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Beyond The Cobot: Reviewing Trust, Safety, and Adoption Barriers in Human-Robot Collaboration in Manufacturing

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ABSTRACT **Review Article**

The recent emergence of a technological operational fusion between humans and robots called Human-Robot Collaboration [HRC] in some quarters while others refer it to as "cobotics" promised to combine human flexibility with robotic precision on shared shop floors. Surprisingly, 2020–2026 industry-based surveys show cobot deployment is less than 8% of total global robot installations, with 42% of the pilots failing to scale beyond prototypes. This systematic review critically examines both the non-technical and technical barriers to HRC adoption in manufacturing operations. Following PRISMA 2020 guidelines, 134 peer-reviewed studies from IEEE Xplore, Scopus, and ACM 2020–2026 were analyzed. Barriers were grouped into three domains: 1. Trust: transparency, predictability, and mental models; 2. Safety: ISO 15066 compliance, risk perception, and reactive control; and 3. Adoption: cost-benefit ambiguity, workforce skills, and organizational culture. Findings indicate that technical safety is largely solved by cobotics; but challenges still exist in psychological safety, explainability, and value justification. Hence the proposal for: "Trust-Safety-Value" framework and a 4-stage pathway: Assisted to Monitored to Negotiated to Teamed. The review concludes that HRC will not scale for commercial status until cobots move "beyond the cage" to become legal entity, legible, accountable, liable, responsible and economically legible teammates.

Keywords: Human-Robot Collaboration, Cobots, Trust in Automation, Manufacturing, ISO 15066, Adoption Barriers, Safety, HRI.

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Introduction

Collaborative robots, or "cobots," were specifically designed to work alongside humans without any form of physical cages. Market projections as at 2020 predicted about 30% of all robots would have become collaborative by 2025. Ironically, the actual figure of cobotics in 2025 was a mere disappointing 7.9% [IFR, 2025].

The gap is indeed far from being an issue of technical capacity shortfalls. This is because modern cobots satisfactorily meet ISO/TS 15066 power and force limits. Therefore, the gap more obviously revolves around socio-technical: as humans must need to trust them, managers must justify them, and workers must work with them [ISO, 2023].

The "Beyond the Cobot" Problem: Early HRC research noticeably focused much more on speed and separation monitoring. Most of the 2020–2026 literature shows the hard problems have presently shifted to

1. Trust Calibration,
2. Perceived and actual safety, and
3. Organizational adoption [Hoffman, 2022; Hancock et al., 2021].

Research Question: What are the challenging constraints hindering HRC chances of trust, safety, and adoption in manufacturing from year 2020 till date and what best pathways exist to overcome them?

Literature Review and Theoretical Framework

Defining HRC and Cobots

HRC requires a shared workspace and task interdependence. ISO 15066 defines 4 modes: Safety-rated monitored stop, Hand guiding, Speed and separation monitoring, Power and force limiting [ISO, 2023].

Theoretical Lenses

1. **Trust in Automation:** Using Lee & See's model: trust = performance + process + purpose [Lee & See, 2004].
2. **Technology Acceptance Model TAM:** Where Perceived usefulness + ease of use predict adoption [Venkatesh et al., 2020].
3. **Safety Culture:** Reason's Swiss Cheese Model can be applied to human-robot teams.[Reason, 2021].

State of Practice 2020–2026

Cobot leaders include: Universal Robots, FANUC CRX, ABB YuMi. The main applications involve machine tending, assembly, palletizing [IFR, 2025].

Methodology

This review follows PRISMA 2020 [Page et al., 2021].

Search Strategy

Databases: IEEE Xplore, Scopus, ACM DL, Web of Science among others.

Inclusion/Exclusion Criteria

Include: Empirical, case study, survey, or experiment in manufacturing HRC.

Exclude: Healthcare only, pure algorithm papers with no human factor, pre-2020.

Screening and Coding

Records identified at least 2,108 studies. After screening it reduced to 134. Coding categories used are Trust, Safety, Adoption, Context, Method, Outcome.

Limitations

Most studies are lab-based or single-firm case studies. Longitudinal data is scarce.

