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Systematic literature review on the impact of multifunctional training on organizational resilience

Impacto de la formación multifuncional en la resiliencia organizacional: una revisión sistemática de la literatura

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ABSTRACT

This systematic literature review examines how multifunctional training (MT) contributes to organisational resilience (OR) and how this relationship has been modelled and measured. Following PRISMA procedures, 87 studies were synthesised through descriptive analysis and a structured qualitative coding framework addressing three research questions. First, we map the methodological approaches used to study the MT–OR relationship and assess the extent to which uncertainty and human and organisational aspects are explicitly incorporated. Second, we synthesise the enablers and barriers affecting MT implementation and operationalisation, coding only mechanisms that are modelled, measured, or empirically reported. Third, we consolidate the metric families used to evaluate MT's contribution to organisational resilience. Results show that the literature predominantly operationalises MT as a skill-coverage architecture and assesses resilience through operational performance proxies under variability (e.g., flow time, work in progress, tardiness, service level, utilisation). Explicit barriers most frequently relate to cost and feasibility frictions (training cost, productivity loss, robustness–cost trade-offs), while coordination mechanisms, organisational conditions, and competence dynamics are less consistently formalised. Overall, the evidence highlights a measurement gap: resilience benefits are widely reported but rarely quantified end-to-end under uncertainty with deployability and human dynamics. The review proposes an agenda for integrating uncertainty-aware modelling with organisational and behavioural realism to enable comparable, decision-relevant evaluation of MT as a resilience strategy.

Keywords: Organizational resilience; Multifunctional training; Cross-training; Workforce flexibility; Uncertainty; Demand variability.

R E S U M E N

Esta revisión sistemática analiza cómo la formación multifuncional (FM) contribuye a la resiliencia organizacional (RO) y cómo se ha modelizado y medido esta relación. Siguiendo PRISMA, se sintetizan 87 estudios mediante análisis descriptivo y codificación cualitativa estructurada en torno a tres preguntas. Primero, se revisan los enfoques metodológicos sobre la relación FM-RO y el grado en que incorporan explícitamente incertidumbre y dimensiones humanas y organizativas. Segundo, se sintetizan facilitadores y barreras para implantar y operacionalizar la FM, codificando solo mecanismos modelizados, medidos o reportados empíricamente. Tercero, se integran las familias de métricas empleadas para evaluar la contribución de la FM a la RO. Los resultados muestran que la literatura operacionaliza mayoritariamente la FM como arquitectura de cobertura de competencias y evalúa la resiliencia con indicadores indirectos de desempeño operativo bajo variabilidad (p. ej., tiempo de flujo, WIP, retrasos, nivel de servicio). Las barreras explícitas se vinculan sobre todo a fricciones de coste y factibilidad (coste de formación, pérdida de productividad, compromisos robustez-coste…), mientras que mecanismos de coordinación, condiciones organizativas y dinámicas de competencias se formalizan de forma irregular. La evidencia apunta a una brecha de medición: los beneficios en resiliencia se reportan ampliamente, pero rara vez se cuantifican bajo incertidumbre incorporando capacidad de despliegue y dinámicas humanas. Se propone una agenda para integrar modelización sensible a la incertidumbre con realismo organizativo y conductual, habilitando evaluaciones comparables y relevantes para la toma de decisiones sobre la FM como estrategia de resiliencia.

Palabras clave: Resiliencia organizacional; Formación multifuncional; Cross-training; Flexibilidad laboral; Incertidumbre; Variabilidad de la demanda.

1. INTRODUCTION

Resilience can be defined as an organization's ability to adapt and recover from shocks, ensuring operational continuity and the effective delivery of products and services (Adrian, 2014; de Carvalho *et al.*, 2018). In recent years, the concept of organizational resilience (OR) has gained relevance across multiple sectors, from healthcare to manufacturing, driven by the increasing frequency and intensity of natural disasters, economic crises, and unforeseen events affecting organizations as a whole (Talab *et al.*, 2024).

Multifunctional training (MT) defined as the acquisition of multiple skills that enables employees to perform different roles within the organization, has been identified as a promising approach to strengthen OR because it enhances flexibility and the capacity to adapt to sudden changes in demand or adverse operational conditions (Day, 2022; Su *et al.*, 2023). Wise *et al.* (2020) further suggest that continuous employee training improves organizational flexibility and may support profitability by enabling faster and more efficient responses to market fluctuations.

Throughout this article, we adopt an inclusive notion of "operational disruption" to cover the heterogeneous conditions studied in the literature, ranging from stochastic demand fluctuations and variability to broader sources of uncertainty such as capacity losses, shortages, crises, or externally driven shocks. Terms such as deterministic and stochastic demand, volatility, variability, uncertainty, and crisis-related disruptions are therefore used to reflect the terminology of the original studies, without implying that these concepts are equivalent or interchangeable.

Although the positive impact of MT on OR is widely acknowledged, a critical gap remains. Its contribution has rarely been objectively measured or modelled, particularly under real-world scenarios of operational volatility. This gap reflects not only limited empirical evidence, but also a methodological divide between human resource management (HRM) and operations-oriented modelling. While management research often frames multifunctionality as a qualitative enabler of resilience, technical modelling studies rarely incorporate human dynamics such as learning curves, adaptability, or job rotation into stochastic optimisation or workforce planning models. As a result, organizations still lack clear guidance on how much multifunctionality is needed to absorb demand uncertainty and variability, or broader resource disruptions, and lack robust metrics to evaluate the return on investment of MT as a resilience asset.

To consolidate the knowledge, this paper presents a systematic literature review that aims to characterise how MT contributes to improving OR across sectors and operational contexts where organisations face demand fluctuations or other disruptions in dynamic, uncertain environments. Based on the review results, we discuss the limitations and challenges that shape the extent to which MT enhances resilience. Beyond synthesising prior work, this review offers a conceptual contribution by explaining how and under what conditions MT fosters OR. We identify the mechanisms linking MT to OR and analyse boundary conditions that amplify or dampen this effect, thereby setting out a theory-driven agenda for future research. In the context of this review, we treat MT and polyvalence training as equivalent concepts, referring to training workers in multiple skills or functions within the organization (González, 2006).

The specific research questions guiding this review are:

- RQ1: What methodological approaches are used to examine the MT-OR relationship, and to what extent do they incorporate uncertainty and human factors?
- RQ2: What organizational enablers or barriers have been reported as relevant for the implementation and operationalization of MT as a resilience strategy?
- RQ3: What metrics, indicators, and evaluation outputs have been used to objectively assess the contribution of MT to organisational resilience?

The paper is structured as follows. Section 2 presents basic background on MT and OR, highlighting key studies and previous literature reviews in these areas. Section 3 details the methodology, including the research protocol and the PRISMA flowchart. Section 4 offers a bibliometric analysis of the systematic literature review (SLR) results. Section 5 classifies and discusses the SLR results and answers research questions RQ1 to RQ3. Finally, Section 6 summarises the main findings and Section 7 proposes avenues for future research.

2. BACKGROUND

This section presents some background and definitions of OR and MT and briefly reviews prior literature linking them.

OR is the capability to maintain continuity while adapting to disruption (Vogus & Sutcliffe, 2007). Beyond disasters such as natural crises or cyberattacks (Talab *et al.*, 2024), OR also covers adaptation to demand variability and other less visible fluctuations that challenge day-to-day operations (Henao *et al.*, 2022; Sawhney, 2013). In the context of this SLR, OR is treated as an operational property that can be observed through the ability of an organisation to sustain service or production performance under variability (e.g., demand uncertainty, capacity loss, and short-notice disruptions).

