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Assessing the Impact of Cobots on Productivity, Ergonomics, and System Flexibility: A Comprehensive Review

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Abstract: *Collaborative robots (cobots) are increasingly used alongside human workers as an intermediate approach between manual production and fully isolated industrial automation. Existing literature frequently evaluates productivity, ergonomics, and manufacturing flexibility as separate outcomes, making it difficult to identify trade-offs that arise when a cobot is integrated into a real workstation. This review critically synthesises evidence across these three dimensions and examines the conditions under which improvement in one dimension may affect another. A structured, PRISMA-informed narrative review approach was used to identify and synthesise literature from major scientific and technical sources, with priority given to publications from 2016–2026 and earlier foundational sources where they underpin established assessment methods or concepts. The review indicates that cobots can reduce physical workload and improve selected productivity indicators in appropriate repetitive and moderate-payload applications, while productivity effects remain highly context dependent. Ergonomic benefits are more consistently reported for physical workload than for cognitive workload, because monitoring, pacing, trust, and safety concerns can introduce additional mental demands. Flexibility benefits are most evident in high-mix, low-volume and frequently reconfigured manufacturing environments, although payload, speed, safety, and integration constraints limit the advantage. A major research gap is the limited number of studies that evaluate productivity, ergonomics, and flexibility simultaneously within the same workstation or production system. The review therefore proposes an integrated conceptual framework and a candidate set of key performance indicators for future empirical studies. The findings support treating cobot adoption as a joint task-, workstation-, and organisational-design decision rather than as a simple technology substitution.*

Keywords: Collaborative robots; cobots; human–robot collaboration; productivity; ergonomics; manufacturing flexibility; Industry 4.0; human factors

I. INTRODUCTION

Industry 4.0 refers to the increasing integration of cyber-physical systems, the Industrial Internet of Things (IIoT), and data-driven decision making into manufacturing, with the objective of making production more efficient, adaptive, and responsive to changes in demand. Within this transition, industrial robotics has progressed from large robots operating inside fenced areas to robotic systems capable of sharing workspaces with human operators. [6] (1996) introduced the term “cobot” for a robotic system designed for direct physical interaction with a human operator. Modern collaborative robots are lightweight manipulators that can use force and torque sensing and other safety functions to support defined forms of human–robot collaboration [18]. Human–robot collaboration provides a middle ground between manual

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production and fully automated, physically separated robotic cells. Human dexterity, judgement, adaptability, and problem-solving can complement robotic strength, repeatability, and endurance ([23], 2018; [1], 2018).

A. Problem Statement

Manual production offers flexibility and dexterity but is affected by worker fatigue, output variability, repetitive strain, and awkward postures. Conventional fixed automation can provide throughput and precision but may require substantial reprogramming, retooling, and dedicated safety infrastructure when product variants or production volumes change [8]. The literature does not consistently show that cobots simultaneously maximise productivity, ergonomics, and flexibility. Some studies report improvement in one dimension while another remains neutral or becomes less favourable, for example when physical workload is reduced but cognitive demands associated with monitoring a robot increase.

B. Research Motivation

Productivity, ergonomics, and flexibility have traditionally been examined through different research streams. Production and industrial engineering studies commonly focus on cycle time, throughput, quality, and cost; ergonomics studies focus on physical and cognitive workload; and operations-management studies focus on reconfigurability and responsiveness to product-mix changes. A workstation design decision such as task allocation, cobot speed, payload, interface design, or degree of physical interaction can affect all three dimensions. Consequently, evaluating each outcome independently can produce incomplete recommendations. This review therefore treats productivity, ergonomics, and flexibility as interrelated outcomes of human–cobot workstation design.

C. Research Objectives

This review aims to:

1. Critically synthesis empirical and review evidence on the productivity effects of cobot adoption relative to manual work and traditional industrial robotics.
2. Examine how human–cobot collaboration affects physical and cognitive ergonomics, including the assessment methods used to measure these effects.
3. Assess the contribution of cobots to manufacturing flexibility, including task, product, volume, and workforce flexibility.
4. Identify the technological, organizational, economic, and human factors that moderate whether cobot adoption improves or worsens these outcomes.
5. Identify limitations and gaps in existing literature.
6. Propose a conceptual framework and a set of candidate key performance indicators (KPIs) for integrated evaluation of cobot-based systems.

