Benchmarking Automation in a Human-centric Way: Implementing *Robô Pescado* for Ergonomic and Productivity Gains in Warehouse Operations

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1. Introduction

The seafood processing industry faces increasing pressure to sustain productivity under extreme cold conditions and repetitive manual labour, conditions that accelerate operator fatigue (Subash et al., 2024). Although automation technology promises to reduce workload (Wong & Seet, 2017), improve ergonomics (Kim et al., 2019) and boost productivity (Pramod, 2022), real-world implementations invert this intended relationship: rather than supporting operators, automated systems often require them to compensate for their limitations (Mital & Pennathur, 2004), repositioning humans as failure safeguards.

Warehouse automation literature compounds this gap by drawing conclusions from simulations or laboratory environments (Azadeh et al., 2019; Grosse et al., 2015) that fail to account the embodied, adaptive nature of real-world operations (Blond, 2019). Suchman (2006) frames this as enduring discrepancy between plans and situated actions, while Lefebvre's (1991) production of space frames operational environments as socially constructed through triadic layers of spatial appropriation. This dimension is invisible to laboratory experiments aiming to optimise performance metrics such as cycle-time reduction (Bottin et al., 2022) but cannot capture the situated decision-making and continuous adaptation that characterise actual shop-floor practice. This research examines "Robô Pescado", an automated sorting and palletising robotic system as embedded in the everyday practices of Portuguese cold-storage seafood warehouses; and asks: *how are ergonomic and productivity considerations translated into operational reality under environmental extremes and spatial constraints?* Our findings reveal a series of paradoxes: ergonomically designed spaces proving operationally impractical, productivity-enhancing technology underperforming manual processes, labour-saving automation intensifying monitoring demands, and error-reduction systems necessitating human intervention.

2. Research Purpose

This study examines how robotic automation is enacted in the embodied, spatial and cognitive realities of an extreme operational environment of cold-storage seafood warehouse. Existing automation studies are dominated by simulation and laboratory evidence (Parasuraman et al., 2000), which insufficiently address how design intention translates into real practices.

To address this gap, we pursue three interrelated aims. *First*, to extend theoretical understanding of human-robot interaction and automation technologies in industrial spaces. We apply Lefebvre's (1991) spatial production triad and Suchman's (2006) framework of situated practice to investigate the discrepancy between Robô Pescado's planned functionality and its operational performance across two implementation stages.

Second, to understand how operators adapt to and work around automation's limitation, and what cognitive and ergonomic costs these adaptations carry. We challenge dominant narrative on automation through Parasuraman et al.'s (2000) model of human-automation interaction and Krzywdzinski's (2017) automation labour strategies to see ergonomic displacement whereby technology transforms physical demands to cognitive workloads.

Third, to advance the emerging field of robot ethnography (Gosnall & Mansouri, 2025) by surfacing practices that quantitative productivity metrics (number of boxes/hour) systematically obscure. Such practices are predictive monitoring, corrective intervention, system-knowledge maintenance, which in turn reveals the shift in worker agency.

3. Theoretical Approach

Lefebvre's (1991) spatial production triad, namely conceived space (representations of space by planners), perceived space (spatial practices by users), and lived space (embodied spatial representations), grounds our analysis of human-robot interactions across three intertwined dimensions: organisation – workers – cold environment. This mapping is paired with Suchman's (2006) distinction between *plans* and *situated practices* to identify factors driving the discrepancy between intended robot functionality and actual operational performance. To further analyse the actual performance, Callary et al.'s (2025) work on dynamic interaction between technological, organisational and human components in cognitively and physically demanding environments extent our analysis of divergent evaluations between managers and operators.

Additionally, Parasuraman et al.'s (2000) model of human-automation interaction further structures our analysis of why certain automation configuration succeeds while others produce problematic workload. Finally, Ang et al.'s (2025) three sociotechnical principles for human-robot team design, namely 'Cognitive Workload Management', 'Adaptive Autonomy' and 'Co-generative Learning', provide a normative baseline against to assess what the current implementations lack. Together, these frameworks illuminate Robô Pescado's implementation as dilemmatic form of automation, situated at the intersection between the design and warehouse reality.