MT (also termed cross-training, multiskilling, skill chaining, or polyvalent/on-the-job training) refers to developing a workforce that can be redeployed across roles to sustain service or production performance under variability, thereby improving operational flexibility and efficiency (Beltrán-Martín & Roca-Puig, 2013; Hopp & Oyen, 2004; Sawhney, 2013). In this review, we focus on objective, decision-relevant evidence and therefore prioritise studies that operationalise MT through explicit skill structures (e.g., chaining/closed chains), assignment rules, and staffing policies, and that quantify performance consequences under variability; this focus is reflected in the eligibility criteria and screening rules in Section 3 (METHODOLOGY). MT's effectiveness depends on how personnel are allocated and how learning/forgetting dynamics are managed (McCreery & Krajewski, 1999). Accordingly, the review distinguishes between MT as a capability-building investment (who is trained for what) and the operationalisation of that capability (how multiskilled workers are scheduled, rotated, and coordinated).

Evidence in the topic is heterogeneous across sectors and methodological traditions. In healthcare, the research on MT focuses mainly on redeployment and rapid upskilling during major events, often emphasising implementation constraints and limited formal evaluation (Coates *et al.*, 2021). In manufacturing and service operations, a large technical stream uses simulation and optimisation to study how multiskilling structures and coordination policies af-

fect robustness to uncertainty, including the presence of learning/forgetting and other human-related dynamics (Felan & Fry, 2001; Henao *et al.*, 2022; Hopp & Oyen, 2004; McCreery & Krajewski, 1999; Slomp & Suresh, 2005). Some work considers crises or resilience more generally without focusing on workforce training, which limits its ability to inform decisions about MT intensity and design.

Integrating MT within an OR framework requires enabling conditions: leadership support for continuous learning, work design that enables redeployment, and coordination routines that translate skill breadth into effective allocation decisions (Coates *et al.*, 2021; Hopp & Oyen, 2004; Sawhney, 2013). From a modelling perspective, integration also requires representing the constraints that govern real redeployment, skill coverage, training costs, coordination rules, and time-dependent proficiency, so that the contribution of MT can be estimated rather than assumed (Hopp & Oyen, 2004; Slomp & Suresh, 2005).

Existing research suggests broad support for MT and role breadth as levers for resilience, while also pointing to gaps in how practices are adapted across contexts and sectors (Coates *et al.*, 2021; Hopp & Oyen, 2004). Crucially, the literature remains fragmented across qualitative and policy-oriented works that identify flexibility actions without quantifying their effects, and technical models that quantify performance but often simplify human and organisational conditions. Accordingly, we treat adaptability (strategic reorientation), flexibility (operational reconfiguration), and resilience (persistence of core functions under disruption) as analytically distinct yet interrelated constructs.

Previous systematic literature reviews

A search for recent reviews indicates that the closest systematic-type evidence directly related to the MT–OR intersection is the rapid scoping review by Coates *et al.*, (2021). In addition, an earlier and influential synthesis by Hopp and Oyen, (2004) provides a structured evaluation framework for cross-training and an explicit survey of the relevant operations literature, but it is not a systematic review (i.e., it does not follow a PRISMA-style search and screening protocol). Together, these works are relevant precursors because they summarise prior knowledge on workforce flexibility while leaving key limitations that motivate the present review.

Coates *et al.* (2021) conducted a rapid scoping review of workforce strategies used during major health emergencies (natural disasters, extreme weather events, and infectious disease outbreaks), using a time-bounded search (2000-2020) in MEDLINE, Embase, and CINAHL and a multi-stage screening process, resulting in 37 included studies. They organise strategies into three levers: increasing participation (numbers), increasing scope/flexibility, and increasing support/sustainability. For the MT-OR gap, this review is useful because it documents real-world flexibility interventions under crisis conditions and reports barriers and facilitators; however, it explicitly excluded purely theoretical and simulation studies and provides limited quantitative modelling of how much MT is needed under volatility. The authors also highlight limited robust evaluation of impact and effectiveness as a recurring weakness in the evidence base.

Hopp and Oyen (2004) propose the Agile Workforce Evaluation (AWE) framework, outlining when and how cross-trained workers should be deployed through a strategic assessment view, a tactical design perspective (architectures and coordination choices), and a structured survey of worker-coordination policies and workforce agility research. This synthesis aligns closely with the operations-research side of our gap, yet it is not systematic and it does not treat resilience as an explicitly measured outcome under stochastic disruptions (e.g., demand volatility, absenteeism shocks), nor does it quantify the resilience return of MT investments through objective, uncertainty-aware metrics.

3. METHODOLOGY

This paper proposes a systematic literature review (SLR) that follows the PRISMA methodology (Page *et al.*, 2021) to identify and analyse relevant studies on MT and OR under conditions of fluctuating demand and operational uncertainty. The sources' selection process is illustrated in the PRISMA flowchart, which details each stage of the process, from initial paper identification to final inclusion, providing transparency and reproducibility. This SLR was guided by previous studies that used similar review methods (Alvarez-Gallo & Maheut, 2023; Badakhshan *et al.*, 2024; Marin-Garcia, 2021).

To ensure the quality and relevance of the selected studies, explicit inclusion and exclusion criteria were established.

Inclusion criteria concerning the format of the papers

— Language: papers published in English or Spanish.
— Publication period: searches were last updated in January 2026.
— Database source: Web of Science (WoS) and Scopus.
— Publication type: peer-reviewed journal papers only.

Inclusion criteria concerning the content of the papers

In the context of this work, we theorise MT as a driver of flexibility and adaptive capacity that, in turn, enables organisational resilience. Eligibility did not require that studies explicitly incorporate uncertainty or human and organisational factors. Instead, these aspects were examined during the analysis stage, based strictly on what each study modelled, measured, or empirically reported. We also extracted the metrics used to evaluate MT's contribution to resilient performance under variability (e.g., demand volatility, absenteeism, failures) (Coates *et al.*, 2021; Henao *et al.*, 2022; McCreery & Krajewski, 1999; Slomp & Suresh, 2005).

— Multifunctional Training (MT): papers addressing MT or polyvalent training of employees, understood as the acquisition of skills to perform multiple organisational functions, specifically through on-the-job training or role rotation.
— Organisational resilience (OR): papers addressing the ability of an organisation to adapt, remain flexible, or recover from operational disruptions, especially in response to demand volatility or uncertainty.
— Organisational context: studies conducted within a business/industrial organisational environment.

Exclusion Criteria

— Type of publications: non-peer-reviewed documents, book chapters, editorials, opinion pieces, technical reports, and documents not indexed in academic databases.

— Training context: studies focusing on online training, e-learning, or off-the-job training programs.
— Thematic misalignment: papers focusing exclusively on psychological, mental health, or personal coping strategies (e.g., burnout, mindfulness, workplace bullying) without a direct link to MT and OR in organizational settings.
— Emerging contexts without clear relevance: studies addressing pandemics, natural disasters, or emergency contexts were excluded only if they did not include an analysis of MT or OR as a strategic organizational response.
— Technological skills focus: papers on training for the implementation of advanced technologies (e.g., augmented reality, Artificial Intelligence) without a focus on polyvalent skill acquisition.

