While the technical advancement was originally intended to decrease the (potentially unreliable) role of the body in flying, accounting algorithms such as cost index or take-off performance, in fact, seem to interfere with the embodied interactions of crew members. The different vignettes and interviews illustrate how improved noise cancellation, the use of carbon composites to offset vibrations, or larger engine perimeters to avoid extreme accelerations distort or, in the worst case, even override pilots' 'feel' for the aircraft. Yet, this physical or embodied feel for an operation is essential: Despite many accounting processes seeming "bodiless" as they are practiced in digital or abstract dimensions, most *handling* of its computational equipment requires the body as much as the human mind. Thus, even the seemingly most "disembodied" accounting data can never be interpreted and made sense of without considering the role of the users' physical bodies.

Therefore, we argue that parallel advances and developments in an industry can result in unforeseen reciprocities and lead to problems absent in the isolated innovation stream itself. Our case, not least, speaks to the *system effects* in complex technological areas where unforeseen entanglements between processes can develop momentum to reroute, derail, or cancel out one another (cfr. Jervis, 1998). In pointing out these system effects, we add to accounting scholarship that has started to examine the shift of accounting's centralization and interferences with its human users. Previous studies have already shown how algorithms allow for an unprecedented decentralization of accounting in everyday life, for example, using the case examples of Uber (McDaid et al., 2023), TripAdvisor (Jeacle & Carter, 2011), or eBay (Kornberger et al., 2017). Rather than "calculative centers," which have been the traditional anchor of accounting's power, we find a calculative agency to become more diffuse and increasingly infuse the everyday action of users, operators, or workers with non-accounting backgrounds. Arguably, algorithms and digital technologies provide seemingly unobtrusive and subtle means of implementing accounting logic in an organization because they make the inherent accounting less visible and its very practice less salient to those practicing it.

Hutchins' earlier mentioned reference to the rapid pace of introducing new computation equipment also has a significant influence on the roles and expertise of pilots and, for us as accounting scholars, on the development of accounting expertise among non-accounting professionals. Past routines are constantly interrupted by new algorithmic management tools affecting the flow of information and the accounting for this information thereof. With pilots taking more and more the role of "hands-off managers" of heavily computerized and automated systems (Schultz, 2018, p. 122), it is of great interest to understand how they interact with new technologies and to which extent they off-set or complement each other in the demands to ensure safe, sustainable, or simply efficient processes in their respective work settings. It implies that pilots are no longer just talented manual controllers of an aircraft but simultaneously have to enact the role of information managers and calculative agents in their own rights. Increasingly, pilots are described as "managers of automated systems" (Rankin et al., 2016, p. 623) monitoring and interpreting highly automated systems by typing "commands into a computer as they monitor displays connected to various onboard sensors" (Holford, 2022, p. 148). They must learn to act in an environment where most data informing their sense-making is provided electronically. Accordingly, the training and socialization of non-accounting professionals, like pilots, should be adapted to mastering a growing dependence on automated cost management and algorithms in cockpit operations (cfr. Chow et al., 2014). Similarly, the trend has implications for designing accounting software and the visualization of accounting data; particularly in high-risk environments, such as airplanes, nuclear plants, or oil platforms, the right design choices can significantly impact human-machine interaction (Oliver et al., 2017). Especially an awareness of the difference between human's focal and subsidiary cognition and sense-making processes can provide a radical reorientation on how to think about designing accounting software and supporting human-computer interaction.

Yet, no matter how well training or design choices are adapted to automation trends, our paper also showed that the spread of digital technologies and calculative software in the cockpit makes accounting less visible and its very practice less salient for the crew practicing it. This somewhat precarious characteristic of the diffusion of accounting reminds one of similar tendencies in everyday life. For example, in Crvelin and Löhlein's (2022) study of collective action networks, it is highlighted that many volunteers do not even realize how their utilization of digital technologies has turned them into calculable selves. While constantly engaging in cost-benefit calculations and budgeting, many were surprised when asked about their apparent accounting affinity in daily practice. Similarly, the growing trend for self-tracking via tools for optimizing the quantified self, such as smartwatches and calorie-counting apps, exemplifies how accounting permeates modern-day routines seemingly unnoticed (Jeacle & Carter, 2023; Lupton, 2014). This phenomenon is also in line with Humphrey's (2018) broader case of how modern media enables new but hidden possibilities for everyday accounting.

This "invisibilization" of accounting enabled through digital technologies *enhances* accounting's power in everyday life by tendentiously escaping explicit awareness and, therewith, reflection. While a certain atomization of cost accounting has already been observed (e.g., Kornberger et al., 2017) and the trend of coupling the computational systems governing our everyday transport systems with cost functions is rather apparent to the public eye, the research on the implications of these algorithmic cost interferences and how this invisibilization enabled by algorithms impacts the work of those operating our daily transport systems is scarce. Although this paper specifically zoomed into the aviation industry, the spread of algorithmic cost interferences extends much beyond the operations of commercial aircraft, with almost all transport infrastructures increasingly embodying algorithmic cost management as a hidden calibrator of their operations. Increasingly, all high-speed trains, buses, vessels, subways, airplanes, and cars become equipped with software that ensures the profitability of their operations at optimized cost levels (cfr. Global Railway Review, 2024; Jungblut et al., 2023).We see our paper as a starting point for opening the conversation regarding the consequences when accounting logic silently interferes with such complex systems through software and algorithms. While organizations seemingly tend to celebrate these developments as contributions to a more sustainable world, we show that these developments can also come with significant implications for us when constructing the intelligibility of a situation.

7. References

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