D. Research Questions

RQ1: How do cobots affect manufacturing productivity compared with manual operations and traditional industrial robots? RQ2: Which measurable productivity indicators are affected by cobot adoption? RQ3: How does human–cobot collaboration influence ergonomics, physical workload, fatigue, MSD risk, and safety? RQ4: Which ergonomic assessment techniques have been used to evaluate cobot-supported workstations? RQ5: How do cobots influence manufacturing flexibility? RQ6: What factors determine whether cobot implementation improves productivity, ergonomics, and flexibility? RQ7: What are the major limitations and research gaps in existing cobot studies? RQ8: What future research directions are required for productive, ergonomic, and flexible human–cobot collaborative manufacturing?

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E. Scope of the Review

The review focuses on industrial and manufacturing applications of collaborative robots, including assembly, machine tending, material handling, packaging, welding, and inspection, and emphasises outcomes that can be quantified or clearly described at task, workstation, or production-line level. Service robotics, surgical robotics, social robotics, and purely simulated non-industrial human–robot interaction studies are outside the primary scope unless they provide directly transferable methodological background.

F. Contributions of the Review

The review cross-references productivity, ergonomic, and flexibility outcomes; synthesises agreement, contradiction, and context dependence; provides an integrated conceptual framework; and proposes a consolidated set of KPIs for future integrated empirical studies.

Critically synthesise empirical and review evidence on the productivity effects of cobot adoption relative to manual work and traditional industrial robotics.

Examine how human–cobot collaboration affects physical and cognitive ergonomics, including the assessment methods used to measure these effects.

Assess the contribution of cobots to manufacturing flexibility, including task, product, volume, and workforce flexibility.

Identify technological, organisational, economic, and human factors that moderate whether cobot adoption improves or worsens these outcomes.

Identify limitations and gaps in the existing literature.

Propose a conceptual framework and a set of candidate key performance indicators (KPIs) for integrated evaluation of cobot-based systems.

RQ1: How do cobots affect manufacturing productivity compared with manual operations and traditional industrial robots?

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RQ6: What factors determine whether cobot implementation improves productivity, ergonomics, and flexibility?

RQ7: What are the major limitations and research gaps in existing cobot studies?

RQ8: What future research directions are required for productive, ergonomic, and flexible human–robot collaborative manufacturing?

II. REVIEW METHODOLOGY

A. Literature Search Strategy

The review used a structured, PRISMA-informed search and synthesis process rather than a fully registered systematic review protocol. The source manuscript specifies Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, Wiley Online Library, MDPI journals, and Google Scholar. Priority was given to literature from 2016–2026, with earlier foundational sources retained where they underpin established methods.

Representative Boolean search strings included:

("collaborative robot" OR "cobot" OR "human-robot collaboration") AND ("productivity" OR "performance" OR "cycle time" OR "OEE")

("collaborative robot" OR "cobot") AND ("ergonomics" OR "human factors" OR "musculoskeletal" OR "RULA" OR "REBA" OR "NASA-TLX")

("collaborative robot" OR "cobot") AND ("flexibility" OR "reconfigurability" OR "changeover" OR "high-mix low-volume")

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("human-robot collaboration") AND ("manufacturing") AND ("review" OR "systematic review")

B. Inclusion Criteria

Industrial or manufacturing applications of collaborative robots.
Peer-reviewed journal articles, peer-reviewed conference proceedings, or recognised technical standards.
At least one measurable or clearly described outcome related to productivity, ergonomics, or flexibility.
Publication in English.
Priority to 2016–2026, while retaining foundational sources for established ergonomic and human-factors methods.

