Organizational Readiness for Human-Robot Collaboration: A Configurational Analysis of Enabling Conditions Across Industry Contexts

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Abstract

Stakeholder acceptance of human-robot collaboration across manufacturing and service industries remains poorly understood. Traditional technology acceptance models such as TAM and UTAUT rely on single factor explanations and assumptions of symmetric causation, limiting their ability to capture the configurational and robot-specific nature of human-robot collaboration adoption. This study addresses these limitations by applying fuzzy set Qualitative Comparative Analysis (fsQCA) to examine organizational, psychological, and cultural configurations shaping human-robot collaboration acceptance across 11 cases drawn from European, Asian, and cross-cultural contexts.

We develop the Human Robot Collaboration Acceptance Model (HRCAM), which centers on perceived competence ambivalence, whereby high robot competence may simultaneously enhance performance expectancy and activate intergroup threat. The findings identify two robust configurational pathways to high acceptance, an Infrastructure Driven pathway and a Trust Driven pathway, alongside a tentative Collectivist Gradual pathway. Perceived competence emerges as a necessary condition within this dataset and calibration, and low threat as near necessary, demonstrating clear asymmetric causation. The study advances technology acceptance research beyond confirmatory testing and provides pathway-specific guidance for organizations implementing human-robot collaboration in diverse institutional and cultural contexts.

Keywords: *configurational analysis, fsQCA, human-robot collaboration, organizational readiness, technology acceptance*

Jel classification: *M10 (Business Administration: General), M15 (IT Management), O33 (Technological Change)*

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1. Introduction

The proliferation of collaborative robots (cobots) and artificial intelligence systems across manufacturing and service industries represents not merely a technological transition, but a fundamental organizational challenge. As Industry 4.0 and Industry 5.0 paradigms reshape production and service systems worldwide,

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organizations increasingly recognize that the success of human-robot collaboration (HRC) depends less on technical capabilities and more on stakeholder acceptance and organizational preparedness (Callari et al., 2024; Liao et al., 2023). Failed implementations carry substantial costs: disrupted operations, stakeholder resistance, and unrealized returns on automation investments. Yet our understanding of what organizational conditions enable successful HRC adoption remains fragmented across disciplines and theoretical frameworks. The remainder of this section reviews the relevant literature on HRC and technology acceptance, and then states the research question, approach, and contributions.

1.1 Theoretical Background and Relevant Literature

HRC refers to cooperative work in which humans and robots operate together within shared production systems. Romero et al. (2016) define this as human-automation symbiosis, where machines assist rather than replace human workers and dynamically adapt to human physical, cognitive, and sensorial capabilities. Collaboration emerges through organizationally embedded task allocation, shared control, and continuous human-machine interaction. Successful HRC deployment therefore depends not only on technical performance but also on stakeholder acceptance, trust, and integration into existing organizational structures (Nahavandi, 2019). Collaborative robots (cobots) exemplify this approach: human-centered machines designed to work alongside operators, balancing efficiency, safety, and meaningful human work in modern manufacturing and service systems (Kagermann et al., 2013; Romero et al., 2016; Law et al., 2020).

This socio-technical framing follows the Industry 4.0 to Industry 5.0 transition. Nahavandi (2019) argues that while Industry 4.0 prioritizes process efficiency and automation, it often marginalizes human involvement, whereas Industry 5.0 reintroduces humans into production systems, pairing human intelligence with autonomous machines that learn from human actions and support task execution. This approach also emphasizes sustainability, workplace safety, and higher-value human work, reinforcing the socio-technical nature of HRC. Consistent with this, Industry 4.0 does not envision fully automated, human-free factories (Kagermann et al., 2013); collaborative robots are instead designed to operate alongside human workers, which requires organizations to integrate robots into existing roles and workflows. Kagermann and Wahlster (2022) accordingly frame collaborative robots not as instruments of automation but as human-centered socio-technical systems whose effectiveness depends on organizational redesign, stakeholder coordination, and meaningful human-machine cooperation. Schwab (2016) characterizes the Fourth Industrial Revolution as a systemic transformation that reshapes how work is organized, how organizations operate, and how value is created: technological outcomes are not determined by technical capability alone, but by how organizations and wider stakeholders adapt to, integrate, and govern new technologies within existing social and institutional structures.

Prior empirical work has demonstrated that stakeholder responses to service and collaborative robots vary significantly, differing according to perceived social role, task context, and expectations of robot competence (Law et al., 2020). Together, these findings reinforce the need to examine HRC adoption as an organizational and psychological phenomenon rather than a purely technological one, and to identify how organizational, psychological, and cultural factors combine to produce high stakeholder acceptance.

The Technology Acceptance Model (TAM), introduced by Davis (1989), provides a foundational framework for understanding user adoption of information systems. TAM proposes that two cognitive beliefs, perceived usefulness (PU) and perceived ease of use (PEOU), shape users' behavioral intentions and, consequently, actual system use. PU is defined as the degree to which a person believes using a system enhances job performance, and PEOU as the degree to which using a system is free of effort. Empirical evidence shows that PU strongly predicts intention to use, while PEOU influences both PU and intention, creating a linear, causal pathway from perception to behavior. The intention to use is also informed by a person's subjective probability of performing the behavior (Fishbein and Ajzen, 1975).