4. Research Methodology

We adopt a qualitative methodology grounded in organisational ethnography (Ybema, 2009) and the emerging principles of robot ethnography (Gosnall & Mansouri, 2025). By foregrounding the embodied dimensions of technological use (Dobrosovestnova et al., 2024), we examine how human improvisations shape technological performance in operational contexts.

Fieldwork comprised two visits, each spanning one week, conducted in February 2025 and February 2026. The sites are located at two Portuguese food distribution warehouses deploying Robô Pescado at different stages: 1) at two-years of implementation, 2) on its planning phase. In total, we conducted 24 semi-structured interviews with operators and supervisors. Our interview guideline follows Spradley's (2011) ethnographic interview framework, covering operators' initial experiences, post-automation role changes, before and after implementation ergonomic perceptions, and cognitive workload assessments. All interviews were conducted in person, audio-recorded with informed consent, transcribed verbatim and pseudonymised. Empirical data were analysed in ATLAS.ti using Braun and Clarke's (2006) reflexive approach, allowing themes to emerge inductively.

Following Barker and Jewitt (2022), we also documented recurring breakdowns, problem-solving strategies and interpretive responses to malfunctions, to surface the hidden maintenance expertise sustaining automated systems. Operational procedures, technical specifications and facility layouts provided supporting documentary evidence.

5. Key Findings

Our findings challenge widely held assumptions about robotic automation across three interrelated themes.

Theme 1: Spatial Practice Dysfunction in Situated Layout Design

Robô Pescado is designed to support the organisation's workflow through specific designated spatial layouts. The integration replaces manual sorting at the entry (A) and exit point (E) of consecutive conveyor lines (Figure 1 and 2), positions where operators manually sorted materials prior to automation.

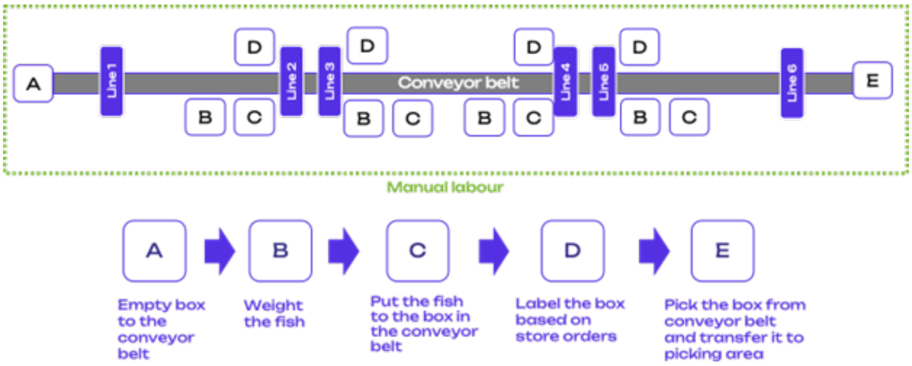

Figure 1. Simplified User Flow Before Robô Pescado

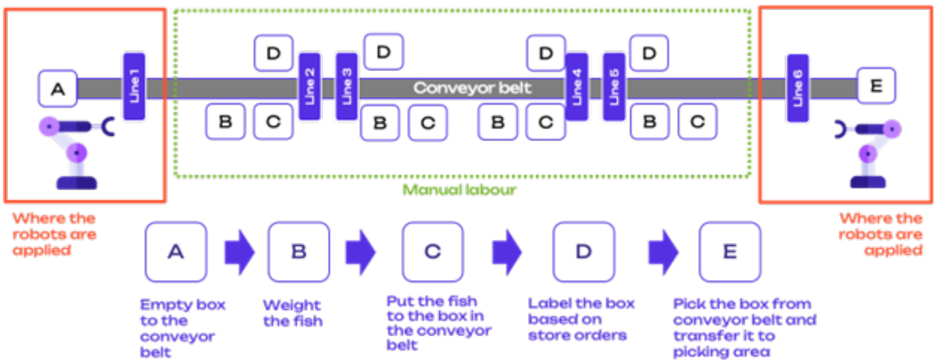

Figure 2. Simplified User Flow After Robô Pescado

Interviews documented unanticipated dysfunctions produced by this spatial redesign that persist well beyond initial implementation. The robot's positioning at both ends of the line exacerbate system failures. At the entry point, the robot is reported to frequently miscalculate box placement frequency, while at the exit stage it misidentifies box labels. These parallel failures trigger workflow interruption as the errors require human correction, either to fully reboot the robot or manually restack the boxes. These are the structural consequences of current configuration that the system fails to anticipate.