C. Exclusion Criteria

Non-industrial robotics without transferable manufacturing relevance.
Duplicate reports of the same dataset.
Studies lacking sufficient methodological detail to assess the reported outcome.
Non-peer-reviewed marketing or vendor material presented as empirical evidence.

D. Study Selection and Review Design

Records were conceptually processed through identification, screening, eligibility, and inclusion stages. Because the source manuscript did not report actual database-search counts or a registered protocol, this paper does not invent numerical PRISMA counts. It is therefore characterised as a structured narrative review informed by PRISMA principles rather than a fully reproducible systematic review. A future systematic update should report search dates, deduplication, exact record counts, exclusion reasons, and a completed PRISMA 2020 flow diagram.
Figure 1. PRISMA-informed literature workflow. Numerical record counts are intentionally omitted because they were not reported in the source review.

E. Data Extraction

For each included study, the review extracted, where reported, author and year, country or region, industry, manufacturing task, cobot type and payload class, degree of human involvement, productivity measures, ergonomic measures, flexibility measures, research method, key findings, and stated limitations.

F. Quality Assessment

Empirical studies were qualitatively appraised for research-question clarity, study-design appropriateness, measurement transparency, and support for conclusions. Systematic reviews were appraised for search and screening transparency. The appraisal was used to moderate confidence in the synthesis rather than to produce a numerical quality score.

III. FUNDAMENTALS OF COLLABORATIVE ROBOTS

A collaborative robot is generally described as a robot designed for direct interaction with a human within a shared workspace. ISO/TS 15066 addresses collaborative operation modes and associated force, pressure, and speed considerations. The original cobot concept was introduced by [6] (1996), while modern cobots use active power, sensing, compliant behaviour, and safety functions to support defined forms of collaboration. Reported applications include assembly, pick-and-place, machine tending, inspection, packaging, fastening, selected welding tasks, and material handling.

IV. IMPACT OF COBOTS ON PRODUCTIVITY

Productivity impacts vary with task characteristics, baseline process maturity, and the definition of productivity. The source review reports an automotive electronics case in which rejects decreased from 0.06% to 0.02%, first-pass yield increased from 96.42% to 98.48%, and OEE increased from 80% to 87.74% [21]. A separate lean/IIoT case reported

OEE increasing from 75% to 85% and throughput from 60 to 90 assemblies per hour, but the gains cannot be attributed solely to cobots [22]. [8] (2019) indicates that collaborative-assembly productivity is condition dependent. Economic evidence is similarly context dependent: [17] (2025) reported an engine-assembly case with estimated annual operating-cost savings of about US$41,600 and ROI of approximately one year and nine months; [2] (2022) found that economic thresholds vary with labour-market costs.

V. IMPACT OF COBOTS ON ERGONOMICS

Evidence reviewed indicates that cobots can reduce repetitive lifting, awkward reaching, and prolonged static postures. [4] (2022) reported reduced workload and improved posture-related outcomes in collaborative e-waste disassembly, while [16] (2023) reviewed evidence that cobots can reduce physical workload in heavy-load and hazardous-material tasks. Cognitive workload is less consistent: monitoring robot state, movement, pacing, trust, and safety can introduce new demands. RULA, REBA, OWAS, the NIOSH lifting equation, NASA-TLX, EMG, motion capture, and physiological measures are reported assessment approaches. Poor workstation design can introduce new ergonomic risks even when physical exertion falls.

VI. IMPACT OF COBOTS ON SYSTEM FLEXIBILITY

Cobots are repeatedly identified as suitable for high-mix, low-volume production because of comparatively rapid reprogramming, hand-guided teaching, smaller footprints, and, in some deployments, mobility ([18], 2019; [14], 2024). [15] (2024) linked cobot adoption with organisational dynamic capabilities. However, quantitative peer-reviewed evidence for specific changeover-time reductions is less extensive than industry claims. Payload, speed, safety, fixture/tooling integration, vision, and manufacturing-execution-system requirements can constrain flexibility.

VII. COMPARATIVE ANALYSIS

Note. Comparative characterisations are qualitative and task dependent.