The dominant approach to understanding technology acceptance relies on models such as TAM and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Davis, 1989; Venkatesh et al., 2003). UTAUT integrates key constructs from prior models, including performance expectancy, effort expectancy, social influence, and facilitating conditions, and accounts for moderating factors such as age, gender, experience, and voluntariness, explaining up to 70% of variance in behavioral intention (Venkatesh et al., 2003). These models have generated valuable insights. However, their application to HRC produces mostly confirmatory findings: training improves acceptance, trust matters, and perceived usefulness predicts adoption. More fundamentally, TAM and UTAUT assume independent, symmetric effects. Technology use is inherently sociomaterial, meaning that human and technological actions are entangled within organizational structures and routines, rather than operating independently (Orlikowski, 2007). HRC acceptance instead exhibits equifinality, where multiple configurations can lead to the same outcome; conjunctural causation, where conditions work in combination; and asymmetric causation, where the factors leading to acceptance differ from those leading to rejection. While TAM and UTAUT provide a strong theoretical foundation, they are insufficient for explaining the organizational and psychological dynamics of HRC.

The Technology Acceptance Model 2, TAM2, extends the original TAM by adding social influence processes, including subjective norm, image, and voluntariness, and cognitive instrumental processes, such as job relevance, output quality, result demonstrability, and perceived ease of use (Venkatesh and Davis, 2000). These constructs explain how perceptions of task importance, system performance, and observable results shape perceived usefulness and usage intentions. While TAM2 provides a richer framework than TAM, it still assumes linear, additive, and symmetric relationships and does not capture the configurational, dynamic, and context-specific factors that characterize HRC. In

HRC contexts, for example, perceived robot competence can both enhance performance expectations and trigger threat perceptions, illustrating the need for a framework that accounts for equifinality, conjunctural causation, and asymmetric effects beyond TAM2.

Building on TAM and TAM2, prior research in human-robot interaction highlights considerations unique to collaborative robots. Law et al. (2020) demonstrate that stakeholders evaluate robots not only on functional task performance, akin to perceived usefulness, but also on perceived ease of interaction, adaptability, and social communication, which serve as robot-specific proxies for PEOU and performance expectancy. These studies further reveal that conventional linear, variance-based approaches, while valuable for identifying predictors of acceptance, often overlook contextual and configurational factors, such as differences across cultural and organizational settings. Importantly, the research identifies robot-specific psychological mechanisms, including perceived threat, social role expectations, and concerns about autonomy, that influence acceptance beyond traditional TAM constructs. Together, these findings underscore both the continued relevance of TAM-derived measures and the need to extend them to account for the context-sensitive, affective, and social factors inherent to HRC.

1.2 Research Question and Contributions

Despite the explanatory power of TAM, TAM2, TAM3, and UTAUT, existing models remain largely variance-based and linear, focusing on independent, additive effects of cognitive and social predictors (Venkatesh et al., 2003; Venkatesh and Bala, 2008). Extensions such as UTAUT2 incorporate constructs like hedonic motivation, habit, and contextual moderators but still rely on symmetric causation and primarily predict intention rather than configurational outcomes (Venkatesh, Thong and Xu, 2012). Empirical findings from HRC contexts reveal contradictory patterns: the same technical features may be perceived as both enabling and threatening, and adoption varies depending on organizational practices, cultural norms, and robot-specific psychological mechanisms such as perceived competence ambivalence (Law et al., 2020). Moreover, prior models often neglect the organizational embedding of technology, how routines, infrastructure, and managerial practices shape interactions between humans and robots (Orlikowski, 2007; Leonardi, 2011), underscoring the need for a configurational approach that captures equifinality, conjunctural causation, and asymmetric effects. Accordingly, this study is guided by the following research question:

What are the organizational and cultural configurations that lead to high stakeholder acceptance of HRC across industry contexts?

To address this question, we employ fuzzy-set Qualitative Comparative Analysis (fsQCA), a set-theoretic method designed to identify sufficient and necessary conditions for outcomes across diverse cases (Ragin, 2008; Schneider and

Wagemann, 2012). This approach addresses the limitations noted above and captures the complex, context-dependent dynamics of HRC adoption. Our analysis draws on 11 cases from European, Asian, and cross-cultural contexts. These cases span manufacturing, logistics, and service sectors and include employee surveys, customer studies, expert panels, and literature syntheses. We examine configurations of robot-specific variables, including perceived competence, functional trust, intergroup threat, and robot-use self-efficacy. We also consider organizational conditions, such as training, facilitating conditions, and management support. Cultural differences are represented through pathway flags derived from Hofstede dimensions.

Three contributions to management theory and practice are offered. First, this study contributes the HRC Acceptance Model (HRCAM), which articulates a robot-specific mechanism absent in traditional TAM/UTAUT applications: perceived competence (PC) ambivalence. Unlike conventional IT systems, robots that are perceived as highly competent can simultaneously enhance performance expectancy and trigger intergroup threat—a paradox requiring configurational analysis to understand when competence leads to acceptance versus rejection. Second, we demonstrate methodologically how fsQCA can advance technology acceptance research beyond "TAM confirmation" by revealing equifinal pathways and identifying necessary and near-necessary conditions within the analyzed cases and calibration. Third, we provide practitioners with pathway-specific prescriptions that reject one-size-fits-all implementation strategies, instead offering evidence-based guidance tailored to organizational and cultural contexts.

2. RESEARCH DESIGN

This study is guided by a single research question: What are the organizational and cultural configurations that lead to high stakeholder acceptance of HRC across industry contexts? In the research design, we translate this question into three analysis components aligned with standard fsQCA outputs: (1) necessary conditions, (2) sufficient configurations (equifinal pathways), and (3) asymmetric causation via configurations for low acceptance.