Furthermore, the interim design has generated a new and unintended role. Because production continues throughout the construction transition, operators are assigned to manually reorient boxes along the conveyor (Figure 3). With its monotonous rhythm over extended periods, operators consistently describe this as not only physically taxing but also mentally demanding.

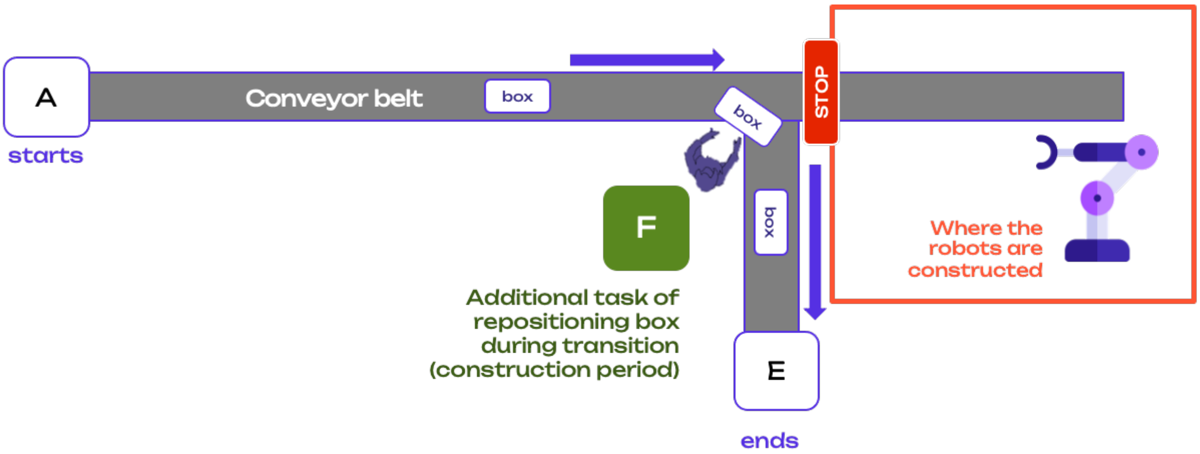

Figure 3. Additional Role to Reposition Boxes during Transition Period

Crucially, the robot's ergonomic benefits have not fully materialised as its spatial configuration still produce awkward roles and extended body strain that negate ergonomic gains. Aside from discovering recurrent issues, interviewees also identified alternative layout. For instance, positioning the robot closer to the entry point of the subsequent workflow would minimise walking distance which would be beneficial in an extreme environment.

These findings reflect a marked divergence of *conceived space* (the planners' design) and *perceived space* (the spatial practices operators perform) of Lefebvre's (1991) framework. Furthermore, the improvisations that sustain daily operations such as reactive stacking and role-switching constitute a form of situated practice (Suchman, 2006) that compensates for design failures while remaining invisible to the organisational accounts.

Theme 2: Performance Paradox – Technology Slower Than Manual Labour

Contrary to expectations, Robô Pescado operates more slowly than manual processing. Instead of increasing throughput, the system fails to meet operational threshold. A manager illustrated the shortfall: "*currently, the robot achieves approximately 500 boxes per hour, far below the 700-800 boxes per hour that workers can achieve*". Consequently, operators develop informal compensatory strategies, such as front-loading boxes at the beginning of the line to offset robot's pace, particularly during peak periods.

This gap inverts the intended human-robot relationship: rather than robots assisting humans, the robot requires continuous supervision and corrective intervention (Gosnall &

Mansouri, 2025). Accumulated operational experience has progressively eroded operators' trust in the technology (Barker & Jewitt, 2022). Although expected to treat the robot as a reliable tool, operators instead resent its situated performance due to repeated exposure to failure. The resulting trustworthiness deficit is not merely attitudinal but constitutes an ongoing cognitive expenditure of whether and when to intervene.

Parasuraman et al.'s (2000) framework identifies this configuration as a problematic intermediate automation level. Operators cannot fully engage in productive tasks because they must remain alert for errors; yet they cannot maintain the direct engagement either, since the robot operates autonomously most of the time. This creates a dilemmatic role to operators of either sustained vigilance with high alertness and low engagement, or manual controlling with high engagement and quick response. Human cognition is poorly suited to either role, while the robot delivers neither. Suchman (2006) explains why algorithm does not translate into superior throughput: experienced operators continuously adjust to immediate perceptual cues, such as variations in box position, weight distribution and task rhythm, that the robot's fixed programme cannot accommodate.