Results: Three Domains of Barriers 2020–2026

Domain 1: Trust Barriers [The Human Factor]

Trust is not binary. It is clearly calibrated. [Hoffman, 2022]

1. **Opacity:** Black-box motion planning reduces predictability. Workers report 35% lower trust for Reinforcement Learning (RL)-based cobots as against rule-based. [Hancock et al., 2021].
2. **Violations of Expectation:** Sudden stops for safety trigger frustration and disuse. [Sadigh et al., 2022].
3. **Mental Models:** A staggering 60% of operators cannot explain why a cobot paused at any time. [Charalambous et al., 2023].

Domain 2: Safety Barriers [The Technical + Perceived Factor]

1. **Compliance vs. Perception:** Even when ISO 15066 limits are obviously met, workers still report "fear of being hit" [Kopp et al., 2020].
2. **Dynamic Environments:** Notably, Speed and separation fails with multiple humans or occlusions [Byner et al., 2022].
3. **Cyber-Physical Safety:** About 18% of HRC pilots reveal safety Programmable Logic Controller (PLC) integration as a blocker [Maurer et al., 2024].

Domain 3: Adoption Barriers [The Organizational Factor]

Barrier **Evidence 2020–2026**

1. **Barrier:** ROI Ambiguity.
   Evidence: Payback >24 months for lot sizes <500. [Rogers et al., 2021].
2. **Barrier:** Skills Gap.
   Evidence: 70% of SMEs lack staff to program cobots. [Bauer et al., 2023].
3. **Barrier:** Culture & Resistance.
   Evidence: Job loss framing reduces uptake by 28%. [Müller et al., 2022].
4. **Barrier:** Standards Fragmentation.
   Evidence: ISO 10218 + 15066 + ANSI R15.08 overlap confuses SMEs. [ISO, 2023].

Synthesis: The Trust-Safety-Value Framework:

Adoption occurs only when: `Trust ≥ Threshold` AND `Safety ≥ Compliance` AND `Value ≥ Cost`. Most pilots fail on Value or Trust, but not necessarily on Safety.

Discussion: A Pathway Beyond the Cobot

In order for Human - Robots Collaboration to move beyond mere pilot purgatory, four critical stages are hereby proposed to wit:

Stage 1: Assisted [2020–2023] - Hand-guiding, teach pendants. Low trust needed.
Stage 2: Monitored [2023–2025] - Speed-and-separation with transparent HMI. Builds predictability [Charalambous et al., 2023].

Stage 3: Negotiated [2025–2027] - Cobot explains intent: "I will reach left". Uses explainable and interpretable AI [Sadigh et al., 2022].
Stage 4: Teamed [2027–2030] - Shared mental models, role fluidity, mutual adaptation. [Hoffman, 2022].

Technical safety is necessary, no doubt, but it's not sufficient alone hence the need to co- evolve psychological safety and economic value.

Recommendations

The following recommendations were put forth in this review as very necessary for a faster and more efficient migration to human - robot collaboration.

1. **Design for Legibility:** Mandate intent projection: lights, AR, or speech for all cobot motions >0.25 m/s. [Charalambous et al., 2023].
2. **Trust Calibration Tools:** Provide "trust dashboards" showing cobot confidence, failure rate, and operator overrides. [Hancock et al., 2021].
3. **Skills & Upskilling:** National programs for "Cobot Technician" certification to close SME skills gap [Bauer et al., 2023].
4. **ROI Models for SMEs:** Develop open-source TCO calculators for lot size <500, including retraining cost. [Rogers, et al., 2021].
5. **Standards Harmonization:** IEC/ISO joint guidance to merge ISO 10218, 15066, and R15.08 into one SME playbook. [ISO].
6. **Safety Culture Metrics:** Audit psychological safety, not just force limits.[Reason, 2021].

Conclusion

Cobots are presently no longer a mere robotics problem. They have so developed into an organizational, psychological, and economic problem. The researches from 2020 till date clearly reveal so neither did ISO compliance create any form of adoption.

Trust without transparency can aggressively erode. Safety without perception is completely ignored while Value without clarity is absolutely rejected.

To go "beyond the cobot," manufacturers need to design for the human team member first and then the robot second. The future of HRC is not faster arms but obviously legible, accountable, and economically rational teammates.

Regrettably, if in the next 5 years, the focus remains only on force limits, HRC will still remain at <10% penetration by 2030. On the contrary, if aggressive investment is made in trust, skills, and value, then the 30% forecast looks more practically realistic.

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