To address these analysis components, we develop the HRC Acceptance Model (HRCAM), as shown in Figure 1. PC generates both positive (PE, FT) and negative (IT) pathways. RSE and OR buffer the negative pathway. Cultural flags determine pathway availability, not direct causation.

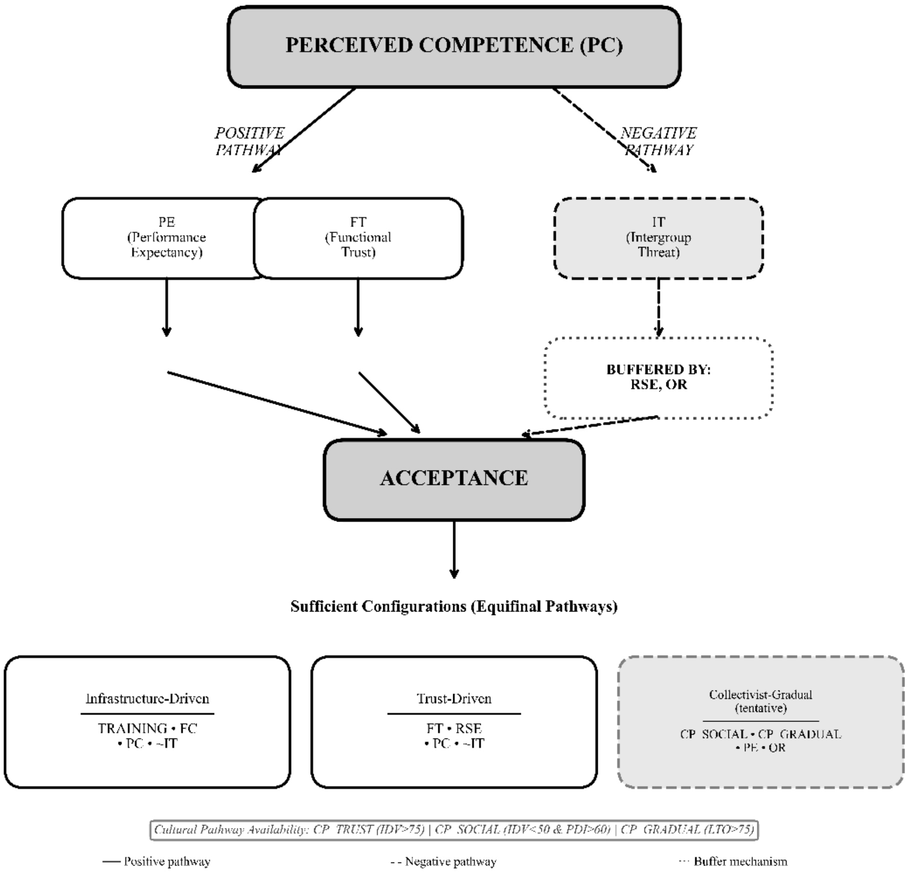

Figure 1. HRCAM Conceptual Framework
Source: Authors' own material

The core proposition of HRCAM is that perceived robot competence exhibits ambivalence: it enables both positive and negative pathways to acceptance outcomes. Along the positive pathway, high PC enhances PE ("this capable robot can help me achieve my goals") and FT ("this competent robot can be relied upon to perform tasks correctly"); along the negative pathway, the same high PC simultaneously activates IT ("this capable robot could replace me").

If PC ambivalence determines that competence alone cannot predict acceptance, what conditions determine whether the positive or negative pathway dominates? HRCAM identifies two bifurcation mechanisms. The first is robot-use self-efficacy (RSE): employees with high confidence in their ability to work effectively with robots can perceive robot competence without threat activation, so that RSE acts as a psychological buffer ("the robot is capable, and so am I - we can collaborate effectively"). When RSE is low, the same PC perception triggers defensive responses ("the robot is capable, but I am not - it threatens my position").

The second mechanism is organizational readiness (OR): organizational conditions - training programs, facilitating conditions (infrastructure and support), and management commitment - collectively signal whether the organization is prepared for successful HRC implementation. We operationalize OR as a composite index, OR = (FC × 0.40) + (TRAINING × 0.35) + (MGMT × 0.25); the theoretical rationale for these weights and their sensitivity are detailed in Section 3.3 (see Equation (2)).

HRCAM operationalizes cultural context through three cultural pathway flags derived from Hofstede dimensions. CP_TRUST (IDV ≥ 75). CP_SOCIAL (IDV < 50 AND PDI ≥ 60). CP_GRADUAL (LTO ≥ 75). Importantly, these flags indicate pathway availability, not requirement. A case with CP_TRUST = 1 means the trust pathway can work effectively, not that it must be used.

3. Methodology

3.1 fsQCA Procedure

Fuzzy-set Qualitative Comparative Analysis (fsQCA) is a set-theoretic method that identifies configurations of conditions that are sufficient and/or necessary for an outcome (Ragin, 2008; Schneider and Wagemann, 2012). Unlike variance-based methods, fsQCA treats cases as combinations of set memberships and is well suited to small- and intermediate-N designs in which equifinality, conjunctural causation, and asymmetry are expected. The procedure comprises two primary stages: an analysis of necessary conditions and an analysis of sufficient conditions using the truth-table algorithm.