VIII. LITERATURE REVIEW TABLE

IX. CRITICAL SYNTHESIS OF EXISTING LITERATURE

Across the reviewed sources, there is broad agreement that cobots can reduce physical workload and improve selected posture-based ergonomic outcomes in repetitive, moderate-payload tasks; are particularly relevant to high-mix, low-volume and frequently reconfigured production; and have productivity effects that are task and context dependent. Contradictions are most evident in cognitive workload and economic outcomes. Contextual moderators include industry, task type, worker experience, cobot payload and speed, production volume, workspace design, safety requirements, and concurrent lean/digital interventions.

X. RESEARCH GAPS

Lack of integrated evaluation of productivity, ergonomics, and flexibility within the same workstation or line.
Lack of standardised and comparable productivity and flexibility indicators.
Limited longitudinal evidence on sustained performance and worker adaptation.
Limited real-world industrial datasets and difficulty isolating the cobot-specific contribution.
Insufficient attention to cognitive ergonomics, trust, and long-term psychological adaptation.
Limited independent economic evaluation across multiple sites and labour-market contexts.
Lack of standardised flexibility metrics comparable in usefulness to OEE.
Limited cross-industry comparison beyond automotive and electronics assembly.
Difficulty translating laboratory physiological findings into live industrial settings.
Limited research on long-term worker adaptation.

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XI. PROPOSED CONCEPTUAL FRAMEWORK

The conceptual model developed from the review is not an empirically tested causal model. It links cobot characteristics (payload, speed, sensing, programming interface, and mobility) to human–robot collaboration mode and then to task and workstation design. These decisions jointly influence productivity, ergonomics, and system flexibility. Moderators include worker experience and training, task complexity, production volume, cobot speed and payload, safety requirements, and organisational factors.

Figure 2. Proposed framework linking cobot characteristics, collaboration mode, workstation design, and the three outcome dimensions.

XII. KEY PERFORMANCE INDICATORS

Note. These KPIs are proposed as a candidate integrated evaluation set, not a validated instrument.

XIII. DISCUSSION

The synthesis suggests that cobots do not automatically produce balanced improvement across productivity, ergonomics, and flexibility. Higher safety compliance can reduce operating speed; flexibility can carry integration overhead; lower physical workload can coincide with higher cognitive workload; human involvement can introduce performance variability; and higher payload or speed requirements can increase investment. The evidence therefore supports a conditional conclusion: simultaneous improvement is most plausible in repetitive, moderate-payload, high-mix tasks with appropriate task allocation, workstation design, and operator training.

XIV. INDUSTRIAL IMPLICATIONS

Cobot adoption should be evaluated according to task profile—payload, repetitiveness, cycle-time tolerance, and product-mix variability—rather than as a universal automation solution. Task allocation and workstation layout can strongly influence all three outcome dimensions. Because cognitive workload evidence is mixed, RULA and REBA should not be treated as sufficient on their own. Vendor flexibility claims should be validated using actual fixtures, tooling, and production conditions, and economic justification should reflect the labour-cost structure of the target region.

XV. CHALLENGES AND LIMITATIONS

Recurring challenges include worker trust and acceptance; integration with fixtures, vision systems, and manufacturing execution systems; operator and maintenance training; payload and speed limitations; workplace redesign; and the lack of standardised flexibility measures. Cybersecurity and regulatory compliance are emerging concerns as cobots become more network connected, but the source review did not identify a substantial body of manufacturing-specific peer-reviewed evidence on cobot cybersecurity outcomes.

A. Limitations of This Review

This is a structured narrative synthesis rather than a fully registered systematic review. Exact record counts were not calculated in the source work. The evidence base is concentrated in automotive and electronics assembly, and some productivity figures arise from interventions combining cobots with lean or digital initiatives. The review is not a meta-analysis and reports no pooled statistical effect sizes.

XVI. FUTURE RESEARCH DIRECTIONS

Integrated multi-dimensional evaluation measuring productivity, ergonomics, and flexibility within the same workstation before and after cobot introduction.

Longitudinal studies of worker adaptation over several months.