3.1. Search strategy and filters

The search strategy was designed to capture studies at the intersection of organisational resilience (OR) and multifunctional training (MT) in real organisational settings. We built a Boolean query structured into three concept blocks: (1) organisational setting, (2) resilience/adaptability, and (3) MT/cross-training terms. The organisational-setting block was adapted from the methodological search filters published by the Centre for Evidence-Based Management (CEBMa, n.d.). The full search strings, including the complete synonym lists and database-specific syntax (Web of Science and Scopus), are reported in Appendix 1 in the Supplementary file.

The three blocks were combined as:

TI-ABS-KEY (Block 1) AND TI-ABS-KEY (Block 2) AND TI-ABS-KEY (Block 3)

— Block 1 (organisational setting): terms capturing organisational and workforce contexts (e.g., work*, organization*, firm*, business*, workforce*, staff*, team*).
— Block 2 (resilience/adaptability): terms capturing resilience and operational adaptability (e.g., resilien*, robust*, adaptabil*, flexibil*, agilit*, including "organizational resilience" and related expressions).
— Block 3 (MT/cross-training): terms capturing MT and related practices (e.g., cross-training, multiskill*, job rotation, polyvalen*, upskill*, reskill*, workforce scheduling).

Applied to Web of Science and Scopus, this query returned 1988 records in WoS and 424 records in Scopus (2412 total).

3.2. Study selection (PRISMA flow)

The search returned 2,412 records across Web of Science (n = 1,988) and Scopus (n = 424). After applying standard automated filters (peer-reviewed journal articles; language restrictions) and removing duplicates, the remaining records were screened by title/abstract/keywords. To reduce false positives from adjacent psychological and online-learning streams, an additional negative filter was applied (see Appendix 1 in the Supplementary file). Full-text assessment was then performed for the shortlisted papers; 12 full texts could not be retrieved. The final dataset comprised 87 studies (76 from Web of Science and 11 from Scopus). A full quantitative breakdown of each step is provided in Figure 1 (PRISMA flowchart) and the full list of the 87 references used is provided in Appendix 4 of the Supplementary file.

3.3. Eligibility criteria

Eligibility was assessed using the inclusion/exclusion criteria reported above; full-text screening retained only records that met the MT, OR, and organisational-context criteria. Details of exclusions are reported in Figure 1 (PRISMA flowchart).

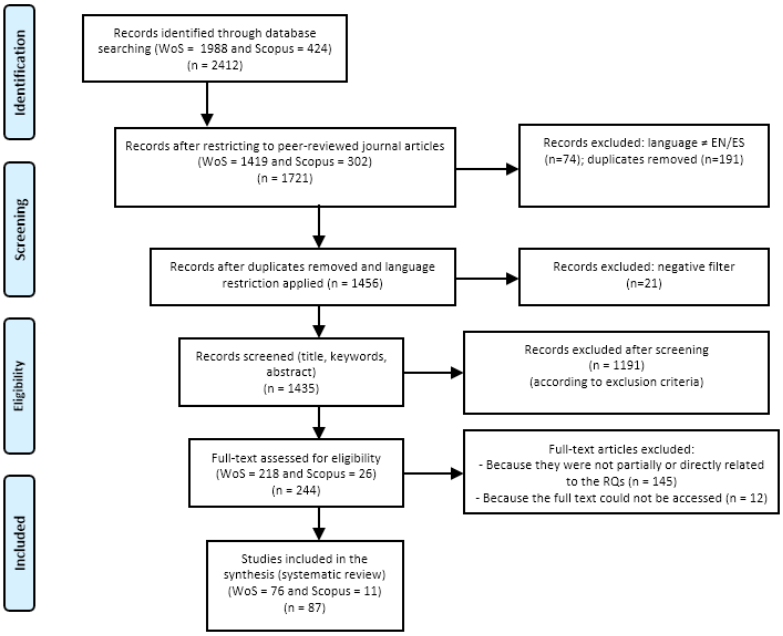

Figure 1
PRISMA flowchart
Source: Own elaboration.

4. DESCRIPTIVE ANALYSIS OF THE RESULTS

We first provide bibliometric information on the final set of papers that resulted from the search and filtering processes.

4.1. Annual scientific production and most frequent journals

The annual publication profile shows a long early period of sporadic contributions, with only isolated papers appearing between 1976 and 2000 (8 studies in total across those years). Research activity becomes more visible from the early 2000s onwards, with a first clear concentration in 2004 (8 articles) and 2005 (6 articles), suggesting that MT-related flexibility began to consolidate as a modelling topic within production and service systems during that period. After a relatively steady but moderate output throughout the 2010s, publication increases again in the most recent years: 2021 and 2022 each contribute 6 articles, followed by sustained activity in 2023 (3), 2024 (5), 2025 (6), and an initial presence in 2026 (1). Overall, the data indicates that the topic has shifted from occasional early contributions to a more continuous stream of publications, with a noticeable recent concentration in the 2021-2025 period.

Publications are concentrated in a small number of core journals. The seven most frequent outlets (International Journal of Production Research (14), Computers & Industrial Engineering (8), IIE Transactions (7), European Journal of Operational Research (5), International Journal of Production Economics (5), Journal of Operations Management (3), and Management Science (3) account for 45 out of 87 articles (51.7%), i.e., just over half of the entire corpus. This concentration highlights the strong anchoring of the MT-OR research stream in production/operations and industrial engineering venues, while the remaining publications are dispersed across a wide range of journals, reflecting the topic's methodological and sectoral breadth beyond its core OR and production-systems foundations.

4.2. Keywords

An analysis of the keywords extracted from the selected papers resulted in the word cloud presented in Figure 2, which illustrates the most prevalent concepts identified across the reviewed literature.

Figure 2
Most popular keywords
Source: Own elaboration.

The keyword cloud highlights a strong concentration around the operations/quantitative core of the MT-OR literature. The most frequent terms relate to cross-training/multiskilling and workforce/labor flexibility, accompanied by typical production and service-systems keywords such as scheduling, simulation, and optimization, as well as structural settings like CONWIP and cellular manufacturing. Keywords linked to uncertainty-aware approaches (e.g., stochastic programming, robust optimization, demand uncertainty) also appear prominently, suggesting that a relevant share of studies explicitly examines MT under operational variability. In parallel, a smaller but visible cluster of health and crisis-related terms (e.g., COVID-19, surge capacity, health workforce) reflects the recent extension of this research stream into healthcare resilience contexts. Overall, the pattern reinforces that the field is primarily organised around workforce flexibility as a mechanism for operational continuity, with secondary emphasis on sector-specific and organisational themes.

Figure 3 presents the keyword co-occurrence network generated with VOSviewer to explore the conceptual structure of the reviewed papers. After applying a minimum total link-strength threshold, 39 keywords met the inclusion criterion and

were organised into 27 clusters. Node size reflects the relative prominence of a keyword in the selected set, while link thickness indicates how frequently two keywords co-occur across papers. The resulting map reveals a highly connected thematic core alongside several more specialised or sector-specific pockets of terminology.