A condition is necessary if the outcome is a subset of the condition—that is, whenever the outcome is present, the condition is also present. We assess necessity using a consistency threshold of ≥ 0.90 (Schneider and Wagemann, 2012). Necessity consistency is calculated as in Equation 1:

$$\text{Necessity consistency} = \Sigma \min(X, Y) / \Sigma Y \quad (1)$$

where X is the condition and Y is the fuzzy ACCEPTANCE outcome (continuous membership scores ranging from 0.12 to 0.85 across the 11 cases).

A configuration is sufficient if it is a subset of the outcome—that is, whenever the configuration is present, the outcome is also present. To identify sufficient configurations, we construct a truth table and apply the following thresholds: a frequency threshold of ≥ 1 case (appropriate for small-N designs), a raw consistency threshold of ≥ 0.80, and a PRI (Proportional Reduction in Inconsistency) threshold of ≥ 0.75. The truth-table algorithm then proceeds by constructing all logically possible configurations, assigning cases to rows on the basis of their fuzzy membership scores, evaluating consistency and PRI for each row, setting the outcome value for each row (1 where the thresholds are met, 0 otherwise), and applying logical minimization to derive the parsimonious and intermediate solutions.

3.2 Calibration Procedure

Fuzzy membership scores were assigned using a rule-based calibration anchored to the three qualitative benchmarks of the direct method (Ragin, 2008):

- **Full membership (1.0)**: The case clearly belongs to the set
- **Crossover point (0.5)**: Maximum ambiguity; neither in nor out
- **Full non-membership (0.0)**: The case does not belong to the set

Table 1 summarizes the variable definitions, codes, and calibration anchors used in this study. Each variable is calibrated using this rule-based approach, anchored to the three qualitative benchmarks of the direct method following Ragin (2008). PC-RSE anchors assume 5-point Likert scales transformed to 0-1 range.

Variable Definitions and Calibration Anchors

Table 1

Variable	Code	Definition	Full (1.0)	Cross (0.5)	Non (0.0)
Perceived Competence	PC	Robot capability perception	>= 4.0*	3.0	<= 2.0
Performance Expectancy	PE	Perceived value/benefits	>= 4.0	3.0	<= 2.0
Collaboration Ease	CE	Work coordination ease	>= 4.0	3.0	<= 2.0
Functional Trust	FT	Task reliability trust	>= 4.0	3.0	<= 2.0
Social Trust	ST	Partner acceptability	>= 4.0	3.0	<= 2.0
Intergroup Threat	IT	Job/identity threat perception	>= 4.0	3.0	<= 2.0
Robot-Use Self-Efficacy	RSE	Confidence working with robots	>= 4.0	3.0	<= 2.0
Training	TRAINING	Training program provision	1.0 (Yes)	0.5 (Partial)	0.0 (No)
Facilitating Conditions	FC	Infrastructure/support	>= 0.85	0.50	<= 0.25
Management Support	MGMT	Management commitment	>= 0.85	0.50	<= 0.25
Organizational Readiness	OR	Composite index	(calculated)		

Source: Authors' analysis based on Ragin (2008)

Because the cases were extracted from published studies rather than collected through a single primary instrument, the source statistics available for calibration were heterogeneous, and the mapping from a study's reported evidence to a fuzzy membership score followed documented decision rules rather than a single mechanical formula. Reported evidence took several forms: scale means on standard Likert anchors (PC, PE, and CE calibrated at ≥ 4.0 = full, 3.0 = crossover, ≤ 2.0 = non on a 5-point scale); adoption or prevalence percentages; directly reported composite metrics; and qualitative High/Moderate/Low descriptors from literature syntheses and expert consensus. Trust constructs (FT, ST) were anchored following Gaudiello et al. (2016), intergroup threat (IT) following Liao et al. (2023), and facilitating conditions and management support against UTAUT-style criteria (strong ≥ 0.85, moderate 0.50, weak ≤ 0.25). Robot-use self-efficacy anchors followed conventional self-efficacy scale conventions transformed to the 0-1 range.

For each case and construct we recorded a measurement-status label—direct, proxy (indirect), or estimated—together with the underlying evidence, in the extraction sheet (columns *_raw and measurement_notes). These labels governed how the reported evidence entered calibration: directly measured values were used as reported; indirect (proxy) values were mapped through documented estimation rules; and estimated values were calibrated conservatively toward the 0.5 crossover to avoid assigning unwarranted extreme memberships. Where a construct was not measured in a source, it was set to the 0.50 crossover or estimated from case context. Directly measured constructs were, in fact, few: functional trust is measured directly only in Gaudiello et al. (2016), and perceived competence, intergroup threat, and robot-use self-efficacy only in Liao et al. (2023) (with IT also available for EU_DE_96); the remaining values relied on proxy or estimated calibration, as the Limitations section discloses.*

The documented estimation rules included using a single reported "trust" measure as FT; setting ST at FT minus 0.05-0.10 where a separate social-trust measure was unavailable; estimating RSE from the training context; and estimating PC from performance-expectancy descriptions together with explicit capability mentions. Two worked examples illustrate the procedure. For EU_DE_96 (Ulrich and Frank, 2021), a reported 5.8% adoption rate was calibrated to ACCEPTANCE = 0.12 (clear non-membership), while the finding that 65% of respondents cited a competence-related barrier was calibrated to IT = 0.75; in both instances the percentage evidence was mapped onto the same three anchor benchmarks tabulated in Table 1 through the documented decision rules, rather than through a literal application of the tabulated Likert values. For EU_DE_205 (Jacob et al., 2023), a systematic literature review with no primary sample, each construct was calibrated from the review's best-practice configuration descriptors, with High/Moderate/Low synthesis statements mapped to the full/crossover/non anchors. Expert-panel and cross-cultural cases were treated analogously: EU_DE_206 (Callari et al., 2024) drew on 30-expert Delphi consensus statements calibrated to the same anchors, and CROSS_EG_MY_17 (Abdelhakim et al., 2023) used UTAUT constructs measured directly in the source, with acceptance inferred from moderate-to-high signals.