Real-time ergonomic monitoring using wearable sensors and computer vision, with privacy and acceptance safeguards.

Predictive and adaptive task allocation using real-time workload or fatigue signals.

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Digital-twin-based pre-deployment evaluation of layouts and task allocation.
Standardised flexibility metrics for changeover and reconfiguration.
Cross-industry and cross-region replication, including sectors and economies underrepresented in the literature.
Human-centred Industry 5.0 evaluation that includes worker wellbeing and resilience.

XVII. CONCLUSION

This review examined collaborative robots in relation to manufacturing productivity, worker ergonomics, and system flexibility. The evidence suggests that cobots can improve OEE, throughput, and quality in suitable applications, but the magnitude and direction of effects are context dependent and constrained by collaborative speed and force requirements. Ergonomic benefits are more consistently associated with physical workload than cognitive workload. Flexibility benefits are particularly relevant to high-mix, low-volume and frequently reconfigured production, although quantitative peer-reviewed evidence for specific changeover-time reductions remains less extensive than industry claims.

The strongest benefits are associated with appropriate task allocation, operator training, and workstation design that avoids awkward fixed postures and excessive time pressure. Cobots should therefore be treated as part of a joint task-, workstation-, and organisational-design decision rather than as an automatic replacement for manual work or traditional robots. Future research should prioritise integrated, longitudinal studies using consistent productivity, ergonomic, and flexibility indicators.

TABLE I
COMPARATIVE ANALYSIS OF COBOT-BASED SYSTEMS

Characteristic	Manual Work	Traditional Industrial Robot	Cobot-Based System
Productivity	Variable; fatigue/skill dependent	High and consistent for fixed high-volume tasks	Moderate-to-high in suited tasks; collaborative speed/force limits
Flexibility	High human adaptability; throughput-limited	Low for frequent changes	High relative to traditional robots for high-mix/low-volume work
Ergonomics	Higher physical/MSD risk in repetitive/heavy tasks	Worker generally separated from cell	Physical risk can be reduced; cognitive effects mixed
Safety	Task-design dependent	Isolation/fencing	Managed through defined collaborative modes
Programming	Worker retraining	Skilled programming often required	Hand-guided/teach-based programming can lower skill threshold
Changeover	Fast human retraining	Slow/costly	Potentially faster; fixtures/tooling still require changes
Human involvement	Full	Minimal	Direct shared workspace/task
Small-batch suitability	Good	Poor to moderate	Good, subject to payload/speed limits

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TABLE II
LITERATURE REVIEW SUMMARY

Author/year	Industry/task	Method	Measures/focus	Key finding	Limitation
Matheson et al. (2019)	Cross-industry HRC	Literature review	Productivity, ergonomics, flexibility/context	Benefits are application specific	No primary data
Villani et al. (2018)	Cross-industry HRC	Survey/review	Safety, interfaces, applications	Synthesises safety/interface considerations	Older relative to newer literature
Faccio et al. (2019)	Assembly	Analytical model	Cycle time; task allocation	Productivity advantage is condition dependent	Analytical, not empirical
Chen et al. (2022)	E-waste disassembly	Experiment	Efficiency/cost; NASA-TLX; posture	Reduced workload and improved posture outcomes	Single task; laboratory
Pinheiro et al. (2022)	Cross-industry; 33 studies	Systematic review	Cognitive, safety, physical, organisational ergonomics	Holistic workstation design needed	Heterogeneous primary studies
Lorenzini et al. (2023)	Cross-industry	Review	Physical/cognitive ergonomics	Physical and hazardous-task burden can be reduced	Effect sizes not pooled
Martin & Facchini (2025)	Engine assembly	Case study	Cost; payback; ergonomic risk	Reported ROI ~1 year 9 months	Single site
Calvo & Gil (2022)	Multi-material assembly	Model + case	Break-even productivity gain	Threshold varies with labour costs	One validation case
Rada et al. (2024)	Automotive electronics	Case study	OEE; FPY; scrap	OEE 80→87.74%; FPY 96.42→98.48%; scrap 0.06→0.02%	Single site
Sundar et al. (2024)	General assembly	Case study	OEE; throughput; headcount	OEE 75→85%; throughput 60→90 units/h	Combined lean/IIoT; not primarily a cobot study