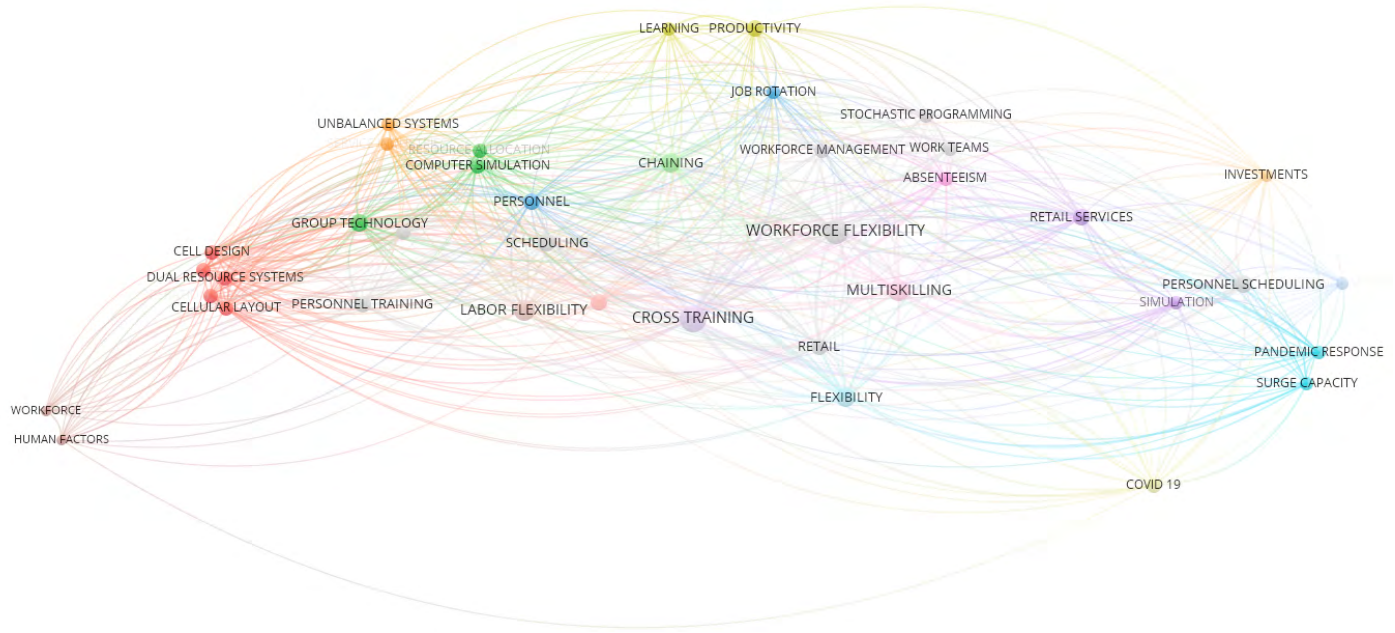

Figure 3
Co-occurrence map
Source: Own elaboration (VOSviewer output).

Overall, the network is anchored by a small set of integrative concepts, most notably cross training, workforce flexibility, labor flexibility, and multiskilling, which function as bridging terms connecting otherwise distinct research strands. Around this core, the map highlights a strong operations/industrial-engineering backbone characterised by manufacturing system design and modelling keywords (e.g., cell design, cellular layout, dual resource systems, operations research, virtual cellular manufacturing) and computation-oriented terms (e.g., computer simulation, group technology, resource allocation, simulation, scheduling). This pattern is consistent with a large portion of studies framing MT primarily as a mechanism for improving operational performance through flexible staffing and assignment decisions.

In parallel, the co-occurrence structure also surfaces a smaller but clearly identifiable set of human- and disruption-oriented themes. Human-centred dynamics appear through keywords such as learning, job rotation, absenteeism, and human factors, indicating that part of the literature explicitly links workforce flexibility to competence evolution, deployment practices, and behavioural constraints. Disruption and crisis-related terminology emerges through a cluster containing pandemic response, surge capacity, and COVID 19/COVID-19, signalling the extension of MT-related flexibility research into healthcare surge capacity and crisis resilience contexts. Finally, sector-driven applications are visible through retail/service scheduling terms (e.g., retail, retail services, personnel scheduling, WORKFORCE management, service industries) and uncertainty-aware modelling terms (e.g., stochastic programming, stochastic program, investments), which connect MT to planning and decision-making under variability.

Taken together, the network suggests that the MT-OR field is structured around a dominant modelling-oriented core (manufacturing/service operations, scheduling, simulation, optimisation) complemented by smaller clusters that capture explicit human dynamics (learning, rotation, absenteeism) and disruption-specific contexts (pandemic response and surge capacity). This provides an additional bibliometric indication, aligned with the methodological findings discussed later, that research attention has been concentrated on operational flexibility mechanisms, while human-factor and crisis-resilience perspectives remain more fragmented and frequently expressed through more specialised keywords.

5. ANALYSIS OF THE INFORMATION OBTAINED FROM THE SELECTED PUBLICATIONS

This section aims to analyze and evaluate how, and to what extent, the reviewed papers address the research questions that underpin this review.

5.1. Methodological approaches used to examine the relationship between MT-OR, and to what extent uncertainty and human factors are incorporated (RQ1)

This review characterises how the MT–OR relationship is examined in the literature by focusing on two methodological dimensions that determine what "resilience effects" can be credibly quantified. First, we examine how studies represent operational volatility through uncertainty modelling (U). Second, we examine whether the workforce is treated as more than a static skill set through human-factor modelling (H). Because prior work spans simulation/optimisation models and empirical/practice accounts, results are often not directly comparable: studies may stress-test MT under disruption without modelling human dynamics, or describe rich human mechanisms without formalising volatility. To make these differences explicit and reproducible, we apply two four-level ordinal coding scales (U0–U3 and H0–H3) based strictly on what each study models, measures, or reports. The aim is not to rank methods, but to clarify what each study is effectively able to quantify: whether MT is tested under operational variability and whether deployability-relevant human mechanisms (e.g., learning/forgetting, fatigue, acceptability constraints) are explicitly incorporated. Across the 87 included studies with complete U/H coding, results reveal a pronounced segmentation between operations-oriented quantitative modelling and practice-oriented empirical accounts. The full classification of all 87 studies (sector, method, U/H codes, and resilience proxies) is provided in Appendix 2 in the Supplementary file.

To ensure a transparent and reproducible interpretation of codes, both dimensions were coded using four-level ordinal scales. Table 1 summarises the coding logic used in this review.

Table 1
Coding framework for uncertainty (U) and human factors (H)

Dimension	Code	Operational meaning	Typical implementation in the reviewed studies
Uncertainty modelling (U)	**U0**	Deterministic; no explicit uncertainty	Fixed inputs; single-point estimates; no variability modelled
	U1	Uncertainty acknowledged but handled deterministically	Scenario/sensitivity analyses; parametric variation; "stress tests" without probability-aware decisions
	U2	Stochastic variability embedded in system evolution (process dynamics)	Discrete-event simulation; stochastic arrivals/processing times; Markov/queueing process assumptions; absenteeism and failure processes
	U3	Formal uncertainty-aware optimisation/valuation	Stochastic programming; robust optimisation; distributionally robust optimisation (DRO); real options valuation; explicit uncertainty sets and/or probability structures
Human-factor modelling (H)	**H0**	MT as a static skill matrix ("who can do what")	Eligibility/coverage only; no heterogeneity or behavioural dynamics
	H1	Limited human realism via parameters	Efficiency/proficiency differences; coordination effort as parameter; collaboration mode assumptions
	H2	Explicit human dynamics affecting feasibility/performance	Learning/forgetting; fatigue; rotation decisions; dissatisfaction costs; evolving coordination burdens
	H3	Rich organisational/behavioural constructs	Well-being/psychosocial indicators; HR strategies; workforce governance/sustainability mechanisms

Source: Own elaboration.

This framework makes the core methodological trade-off visible: studies may be strong in modelling disruption (high U) while simplifying workforce adaptation (low H), or they may describe human mechanisms in depth (high H) while remaining non-probabilistic in the treatment of volatility (low U).