All calibration was performed by a single coder applying these documented decision rules, with per-construct evidence cells and author self-checks, namely consistent threshold application, manual recalculation of the OR composite for every case, and sensitivity checks on boundary cases near 0.50. No inter-coder reliability statistic was computed; this is acknowledged as a limitation.

3.3 Organizational Readiness Composite

Organizational readiness (OR) enters the analysis as a composite index rather than as a directly observed construct:

$$OR = (FC \times 0.40) + (TRAINING \times 0.35) + (MGMT \times 0.25) \quad (2)$$

The weights were set a priori on theoretical grounds. Facilitating conditions receive the largest weight because they represent the most fixed and structural precondition for human-robot collaboration—the physical infrastructure and technical support that must be in place before deployment—mirroring the role of facilitating conditions in UTAUT as a direct determinant of use behavior. Training carries the next-largest weight as the most proximal human-capital investment through which organizations convert infrastructure into workforce capability. Management support receives the smallest weight, reflecting its more distal, signaling role rather than a direct operational effect.

Because the weighting is a modelling choice, we examined its influence by recomputing OR under three alternative specifications alongside the base weights: equal weights (1/3 each), an FC-heavy specification (0.50/0.25/0.25), and a training-heavy specification (0.25/0.50/0.25). Crucially, OR appears in only one of the sufficient configurations—the Collectivist-Gradual pathway (CP_SOCIAL * CP_GRADUAL * PE * OR). The Infrastructure-Driven and Trust-Driven pathways contain no OR term and are therefore invariant to the weighting by construction. Under the alternative specifications, the single Collectivist-Gradual case (CROSS_CN_72) retains its pathway membership. We therefore treat the weighting as consequential only for the tentative third pathway, and we do not claim a validated statistical stability test across all pathways.

3.4 Cultural Pathway Flag Construction

Cultural flags are calculated from Hofstede dimension scores and shown in Table 2 (Maseland and van Hoorn, 2017):

- CP_TRUST = 1 if IDV >= 75 else 0
- CP_SOCIAL = 1 if (IDV < 50 AND PDI >= 60) else 0
- CP_GRADUAL = 1 if LTO >= 75 else 0

Each flag corresponds to the cultural precondition of one acceptance route. High individualism ($IDV \geq 75$) signals a context in which interpersonal and institutional trust-building is an available route (CP_TRUST), consistent with the Trust-Driven pathway; the combination of low individualism and high power distance ($IDV < 50$ and $PDI \geq 60$) signals a context of socially mediated influence (CP_SOCIAL); and strong long-term orientation ($LTO \geq 75$) signals tolerance for gradual familiarization over time (CP_GRADUAL). The dimension thresholds follow Caputo et al. (2018).

Cultural Pathway Flag Assignment

Table 2

Case	IDV	PDI	LTO	CP_TRUST	CP_SOCIAL	CP_GRADUAL
EU_FR_67/200	71	68	63	0	0	0
EU_DE_96/205/206	67	35	83	0	0	1
AS_CN_204	20	80	87	0	1	1
CROSS_EG_MY_17	25	85	24	0	1	0
CROSS_US_72	91	40	26	1	0	0
CROSS_CN_72	20	80	87	0	1	1
EU_SP_194	51	57	48	0	0	0
EU_IT_138	76	50	61	1	0	0

Source: Hofstede Insights (2023); thresholds following Caputo et al. (2018).

3.5 Solution Interpretation

We report the intermediate solution, which incorporates theoretical expectations about directional relationships while avoiding untenable simplifying assumptions (Ragin, 2008; Schneider and Wagemann, 2012). Following standard fsQCA reporting conventions, configurations are interpreted through three condition roles: core conditions, which appear in both the parsimonious and intermediate solutions and represent the strongest causal contributors; peripheral conditions, which appear only in the intermediate solution and play a contributing but non-essential role; and INUS conditions—conditions that are Insufficient but Necessary parts of configurations that are themselves Unnecessary but Sufficient for the outcome. This distinction shapes how the results are presented: the sufficient configurations in Section 5.2 are reported as combinations of conditions, none of which is individually sufficient; consistency indicates how reliably each configuration is a subset of the outcome; and coverage indicates the empirical relevance of each pathway. Interpreting pathways as bundles of core and peripheral conditions, rather than as independent variables, is what allows the analysis to express equifinality and conjunctural causation.

4. DATA

The unit of analysis in this study is the case, not the individual survey respondent. Each case represents a configuration of organizational, psychological, and cultural conditions associated with an acceptance outcome, extracted from a published empirical study. On this basis, we assembled 11 cases from published studies (2016-2024) spanning manufacturing, logistics, and service sectors and including employee surveys, customer studies, expert panels, and literature syntheses, as shown in Table 3. This deliberate heterogeneity supports configurational theorizing and broadens external validity, while the differences in unit type across cases are carried forward transparently (see the Limitations in Section 6.4) and documented case by case.