Theme 3: Workload Displacement – From Physical to Mental Labour

The supervisory inversion described above carries significant consequences for overall operational burden. We conceptualise this as *ergonomic displacement*: the physical workload does not decrease, but transforms into sustained cognitive labour of monitoring, error interpretation, decision making and correction.

Three converging factors support this finding. First, troubleshooting demands flexible personnel allocation that the post-automation staffing model cannot easily provide. Automation has reduced the number of operators assigned at whole line, thus those remaining must sustain continuous attention and dynamically reassign their roles when errors occur. With fewer workers retained on the line, breakdowns require reassigning remaining personnel, thus creating a recurrent staffing dilemma. Team leader describes this to be mentally exhausting and as an intensifying subjective burden rather than relieving the original physical load.

Second, the trust deficit identified in Theme 2 generates a form of cognitive expenditure that would not exist under either a fully manual or a fully autonomous system. Sustained vigilance under conditions of low predictability is well-documented as cognitively taxing, because it demands high alertness while providing minimal engagement or feedback to signal when attention may safely relax (Xu et al., 2023).

Third, the cold environment imposes a physiological penalty on the cognitive capacities that supervisory role demands the most, since prolonged cold exposure impairs sustained attention, working memory and executive function (Mäkinen et al., 2006). Operators thus perform the most cognitively demanding tasks under least conducive cognitive performance.

These dynamics challenge the prevailing assumption that automation inherently reduces worker strain. Intermediate automation of Robô Pescado redistributes burden into a domain that is harder to measure, harder to recover from, and, in extreme environments, physiologically disadvantaged. The result is a wellbeing risk that remains largely invisible in conventional productivity assessments yet is acutely felt by operators.

6. Implications and Conclusions

This research demonstrates that the discrepancy between anticipated automation benefits and operational reality is not incidental but systematic, arising from misalignments between design assumptions and the actual practices. We extend the analysis of human-automation interaction in situated spatial practice, showing how technological limitations shape human behaviour and how it requires continuous human involvement in an extreme environment.

Our research contributes to several aspects. Methodologically, we contribute to emerging field of robot ethnography (Gosnall & Mansouri, 2025) by surfacing specific forms of hidden labour that quantitative productivity metrics systematically exclude. The practices include predictive monitoring, corrective intervention, system-knowledge maintenance and spatial choreography. These demonstrate how practices shift worker agency towards discretionary judgement on situational interventions.

Empirically, our findings map deviation patterns on human-robot interactions onto three paradoxical absences in current sociotechnical design principles (Ang et al., 2025). First, 'Cognitive Workload Management' principle has not fully operationalised due to the supervisory cognitive demands during robot failure were not anticipated. This is caused by a workload displacement that conventional productivity metrics do not capture. Second, 'Adaptive Autonomy' principle of human-robot bidirectional task control adjustments is absent from the current configuration since the robot operates at a fixed level of autonomy. This reflects how intermediate automation treats autonomy as a binary rather than a continuum state. Third, 'Co-generative Learning' principle of two-ways behavioural learning is not reciprocal because the automation errors require operators responses, but operators have no channel back into the system. This leaves contextual operational expertise un-absorbed by system.

Taken together, these absences indicate that the design privileges technical specifications and anticipated efficiency gains over sociotechnical integration required for effective human-robot teaming. Two implications follow. First, operators must be explicitly equipped with competencies for managing, diagnosing and recovering from system under performance rather than developing these skills informally and at individual cost. Second, spatial and environmental constraints must be addressed at the design stage. Systems optimised for predictable environments cannot be transplanted into constrained contexts without coontextual redesign.

Finally, we advocate reconceptualising for a broader definition of what counts as successful automation. Current evaluations focus on output measures, which are necessary but insufficient. Effective evaluation must incorporate cognitive workload assessments, spatial practice analysis, trust calibration and qualitative accounts of work experience changes. Recognising these connections allow organisation to treat operators wellbeing and performance as mutually reinforcing rather than as a trade-off.

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