The corpus is heavily skewed toward quantitative modelling and decision-analytic approaches. Out of the 87 coded studies, 71 (81.6%) rely primarily on simulation, analytical queueing / Markov modelling, optimisation (including robust/stochastic/DRO), simulation–optimisation, metaheuristics, computational/AI decision frameworks, or economic evaluation. In contrast, 12 studies (13.8%) are empirical/practice contributions (case studies, mixed-methods, action research, descriptive implementation reports), and 4 (4.6%) are conceptual or review-type contributions. This methodological split is not merely descriptive; it determines which dimensions of "resilience" become measurable and comparable across studies. Quantitative models tend to operationalise resilience through performance proxies under volatility, whereas empirical/practice accounts more often describe resilience as organisational continuity and adaptive capacity, often without a single standardised indicator.

Uncertainty incorporation is heterogeneous. Across the 87 studies, 14 (16.1%) are fully deterministic (U0), 29 (33.3%) handle volatility via deterministic scenarios (U1), 26 (29.9%) embed stochastic variability through simulation or stochastic process assumptions (U2), and 18 (20.7%) adopt formal uncertainty-aware frameworks (U3). Taken together, 44/87 (50.6%) incorporate uncertainty at a relatively high level (U2–U3), yet

only 18/87 (20.7%) reach U3, where uncertainty is not merely tested but explicitly embedded in decision-making through robust/stochastic/DRO (or real-options) logic.

A key pattern is the prevalence of U1. Many papers explicitly acknowledge volatility (demand variability, congestion, shortages, absenteeism) but translate it into scenario comparisons rather than probability-aware or robustness-aware decision modelling. This creates an interpretability gap: scenario-based studies can show that MT performs better under "stressful conditions", but they typically do not quantify risk exposure, tail outcomes, or provide guarantees about performance under uncertainty. By contrast, U3 studies directly translate volatility into actionable decision rules, for instance by producing training and allocation plans that remain feasible and cost-effective across uncertain demand realisations.

Human-factor integration is generally weaker. Within the full set of 87 studies, 32 (36.8%) remain at H0, representing MT as a static eligibility structure; 29 (33.3%) fall into H1, introducing heterogeneity or coordination only through parameters; 21 (24.1%) reach H2, explicitly modelling human dynamics such as learning/forgetting, fatigue, or rotation-related acceptability costs; and only 5 (5.7%) reach H3, where richer organisational and behavioural constructs are central. Overall, 61/87 (70.1%) remain at H0–H1, meaning that multifunctionality is primarily modelled as structural capacity, who can cover which tasks, sometimes with proficiency differences, but usually without representing learning, fatigue, resistance to redeployment, governance requirements for rotation, or coordination burdens that intensify under disruption.

This is precisely where a measurement gap emerges. A large share of models can demonstrate that "more skills help" in principle, but do not intend to quantify whether that flexibility remains deployable when disruptions occur and workforce constraints become binding. The small H3 subset is mainly practice-oriented and healthcare-focused, where MT is tied to role redesign, scope-of-practice extension, surge capacity strategies, and workforce sustainability mechanisms. These contributions often provide strong explanatory richness on how MT interventions work in reality but rarely embed formal uncertainty optimisation.

A central finding for RQ1 is that very few papers jointly model operational uncertainty and human dynamics. Only 10/87 studies (11.5%) lie in the "high-high" quadrant ($U \geq 2$ and $H \geq 2$). These include approaches such as simulation studies incorporating learning/forgetting under stochastic shop-floor dynamics; simulation–optimisation formulations with fatigue; real-time recovery scheduling frameworks that internalise dissatisfaction costs; robust job-rotation approaches modelling competence evolution; and a Markovian workforce-planning study that represents uncertain human-caused events alongside behavioural tendencies.

To make this joint coding more visible within the modelling literature, Table 2 provides a U×H distribution for quantitative/Operations-Research modelling studies only (n = 71), excluding empirical/practice and review/conceptual contributions.

Table 2
U×H distribution for quantitative/ Operations Research-oriented studies (n = 71)

H \ U	U0	U1	U2	U3
H0	4	6	14	8
H1	6	4	5	7
H2	2	5	7	2
H3	0	0	0	1

Source: Own elaboration.

The distribution confirms a structural pattern: uncertainty is more frequently modelled formally in Operations Research studies than human dynamics, while richer human modelling remains concentrated in a minority of contributions. As a result, organisations are left with limited guidance on how much MT is "enough," and under which disruption regimes MT remains operationally deployable once learning, fatigue, coordination costs, and workforce acceptability constraints are considered.

A second major finding concerns how organisational resilience is operationalised in the reviewed studies. Resilience is rarely defined and measured as a standalone construct; instead, papers typically rely on proxy metrics that represent performance preservation under variability or disruption. These proxies cluster into a small number of families: responsiveness metrics (lead time, waiting time, WIP, cycle time and variability), delivery reliability (tardiness, % tardy jobs, schedule adherence, downtime), service coverage (unmet demand, coverage ratios, order fulfilment, retail market impacts), productivity measures (throughput, labour utilisation, labour efficiency), economic indicators (labour costs, training and productivity-loss costs, surplus/shortage penalties, lost profit, ROI/break-even time), robustness indicators (workload dispersion, performance variance under stress, comparison against deterministic baselines), and, less frequently, human sustainability and acceptance measures (fatigue, dissatisfaction costs, job satisfaction, burnout/role conflict/ambiguity).

A key implication is that the practical meaning of "resilience" differs by method family. Operations research models often equate resilience with operational continuity and efficiency under disruption, while empirical studies tie resilience more strongly to feasibility of role redesign, organisational adaptability, and workforce sustainability. Without greater alignment across proxy families, it remains difficult to compare effect sizes or build cumulative evidence on MT as a resilience asset across sectors.

Taken together, three conclusions emerge robustly from the coded evidence. First, the MT–OR literature remains methodologically fragmented: quantitative studies dominate and quantify performance under variability but frequently operationalise MT as a static coverage structure; empirical/practice studies provide richer organisational mechanisms and behavioural realism but rarely quantify uncertainty exposure or resilience trade-offs. Second, formal uncertainty-aware modelling exists but is not yet the norm. Only around one-fifth of the coded studies adopt U3 approaches, which limits the translation of research findings into decision rules for training investment under risk and volatility.

Third, and most importantly, joint modelling of uncertainty and human dynamics remains rare. The small high–high subset (≈11.5%) indicates that the methodological bridge between HR/organisational realism and uncertainty-aware operations modelling is still underdeveloped. This directly explains why organisations struggle to quantify MT's ROI as a resilience investment under real-world volatility: most models omit the human dynamics that determine whether multifunctionality remains deployable when disruptions occur.

These results define a clear agenda for future work: integrate uncertainty-aware workforce planning (stochastic/robust/DRO) with competence evolution (learning/forgetting), fatigue, coordination burdens, and rotation/acceptance mechanisms, while moving toward a more standardised mapping between resilience proxy families and MT design decisions so that evidence becomes comparable across sectors.

5.2. Enablers or barriers that have been reported as relevant for the implementation and operationalization of MT as a resilience strategy (RQ2)

While much of the literature models MT as an operational lever, the organisational conditions that make MT implementable and deployable during disruptions are often less visible or unevenly integrated across approaches.