Case Overview

Table 3

Case ID	Country	Context	Case Type	Sample	Acceptance
EU_FR_67	France	Research/Lab	Employee survey	56	0.32 (Low)
EU_FR_200	France	Manufacturing	Employee survey	6	0.50 (Cross)
EU_DE_96	Germany	SMEs	Employee survey	283	0.12 (Low)
EU_DE_205	Germany	Warehousing	Literature synthesis	N/A	0.75 (High)
EU_DE_206	Germany/UK	Manufacturing	Expert panel	30	0.80 (High)
AS_CN_204	China	Manufacturing	Employee survey	300	0.45 (Low)
CROSS_EG_MY_17	Egypt/Malaysia	Fast-food	Customer survey	N/A	0.65 (Cross)
CROSS_US_72	USA	Hospitality	Customer survey	491	0.85 (High)
CROSS_CN_72	China	Hospitality	Customer survey	495	0.75 (High)
EU_SP_194	Spain	Manufacturing	Aggregate analysis	Firm-level	0.60 (Cross)
EU_IT_138	Italy	Manufacturing	Aggregate analysis	Regional	0.55 (Cross)

Note: Case-source mapping: EU_FR_67 (Gaudiello et al., 2016); EU_FR_200 (Cippelletti et al., 2023); EU_DE_96 (Ulrich and Frank, 2021); EU_DE_205 (Jacob et al., 2023); EU_DE_206 (Callari et al., 2024); AS_CN_204 (Liao et al., 2023); CROSS_EG_MY_17 (Abdelhakim et al., 2023); CROSS_US_72/CN_72 (Chi et al., 2023); EU_SP_194 (Camiña et al., 2020); EU_IT_138 (Cirillo et al., 2024).

S*ource*: Authors' compilation from published empirical studies (2016-2024).

5. Results

5.1 Necessary Conditions

Table 4 reports the necessity analysis for high acceptance. Perceived competence (PC) and performance expectancy (PE) both reach perfect necessity consistency (1.000), and functional trust (FT, 0.976), low intergroup threat (~IT, 0.945), robot-use self-efficacy (RSE, 0.953), and facilitating conditions (FC, 0.913) all clear the ≥ 0.90 threshold, forming a near-necessary set. Organizational readiness (OR, 0.897) falls just below the threshold. These figures are read here as descriptive subset relations within the 11-case sample; their theoretical interpretation is developed in Section 6.1.

Analysis of Necessary Conditions for Acceptance

Table 4

Condition	Consistency	Interpretation
PC (Perceived Competence)	1.000	Necessary in this dataset
PE (Performance Expectancy)	1.000	Necessary in this dataset
FT (Functional Trust)	0.976	Near-necessary (>= 0.90)
~IT (Low Threat)	0.945	Near-necessary (>= 0.90)
RSE (Robot-use Self-Efficacy)	0.953	Near-necessary (>= 0.90)
FC (Facilitating Conditions)	0.913	Near-necessary (>= 0.90)
OR (Organizational Readiness)	0.897	Does not meet 0.90 threshold

Source: Authors' analysis.

5.2 Sufficient Conditions for Acceptance

Table 5 presents the sufficient configurations for high acceptance identified through the truth table algorithm. Three distinct pathways emerge.

Sufficient Configurations for Acceptance (fsQCA Analysis)

Table 5

Pathway	Configuration	Consistency	Raw Coverage	Unique Coverage
Infrastructure-Driven	TRAINING * FC * PC * ~IT	0.98	0.69	0.00
Trust-Driven	FT * RSE * PC * ~IT	0.98	0.92	0.18
Collectivist-Gradual (tentative)	CP_SOCIAL * CP_GRADUAL * PE * OR	1.00	0.16	0.01

Solution consistency: 0.97; Solution coverage: 0.93
Note: * = AND; ~ = absence.

Source: Authors' analysis.

Case-level membership of each high-acceptance case in the three sufficient configurations is reported in Table 6.

High-Acceptance Case Membership in Sufficient Configurations

Table 6

Case	ACCEPTANCE	Infra. Config	Trust Config	Collect.-Grad. Config
EU_DE_205	0.75	0.80	0.80	0.00
EU_DE_206	0.80	0.85	0.80	0.00

Case	ACCEPTANCE	Infra. Config	Trust Config	Collect.-Grad. Config
CROSS_US_72	0.85	0.75	0.80	0.00
CROSS_CN_72	0.75	0.65	0.70	0.75

Note: Config membership = min(condition memberships).

Source: Authors' analysis.

Pathway 1: Infrastructure-Driven (robust). The configuration [TRAINING * FC * PC * ~IT] is sufficient for high acceptance with consistency 0.98 and raw coverage 0.69. Its unique coverage is 0.00 because every case satisfying this configuration also satisfies the Trust-Driven configuration. Four high-acceptance cases exhibit membership > 0.5: EU_DE_205 (0.80), EU_DE_206 (0.85), CROSS_US_72 (0.75), and CROSS_CN_72 (0.65).

Pathway 2: Trust-Driven (robust). The configuration [FT * RSE * PC * ~IT] is sufficient with consistency 0.98, the highest raw coverage (0.92), and a unique coverage of 0.18. High-acceptance cases with membership > 0.5 include EU_DE_205 (0.80), EU_DE_206 (0.80), CROSS_US_72 (0.80), and CROSS_CN_72 (0.70).