TABLE III
PROPOSED KEY PERFORMANCE INDICATORS

Category	Indicator	Relevance
Productivity	Cycle time	Task-level throughput capacity
Productivity	Throughput (units/hour)	Line-level output

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Productivity	OEE	Availability, performance, and quality
Productivity	Productivity per worker	Labour-productivity effect
Productivity	Downtime	Reliability and integration quality
Productivity	Defect/scrap rate	Quality dimension
Productivity	Utilization	Cobot capacity use
Ergonomics	RULA / REBA	Postural risk
Ergonomics	EMG activity	Muscular-load measure
Ergonomics	Fatigue indicators	Sustained performance and safety
Ergonomics	NASA-TLX	Subjective multidimensional workload
Ergonomics	Worker satisfaction	Acceptance and wellbeing
Ergonomics	Perceived safety	Trust and willingness to collaborate
Flexibility	Changeover time	Reconfiguration speed
Flexibility	Number of product variants	Product-mix flexibility
Flexibility	Reconfiguration time	Physical/layout flexibility
Flexibility	Task-switching time	Task/workforce flexibility
Flexibility	Programming/re-teaching time	Redeployment ease
Flexibility	Volume adaptability	Demand responsiveness

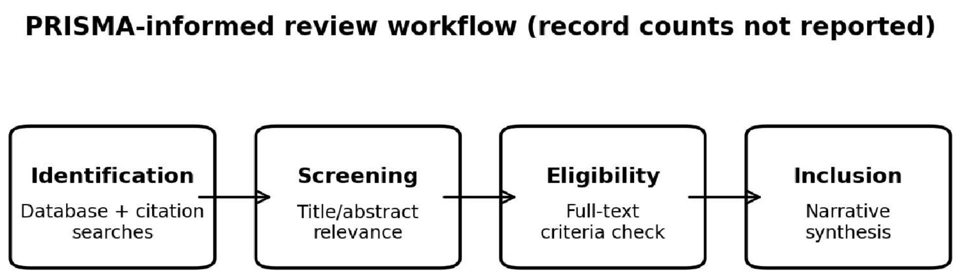

Fig. 1. PRISMA-informed literature workflow. Numerical record counts are intentionally omitted because they were not reported in the source review.

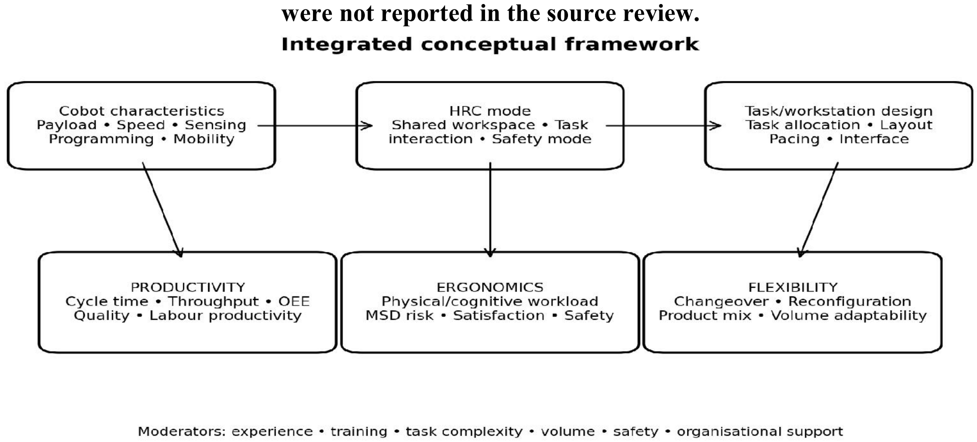

Fig. 2. Proposed framework linking cobot characteristics, collaboration mode, workstation design, and the three outcome dimensions.

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