To answer RQ2, we used a structured qualitative synthesis grounded strictly in explicit evidence, supported by a two-step coding logic. First, we defined an a priori coding framework to capture the organisational conditions that enable or constrain MT as a resilience strategy (Table 3). The framework was informed by the MT-operations research tradition (skills architectures, coordination policies, and feasibility/cost trade-offs) and by implementation-focused work emphasising team/organisational conditions and human dynamics. Second, we pilot-tested and refined the framework through iterative reading and reconciliation on a subset of studies before applying it to the full corpus.

A study feature was coded as an enabler or barrier only when it was explicitly represented as: a model element (decision variable, constraint, objective, parameter), a measured construct (e.g., survey scale, observed mechanism), or a reported empirical practice directly operationalising the factor (e.g., measured coordination effort, modelled dissatisfaction, learning/forgetting dynamics, explicit training or productivity-loss costs). If a factor is not coded for a paper, it is treated as not explicitly addressed (not as absent in real organisations). The full extraction table and complete evidence synthesis matrix are provided in Appendix 3 in the Supplementary file.

We also coded whether each paper addresses MT primarily as an implementation issue (I: design/roll-out feasibility, training/rotation plans, team formation), as an operationalisation issue (O: redeployment and allocation during volatility/disruptions), or both (I-O). This distinction separates "building" multifunctionality from "activating" it under disruption.

Table 3
RQ2 coding framework used in this review

Dimension	Values / codes	Operational meaning (coded only when explicit)
Stage	I, O, I–O	**Implementation (I):** MT design/roll-out feasibility (training plans, staffing formation, rotation planning). **Operationalization (O):** MT use during volatility/disruptions (reassignment, recovery, real-time allocation). **I-O**: both.
Enablers / Barriers codes	SKILLS	Skill architecture / MT design (skill matrix, chaining/closed chains, hierarchical cross-training, structured multiskilling).
	COORD	Coordination and decision rules for deploying MT (dispatch/redeployment rules, measurable coordination effort, real-time recovery actions).
	HUM-DYN	Human competence dynamics (learning/forgetting, fatigue, productivity heterogeneity, worker performance).
	COST/FEAS	Cost and feasibility frictions (training cost, productivity loss, overtime/contract feasibility, robustness–cost trade-offs, feasibility constraints).
	TEAM/ORG	Team and organizational conditions (implementation sophistication, collaboration, priorities, job rotation as practice, satisfaction/dissatisfaction, role redesign/scope expansion, crisis governance principles).
Resilience framing	R-explicit, R-proxy, R-none	**R-explicit:** resilience/robustness is explicitly framed. **R-proxy:** resilience assessed via operational proxies under variability/disruption (e.g., service level, unmet demand, tardiness, WIP, downtime, continuity). **R-none:** no clear resilience framing and/or only weak indirect proxies.

Source: Own elaboration.

Based on the coding defined in Table 3, the results are synthesised in Table 4:

Table 4
RQ2 evidence synthesis matrix (explicit enablers and barriers)

Code	What the literature explicitly uses as an enabler	What the literature explicitly reports/models as a barrier	Where it appears most (Stage)
SKILLS	MT operationalized as skill architecture (matrices; chaining/closed chains; hierarchical skills; multiskilled staffing structures). This is the dominant "enabler" construct across methods.	Rarely coded as barrier in the corpus; the limiting factors are usually expressed through costs/feasibility rather than "skills are bad".	Mostly O and I–O
COST/ FEAS	Sometimes appears as enabler when feasibility levers expand deployability (e.g., overtime/annualized hours; integrated sizing with feasibility).	Most frequent explicit barrier family: training cost and productivity loss, robustness–cost conservatism, penalties for under/overcoverage, overtime cost, inventory–flexibility trade-offs, downtime vs staffing costs, ROI/break-even constraints.	Strong in I–O (design under constraints) and O (recovery trade-offs)
COORD	MT becomes deployable via explicit coordination mechanisms: real-time allocation policies, recovery actions, task reassignment logic, decision rules; in one case coordination effort is explicitly measured.	Coordination appears as barrier when explicitly modelled/measured as burden or when changes generate acceptance costs (e.g., dissatisfaction from schedule modifications).	Mainly O and I–O
HUM-DYN	MT effectiveness depends on competence dynamics explicitly modelled: learning/forgetting; fatigue; productivity effects; heterogeneity; worker performance.	Explicit barriers arise when dynamics represent degradation/limits, e.g., forgetting and fatigue as performance-degrading mechanisms.	Mostly I–O and O
TEAM/ ORG	MT is enabled by organizational implementation capability and team conditions: implementation sophistication, collaboration/shared priorities, role redesign/scope expansion, governance principles for crisis redeployment, job rotation as practice to build redundancy.	Explicit TEAM/ORG barriers include implementation frictions, psychosocial risks (burnout/role conflict/ambiguity), and dissatisfaction/acceptability costs when schedules are modified.	Concentrated in I–O (empirical/ practice)

Source: Own elaboration.

Across the reviewed studies, the most consistent explicit enabler is SKILLS, with MT operationalised as structural coverage capacity (e.g., skill matrices, hierarchical cross-training, chaining/closed chains, structured multiskilled staffing). This pattern dominates simulation and analytical/optimisation work in job shops, flow lines, warehousing, and retail/service scheduling, where resilience is predominantly assessed via operational proxies under variability (R-proxy), such as tardiness, WIP, throughput, unmet demand, or service level. However, many technical studies treat redeployability as implicit once skills exist, leaving the organisational and decision conditions that make skills actionable in real time inconsistently formalised.

Where barriers are explicitly modelled, they most often appear as COST/FEAS constraints, reinforcing that MT-enabled resilience is rarely "free". Common frictions include training costs, productivity losses due to skill acquisition or switching, robustness–cost conservatism in stochastic/robust formulations, overtime/contract feasibility limits, and under/overcoverage penalties. Economic valuation studies strengthen this boundary-condition framing by treating cross-training as an investment under uncertainty: flexibility value depends on uncertainty, irreversibility, and workforce/task heterogeneity, and "more MT" can become suboptimal (e.g., overtraining or diminishing marginal value). Operational evidence also shows that feasibility frictions depend on the structure of uncertainty, for instance, flexibility may buffer random variability more effectively than systematic bias in forecasting, which matters for implementation decisions.

The synthesis also highlights COORD as the mechanism that converts "available skills" into "implemented flexibility". Coordination becomes explicit when studies operationalise assignment and redeployment rules (e.g., job release mechanisms, dispatching logic, worker-selection policies, real-time recovery actions). Several studies indicate that outcomes can hinge on who is assigned when multiple workers are eligible and on interactions between release and assignment rules under tight due dates and congestion. Coordination is also modelled as a friction when it is measured as effort or when recovery actions induce acceptance costs (e.g., dissatisfaction due to schedule modifications). Overall, MT's resilience contribution is not only a function of skill breadth, but also of how redeployment decisions are designed and governed under time pressure.

A meaningful subset of studies incorporates HUM-DYN explicitly, showing that MT effectiveness depends on competence dynamics such as learning/forgetting, fatigue, productivity differentials, and heterogeneity. In this subset, heterogeneity appears both as an operational reality shaping assignment performance (e.g., proficiency differences relevant to worker-selection rules) and as a determinant of flexibility value in investment-based formulations. Importantly, barriers in this category are mechanistic: forgetting, fatigue, and switching-related efficiency loss are modelled as performance-degrading processes that limit how far MT can be stretched without erosion of gains.