Pathway 3: Collectivist-Gradual (tentative). The configuration [CP_SOCIAL * CP_GRADUAL * PE * OR] exhibits consistency 1.00 but low raw coverage (0.16) and unique coverage 0.01, and its membership > 0.5 rests on a single case, CROSS_CN_72 (0.75).

5.3 Asymmetric Causation: Configurations for Low Acceptance

To examine asymmetric causation, Table 7 presents configurations associated with low acceptance outcomes. These low-acceptance configurations are not the Boolean negations of the acceptance configurations in Table 5—most notably, high perceived competence appears both in the acceptance pathways and in the Threat-Barrier pattern, while social trust features only in a low-acceptance configuration—which is the descriptive signature of asymmetric causation. Read descriptively, the Threat-Barrier pattern combines high perceived competence with high intergroup threat and low robot-use self-efficacy (PC * IT * ~RSE, consistency 0.95); the Organizational-Unreadiness pattern reflects the joint absence of training, facilitating conditions, and management support (~TRAINING * ~FC * ~MGMT, 0.92); and the Trust-Deficit pattern reflects the joint absence of functional trust, social trust, and performance expectancy (~FT * ~ST * ~PE, 0.88). Mechanism-level interpretation of these patterns is reserved for the Discussion.

Configurations for Low Acceptance (< 0.50)

Table 7

Pattern	Configuration	Consistency	Cases
Threat Barrier	PC * IT * ~RSE	0.95	AS_CN_204
Organizational Unreadiness	~TRAINING * ~FC * ~MGMT	0.92	EU_DE_96

Pattern	Configuration	Consistency	Cases
Trust Deficit	~FT * ~ST * ~PE	0.88	EU_FR_67

Source: Authors' analysis.

5.4. Robustness Analyses

To assess the stability of our findings, Table 8 reports consistency threshold sensitivity analysis for all three pathways across different threshold specifications.

Consistency Threshold Sensitivity

Table 8

Pathway	Consistency	theta=0.80	theta=0.85	theta=0.90	theta=0.95
Infrastructure-Driven	0.978	Pass	Pass	Pass	Pass
Trust-Driven	0.978	Pass	Pass	Pass	Pass
Collectivist-Gradual	1.000	Pass	Pass	Pass	Pass

Source: Authors' analysis.

All pathways remain sufficient at theta=0.95. Leave-one-out analysis indicates that the Infrastructure-Driven and Trust-Driven pathways remain stable when anchor cases are removed, owing to multiple supporting cases, whereas the Collectivist-Gradual pathway depends on a single case and is therefore tentative. Regarding the OR composite weighting, because organizational readiness enters only the Collectivist-Gradual configuration, the Infrastructure-Driven and Trust-Driven pathways are invariant to the weighting by construction; under the alternative weight specifications examined in Section 3.3 (equal, FC-heavy, and training-heavy), the single Collectivist-Gradual case retains its pathway membership.

6. Discussion

6.1 Theoretical Implications: Necessity and Competence Ambivalence

This study demonstrates how configurational analysis can advance technology acceptance research beyond confirmatory findings. Rather than concluding simply that "training matters" or "trust is important," HRCAM specifies *when* and *why* these conditions enable acceptance. The perceived-competence ambivalence mechanism—unique to embodied, autonomous agents such as robots—explains why the same high competence perception can lead to opposite outcomes.

In this dataset and under this calibration, PC and PE exhibit perfect necessity consistency (1.000), indicating that acceptance does not exceed stakeholders' perception of robot competence or performance expectancy. This is an empirical pattern consistent with the theoretical expectation that stakeholders cannot accept robots beyond their perception of robot capability; it should not, however, be read as a universal theoretical necessity, since the perfect consistency here reflects the bounded nature of the 11-case sample. Critically, PC is not sufficient on its own precisely because of its ambivalence: the near-necessity of low threat (~IT, consistency 0.945) shows that competence perception must be accompanied by threat mitigation for acceptance to occur.

The identification of two robust equifinal pathways (Infrastructure-Driven and Trust-Driven) challenges the assumption that a single set of universal best practices exists for HRC implementation. Organizations can achieve high acceptance either through comprehensive infrastructure investment or through individual trust and self-efficacy development. A third pathway (Collectivist-Gradual) is suggested by a single case but requires additional empirical support. This configurational reading aligns with recent calls for set-theoretic perspectives in management research (Fiss, 2011).

6.2 Configurational Pathways to Acceptance

The two robust pathways operate through distinct mechanisms. In the Infrastructure-Driven pathway, robust training and infrastructure allow stakeholders to develop both a perception of robot competence and the skills to use that competence; the combination of comprehensive organizational support and low threat creates conditions in which the positive pathway from PC dominates. In the Trust-Driven pathway, high functional trust combined with high robot-use self-efficacy allows stakeholders to perceive robot competence without activating threat. RSE serves as the critical buffer—"the robot is capable, and so am I"—and the pathway's high coverage suggests that, in strongly individualist cultures such as the US service context of CROSS_US_72 (CP_TRUST = 1, IDV = 91), personal trust-building is an effective acceptance route.

The tentative Collectivist-Gradual pathway suggests that collectivist social dynamics combined with a long-term orientation may create conditions for gradual acceptance development. Its perfect consistency but single-case support means that the pathway is highly predictive when present, yet its generalizability remains uncertain; replication with additional cases from collectivist, long-term-oriented contexts is needed.