Finally, TEAM/ORG conditions, implementation capability, collaboration and shared priorities, role redesign and scope expansion, and governance principles for redeployment, are most visible in empirical and practice-oriented studies. These studies emphasise that MT is enabled not only by skill acquisition but also by organisational readiness (implementation sophistication, cross-functional cooperation, partner alignment, institutional integration). Barriers at this layer include implementation frictions, institutional

silos, compliance/administrative burdens, and psychosocial risks or acceptability constraints (e.g., dissatisfaction with re-rostering). Union/contract constraints also appear as explicit organisational limits on deployability, illustrating that real-world feasibility may be constrained even when skill coverage exists.

Focusing strictly on what studies explicitly model or measure as enabling or constraining MT helps explain why end-to-end quantification of MT as a resilience investment remains limited. Across the corpus, operations-research-oriented studies often operationalise MT mainly as skill coverage and evaluate outcomes through operational proxies under variability, while treating activation frictions (coordination burden, acceptability, competence decay, organisational readiness) as implicit. In contrast, empirical and practice-oriented studies foreground implementation sophistication and organisational constraints but less frequently translate these frictions into uncertainty-aware decision models. This "acquired vs. deployable flexibility" gap has been noted in prior work and is also visible in our coded evidence base (Coates *et al.*, 2021; Graham & Rosenthal, 1986; Hopp & Oyen, 2004; Sawhney, 2013). By consolidating explicit evidence across 87 studies (Appendix 3 in the Supplementary file), this review identifies organisational boundary conditions already present, especially COST/FEAS trade-offs, coordination rules and burdens, dissatisfaction/acceptability costs, and competence degradation, and highlights that these are still rarely integrated jointly within uncertainty-aware formulations. This provides a targeted agenda for bridging HR/management insights with operations research models that can quantify MT under realistic constraints and disruption regimes.

5.3. *Metrics, indicators, and evaluation outputs used to assess the contribution of MT to organisational resilience (RQ3)*

RQ3 examines how both MT and organisational resilience are operationalised and quantified in the reviewed literature. The key issue is not whether MT is conceptually associated with resilience, but how MT is measured as an input/capability (e.g., skill coverage, redeployment rules, training intensity/cost) and how resilience is measured as an outcome under disruption (e.g., service continuity, flow stability, robustness, cost and feasibility trade-offs), in ways that are comparable across studies and informative across disruption contexts. Resilience is rarely expected to be captured by a single index because it is inherently multi-dimensional; accordingly, most studies operationalise resilience through families of indicators that reflect different dimensions (e.g., buffering, reconfiguration, and feasibility under stress). In practice, MT is therefore evaluated through operational and economic performance indicators under variability or disruption conditions (e.g., demand/mix uncertainty, worker absence, machine failures, forecast errors, schedule recovery), with only a smaller subset using explicit resilience/robustness terminology.

To synthesise this evidence, we extracted the explicit metrics, indicators, and evaluation outputs reported in each study and grouped them into recurring metric families. A metric family was coded only when it was explicitly used as an outcome, an objective function, or a measured indicator in the study (e.g., flow time/WIP; service level; unmet demand; total cost decomposition; downtime; coordination effort; dissatisfaction; learning/forgetting or fatigue measures; ROI/break-even outputs).

Table 5 summarises the dominant metric families used to quantify MT as a resilience-relevant capability, together with illustrative indicators drawn from the included studies and the main resilience dimension each family captures.

To interpret these metric families, we use a four-dimension resilience lens: preparedness (pre-shock readiness), absorptive (buffering under shock), adaptive (reconfiguration), and restorative (recovery). This mapping is used as an interpretive device to clarify what each metric family captures, rather than as an additional inclusion or coding requirement.

Table 5
RQ3 metric families used to assess MT's contribution to OR

Metric family (code)	What is assessed (objective outcome)	Examples of indicators used in the included studies	How it captures MT → OR	Primary resilience dimension captured*
TIME/FLOW	Congestion and time stability under volatility	Flow time / time-in-system; cycle time (mean/variance); lead time; response time; makespan; WIP/inventory	MT reduces bottleneck congestion by enabling task reallocation, limiting delay accumulation during shocks	**Absorptive** (shock buffering)
SERVICE/ RELIABILITY	Continuity of delivery/service under disruption	Service level; % jobs tardy; mean tardiness; unmet demand/shortage; coverage shortfalls; order-fulfilment tardiness	MT acts as redundancy to maintain service performance when demand spikes or resources/ skills are temporarily unavailable	**Absorptive** + **Adaptive**
CAPACITY/ UTILISATION	Effective capacity conversion and workload balancing	Throughput; labour utilisation; bottleneck-worker load; workload distribution variability; minimum staffing level to meet output targets	MT increases effective capacity and reduces overload by enabling cross-support across stations/roles	**Adaptive**
COST/FEAS	Economic and feasibility boundary conditions of MT-based resilience	Training cost; productivity-loss cost; overtime cost; total labour cost; penalty costs (under/overcoverage); downtime vs staffing cost; lost profit	Quantifies the trade-off that makes MT deployable (or not) under resource and cost constraints	**Preparedness** + **Adaptive**

Metric family (code)	What is assessed (objective outcome)	Examples of indicators used in the included studies	How it captures MT → OR	Primary resilience dimension captured*
ROBUSTNESS/ RISK	Performance stability under uncertainty-aware formulations	Robust vs deterministic gap; scenario-based performance/cost stability; uncertainty-penalised objectives (shortage/ coverage/cost)	MT is evaluated as a hedge against uncertainty, improving stability rather than only average performance	**Absorptive** (stability)
COORD/ DEPLOYABILITY	Real-time usability of MT through decision rules	Real-time allocation/recovery actions; dispatching/assignment logic (including worker-selection rules); coordination effort (when measured); number/impact of schedule changes	Shows that skills deliver resilience only when deployable via explicit redeployment rules and coordination capacity	**Adaptive**
HUM-DYN	Human competence dynamics and performance limits	Learning/forgetting effects; fatigue measures; productivity heterogeneity; efficiency loss due to switching	Captures that MT benefits depend on competence accumulation/ decay and human constraints under stress	**Adaptive** (bounded)
TEAM/ORG	Organisational readiness and sustainability of implementation	Team processes (communication, conflict handling); collaboration/shared priorities; implementation sophistication; job satisfaction; burnout/role conflict/ ambiguity; union/contract constraints (when explicit)	Identifies organisational conditions that enable MT to function during disruption without unacceptable frictions	**Preparedness** + **Adaptive**

Note: Resilience dimensions are used as an interpretive lens: preparedness (readiness), absorptive (buffering), adaptive (reconfiguration), and restorative (recovery). Most indicators in the corpus capture absorptive/adaptive dimensions; restorative outcomes are less often operationalised explicitly (e.g., time-to-recovery).

Source: Own elaboration.

Table 5 shows that time-and-flow metrics (TIME/FLOW) and service continuity metrics (SERVICE/RELIABILITY) form the backbone of objective assessment in the corpus, especially in manufacturing/job-shop and retail/service scheduling contexts. These measures operationalise resilience primarily as the ability to avoid congestion collapse and preserve delivery/service performance under operational shocks. Capacity conversion indicators (CAPACITY/UTILISATION) are also common, capturing whether cross-trained capacity can be converted into throughput and whether bottlenecks can be relieved through reassignment.

Beyond operational performance proxies, a substantial subset of studies evaluates MT through explicit economic and feasibility metrics (COST/FEAS), including training cost, productivity-loss, overtime, shortage/coverage penalties, downtime, staffing trade-offs, and lost-profit outputs, reflecting that MT-enabled resilience is constrained by investment and deployability frictions, not simply by the existence of skills (Azizi & Liang, 2013; Iravani & Krishnamurthy, 2007; Porto *et al.*, 2022). In the uncertainty-aware stream, robustness-oriented evaluations (ROBUSTNESS/RISK) quantify MT's contribution as performance stability under demand/absence uncertainty, rather than only improved averages, aligning the resilience framing more explicitly with volatility (Henao *et al.*, 2016; Porto *et al.*, 2025).

Importantly, the metrics that capture MT's deployability and degradation mechanisms are less consistently reported than standard operational proxies. Coordination- and deployability-related indicators (COORD/DEPLOYABILITY), such as explicit redeployment rules, worker-selection logic, and recovery actions, appear in a subset of studies, and only rarely is coordination operationalised as an explicit measurable burden (e.g., "coordination effort"). Similarly, competence dynamics metrics (HUM-DYN) such as learning/forgetting and fatigue are present in a meaningful but smaller subset, showing that MT's benefits may degrade over time or be bounded by human performance limits. Finally, empirical and practice-oriented studies contribute TEAM/ORG indicators (e.g., implementation sophistication, team processes, satisfaction and psychosocial risks), which are essential to understanding whether MT remains sustainable during disruptions, yet they are less frequently translated into uncertainty-aware operational metrics.

Across the reviewed studies, objective assessment is implemented mainly through: simulation-based stress testing under disruption scenarios, analytical/queueing formulations capturing congestion mechanisms, optimisation models for staffing/ scheduling/assignment design, and stochastic/robust formulations that explicitly incorporate uncertainty. These approaches naturally prioritise TIME/FLOW, SERVICE/RELIABILITY, and COST/FEAS metrics. In contrast, empirical and practice-based designs are better suited to expose TEAM/ORG and COORD realities, but often provide fewer directly comparable, scenario-based resilience outputs.

Taken together, the RQ3 synthesis suggests that end-to-end quantification of MT as a resilience investment remains limited despite extensive modelling. The literature is strongest at measuring structural skill capacity and operational proxies under volatility, but less consistent in measuring the coordination, human dynamics, and organisational feasibility mechanisms that determine whether MT can be reliably deployed during disruptions. Therefore, the most actionable measurement agenda emerging from the included evidence is not to replace operational prox-

ies, but to complement them with deployability- and feasibility-aware indicators that already appear explicitly in subsets of the corpus (e.g., coordination effort, dissatisfaction/acceptability costs, learning/forgetting/fatigue, productivity-loss and ROI metrics). This integration provides a concrete bridge between the methodological emphasis of RQ1 (uncertainty and modelling approaches), the organisational enabling conditions identified in RQ2, and the objective performance measurement focus consolidated in RQ3.

6. DISCUSSION

Rather than reiterating the RQ-level findings, this discussion interprets them through an implementability lens. Taken together, Sections 5.1–5.3 show that MT is consistently associated with improved continuity under volatility, yet the evidence base remains difficult to cumulate because MT is not evaluated as the same "capability" across methodological traditions. A central integrative insight emerging from the synthesis is that MT behaves as a contingent resilience asset: its value depends not only on skill coverage, but on whether multifunctionality can be activated and sustained under disruption regimes.

This helps reconcile the apparent fragmentation in the literature. A dominant operations/operations research stream typically models MT as structural coverage and measures resilience via operational performance proxies under variability. In doing so, deployability is often treated as frictionless once skills exist. However, when studies make activation frictions explicit, such as redeployment rules, coordination burdens, acceptability constraints, learning/forgetting or fatigue, and productivity-loss during upskilling, the resilience contribution becomes conditional and strongly context-dependent. The synthesis therefore points to a "deployability wedge" between having multifunctional capacity and being able to use it reliably when disruptions occur. This wedge is precisely what prevents organisations from translating MT into decision-relevant ROI under real volatility: the mechanisms that govern activation and degradation are unevenly represented and rarely co-modelled with uncertainty.

From a measurement standpoint, the review suggests that future comparability will require treating MT-enabled resilience as a layered construct with capacity (skill coverage), activation (rules, coordination, decision rights), and sustainability (competence dynamics and workforce acceptance). This layered view does not replace operational proxies; it clarifies when those proxies are informative and when they are likely to overstate resilience by omitting activation and degradation mechanisms. This interpretation also supports actionable implications for training design and governance under risk.

For practitioners, the synthesis suggests that MT should be treated as a layered resilience capability rather than a simple upskilling initiative. Skill coverage (SKILLS) is a foundational requirement, but resilience value depends on: whether MT can be deployed through operational decision rules and coordination structures (COORD), whether training investments are justified within cost and feasibility boundaries (COST/FEAS), and whether competence dynamics and workforce acceptance constraints are managed over time (HUM-DYN and TEAM/ORG). In practice, this implies that organisations should complement training plans with explicit redeployment protocols, governance arrangements, and monitoring of performance degradation risks (e.g., fatigue, forgetting, efficiency loss under frequent switching).

7. CONCLUSIONS

This review synthesised 87 studies to clarify how MT is conceptualised, implemented, and evaluated as a contributor to OR. The evidence confirms that MT is consistently associated with improved operational adaptability and continuity under volatility, but it also demonstrates that MT's resilience value is rarely quantified "end-to-end". Instead, most studies operationalise MT as structural skill coverage and evaluate resilience via operational proxies (time/flow stability, service reliability, throughput and utilisation), while fewer explicitly incorporate the organisational and behavioural mechanisms that condition deployability under disruption.

Across the three research questions, three conclusions emerge. First, the MT–OR field remains methodologically segmented: quantitative/Operations Research approaches dominate and quantify performance under variability but often simplify workforce dynamics; empirical and practice-oriented work offers richer organisational realism but less frequently formalises uncertainty and resilience trade-offs. Second, uncertainty-aware optimisation exists but is not yet the norm, limiting decision relevance for training investment under risk. Third, explicit integration of uncertainty and human dynamics remains rare, directly explaining why organisations still lack robust, comparable metrics to justify MT strategically as a resilience asset.

By consolidating explicit evidence on enablers, barriers, and metric families, this review provides both a structured interpretation of the existing literature and a concrete agenda for future work: to bridge HR and organisational insights with uncertainty-aware operations modelling, and to move toward standardised resilience-relevant measurement architectures.

Taken together, the findings across RQ1–RQ3 define a concrete agenda for advancing the field. Future work should prioritise "end-to-end" formulations that integrate uncertainty-aware workforce planning (stochastic/robust/DRO and real-options valuation), competence evolution and behavioural realism (learning/forgetting, fatigue, heterogeneity, acceptability constraints), and deployability mechanisms (coordination rules, decision rights, governance, and implementation sophistication). Such integration would directly address the current evidence gap: models that quantify resilience gains under volatility but omit the organisational frictions that determine whether MT remains implementable when disruptions occur.

This review is subject to several limitations. First, the included evidence base is methodologically heterogeneous, with strong dominance of OR modelling and sector concentration in manufacturing/service operations and healthcare-related contexts, which may limit generalisability to other organisational settings. Second, although the review applies explicit coding rules to avoid inferring unreported mechanisms, this approach necessarily underrepresents enablers/barriers that may exist in practice but are not explicitly modelled or measured. Finally, despite synthesis-

ing metric families, the lack of standardised indicators for MT intensity and resilience outcomes limits the possibility of aggregating results quantitatively. These limitations reinforce the need for more consistent measurement frameworks and cross-sector empirical validation.

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9. CONFLICT OF INTEREST AND AUTHORSHIP

The authors declare no conflicts of interest related to this study.

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