More broadly, HRCAM reconceptualizes the role of culture in technology acceptance. Rather than treating Hofstede dimensions as direct predictors, the analysis shows that cultural context determines *which pathways are accessible*. This helps explain why cross-cultural studies often yield inconsistent findings: different cultural contexts enable different—but equally effective—acceptance routes. Consistent with this, social influence (SI) was not directly measured across the dataset; it was operationalized through pathway-availability flags (CP_SOCIAL, CP_TRUST, CP_GRADUAL) derived from Hofstede dimensions, which capture the structural availability of social-influence pathways rather than measuring social influence directly.

6.3 Managerial Implications: Pathway-Specific Prescriptions

Based on the configurational findings, Table 9 provides a pathway selection matrix to guide practitioners in identifying appropriate implementation strategies based on organizational context and cultural characteristics. Each recommendation traces to a specific result. The first three rows correspond directly to the three sufficient pathways in Table 5. The resource-constrained recommendation follows the Trust-Driven pathway (Table 5, Pathway 2) as the lower-infrastructure route to acceptance, while the high-threat-perception recommendation derives from the low-acceptance Threat-Barrier configuration (Table 7) together with the near-necessity of low threat (~IT) in Table 4.

Pathway Selection Matrix for Practitioners

Table 9

Context	Pathway	Priority Actions	Evidence base
High resource	Infrastructure-Driven	Training before deployment; IT support	Table 5, Pathway 1
Individualist (IDV >= 75)	Trust-Driven	Pilot programs; participatory design	Table 5, Pathway 2
Collectivist + LTO	Collectivist-Gradual (tentative)	Management endorsement; patient timeline	Table 5, Pathway 3
Resource-constrained	Trust-focused	RSE training; social proof	Trust-Driven route (Table 5, Pathway 2)
High threat perception	Address threat first	Self-efficacy training; job security	Threat-Barrier config (Table 7) + near-necessity of ~IT (Table 4)

Source: Authors' recommendations based on fsQCA findings.

The PC Paradox: Our findings reveal a counterintuitive implication: organizations should *not* simply showcase robot capabilities during implementation. High PC without an RSE buffer activates threat mechanisms. Instead, practitioners should:

1. Sequence matters: Build self-efficacy *before* demonstrating full robot competence
2. Frame complementarity: Emphasize "robot handles X so you can focus on Y" rather than "robot can do X"
3. Address threat proactively: Provide job security guarantees *alongside* capability demonstrations
4. Gradual introduction: Allow employees to observe reliability over time, especially in high-LTO contexts

6.4 Limitations and Future Research

First, this study relies on literature-based case extraction with some variables estimated from indirect indicators, and all calibration decisions were made by a single coder applying the documented decision rules, without an inter-coder reliability check. The FT/ST distinction is directly measured only in Gaudiello et al. (2016), and RSE is directly measured only in Liao et al. (2023). We addressed this through conservative calibration, transparency about measurement status, and sensitivity analyses, but primary data collection measuring all HRCAM variables directly, coded independently by multiple raters, would strengthen findings. Second, cases represent heterogeneous units of analysis (employee surveys, customer studies, expert panels, literature syntheses), which limit strict comparability. However, this heterogeneity is intentional for configurational theorizing and provides broader external validity. We transparently marked case types in Table 3 and constrain our conclusions accordingly. Third, the Collectivist-Gradual pathway depends on a single anchor case (CROSS_CN_72), making it tentative rather than confirmed. We emphasize this limitation throughout the results and conclusions. Additional cases from strongly collectivist, long-term oriented contexts would enhance confidence in this culturally specific pathway. Finally, cultural pathway flags are based on national Hofstede scores, which may not capture organizational or individual-level cultural variation.

Future research directions:

1. Direct measurement: Empirical studies measuring all HRCAM variables using validated scales
2. Longitudinal designs: Tracking PC-IT dynamics as employee familiarity increases
3. Intervention studies: Testing RSE training as a threat buffer intervention
4. Additional Collectivist-Gradual cases: Replication in other collectivist, high-LTO contexts

7. Conclusions

This study asked what organizational and cultural configurations lead to high stakeholder acceptance of human-robot collaboration across industry contexts. Applying fuzzy-set Qualitative Comparative Analysis to 11 cases spanning European, Asian, and cross-cultural manufacturing, logistics, and service settings, we identified two robust equifinal pathways to acceptance—Infrastructure-Driven and Trust-Driven—and a third, tentative Collectivist-Gradual pathway, showing that single-factor explanations are insufficient.

The study's theoretical contribution is the Human-Robot Collaboration Acceptance Model (HRCAM), built around perceived-competence ambivalence: unlike conventional IT systems, robots are sufficiently autonomous and capable that high perceived competence can simultaneously raise performance expectancy and activate intergroup threat. Robot-use self-efficacy and organizational readiness act as the bifurcation mechanisms that determine which pathway dominates, and the results display clear asymmetric causation, with low threat near-necessary for acceptance and distinct configurations producing rejection.

For managers navigating Industry 4.0 and 5.0 transitions, the equifinal pathways imply that acceptance can be achieved through different configurations matched to an organization's resources and cultural context, and that showcasing robot capability without first building stakeholder self-efficacy may backfire. These conclusions are tempered by the study's reliance on literature-based cases with some variables estimated, its heterogeneous units of analysis, and the single-case dependence of the Collectivist-Gradual pathway. Primary data collection measuring all HRCAM variables directly, longitudinal tracking of competence-threat dynamics, and intervention tests of self-efficacy training as a threat buffer are the priorities for future research.

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