International Journal of Engineering in Computer Science

E-ISSN: 2663-3590
P-ISSN: 2663-3582
Impact Factor (RJIF): 5.52
www.computersciencejournals.com/ijecs
IJECS 2025; 7(2): 143-151
Received: 15-07-2025
Accepted: 18-08-2025

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Wearable technology in real time decision support

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DOI: https://www.doi.org/10.33545/26633582.2025.v7.i2b.210

Abstract
Wearable technologies are increasingly central to real-time decision support across healthcare, occupational safety, sports, defense, and emergency response. By continuously capturing physiological, behavioral, and environmental data, these devices provide actionable insights that enhance both individual care and organizational performance. Their value lies in four domains: personalization of decisions, predictive analytics for early intervention, population-level intelligence to inform policy, and hybrid intelligence that augments human judgment. Despite these opportunities, unresolved challenges persist, including variable data accuracy, privacy risks, limited interoperability, and barriers to sustained user adoption. Addressing these issues requires stronger ethical frameworks, reliable integration standards, and attention to socio-technical factors influencing uptake. Advances in edge computing, multimodal data fusion, and governance mechanisms further underscore the field's trajectory. This article argues that realizing the transformative potential of wearable technologies depends on interdisciplinary collaboration that bridges engineering, healthcare, ethics, and policy to create trustworthy decision-support ecosystems.

Keywords: Ethical governance, occupational safety, predictive analytics, precision healthcare, real-time decision support, wearable technology

1. Introduction
Decision-making under conditions of uncertainty is central to many domains of human activity, from clinical medicine and emergency response to industrial operations and defense. The quality and timeliness of decisions often determine not only efficiency and economic outcomes but also human lives. Conventional decision support systems (DSS) emerged in the mid-twentieth century as tools to assist managers and professionals in processing large amounts of structured information for improved judgment (Di Matteo *et al*., 2020) [18]. However, these systems were typically retrospective, relying on historical or static data and designed for settings where decisions could be planned rather than executed in real time. In environments where the situation evolves rapidly, such as acute patient care, disaster management, or hazardous industrial operations, static decision inputs are insufficient. What is required is real-time decision support, underpinned by continuous data streams and adaptive analytics capable of guiding users as events unfold (Gathright *et al*., 2024) [50].
The emergence of wearable technology has provided an important pathway toward such real-time systems. Broadly defined, wearables are sensor-equipped devices worn on or close to the human body that capture physiological, behavioral, and environmental parameters (Patel *et al*., 2012; Dias & Cunha, 2018) [36, 19]. Early generations of wearable devices, such as pedometers and consumer-grade activity trackers, primarily served lifestyle and fitness markets (Piwek *et al*., 2016) [38]. More recently, rapid advances in miniaturized sensors, wireless communication (including Bluetooth Low Energy and 5G), edge computing, and artificial intelligence have transformed wearables into highly sophisticated platforms. These systems are now capable of not only recording data but also transmitting, processing, and analyzing it in ways that yield actionable insights within seconds (Mu *et al*., 2025) [51].
The healthcare sector illustrates the profound implications of this technological shift. For instance, continuous glucose monitors (CGMs) allow patients with diabetes to receive alerts on impending hypoglycemia or hyperglycemia, enabling immediate corrective action rather than relying solely on periodic blood tests (Bergenstal *et al*., 2013) [9]. Similarly, continuous ECG patches can detect paroxysmal atrial fibrillation that might otherwise go unnoticed during intermittent clinical examinations, thereby reducing stroke risk (Steinhubl *et al*.,

2018) [44]. In critical care settings, wearable sensors integrated with early warning systems have been shown to improve recognition of patient deterioration (Gluck *et al*., 2017) [23]. These examples demonstrate how wearables extend decision-making capacity by reducing temporal gaps between physiological events and interventions, a cornerstone of real-time decision support.

Beyond healthcare, wearables are increasingly relevant in occupational safety and industry. In construction, mining, and chemical manufacturing, smart helmets and sensor-embedded garments monitor worker fatigue, exposure to harmful substances, and ergonomics in real time (Jacobs *et al*., 2019) [26]. By alerting workers and supervisors to hazards before incidents occur, these devices contribute to preventive safety strategies and align with the principles of proactive risk management. In transportation, wearable fatigue-detection systems for drivers and pilots can prevent catastrophic accidents by triggering alerts when biometric signals indicate reduced alertness (Chang *et al*., 2023) [12].

The sports and performance sector has also embraced wearable-enabled decision support. Professional athletes and coaches rely on real-time monitoring of heart rate variability, acceleration, oxygen saturation, and other parameters to optimize training loads and reduce the likelihood of overtraining injuries (Li, *et al*., 2015) [28]. These data streams are increasingly integrated with video analytics and environmental sensors, providing coaches with multidimensional insights that inform in-game tactical decisions as well as long-term performance planning (Windt & Gabbett, 2017) [49].

In defense and emergency response, wearables are becoming critical for situational awareness in extreme environments. Soldiers equipped with biometric monitoring systems can be assessed for hydration, thermal strain, and stress levels, which informs command-level decisions about deployment and rotation (Bonato, 2010) [10]. Firefighters and disaster-response teams benefit from location-tracking wearables combined with environmental sensors that provide real-time alerts on toxic exposures or structural risks (Huhn *et al*., 2022) [25]. In these high-stakes contexts, decision support is inseparable from survival, making the reliability of wearable technologies a matter of strategic importance.

Despite the potential, adoption of wearable-based decision support systems faces several barriers and unresolved questions. First, the accuracy and reliability of data remain inconsistent across devices. Studies have shown that motion artifacts, sensor placement, and environmental interference can significantly distort readings, especially for optical heart-rate sensors and consumer-grade accelerometers (Bent *et al*., 2020) [8]. Inaccurate data not only undermines trust but may also lead to harmful decisions if false positives or negatives go unchecked. Second, privacy and ethical concerns are significant, as wearable devices generate some of the most intimate categories of personal data. The potential misuse of biometric information for surveillance or commercial exploitation raises questions about autonomy, consent, and data governance (Sharon, 2017; Mittelstadt, 2017) [43, 32]. Third, the lack of interoperability between devices and platforms limits the integration of wearables into broader decision support ecosystems, such as electronic health records or enterprise safety dashboards (Ghadi *et al*., 2025) [21]. Finally, human and organizational factors, including user comfort, compliance, digital literacy, and institutional readiness, strongly influence whether wearable systems realize their full potential (Chung *et al*., 2017) [15]. These trends suggest that wearable technology represents both a transformative opportunity and a complex challenge for the future of real-time decision support. On one hand, wearables extend decision-making capacity by providing continuous, personalized, and context-rich data that can be translated into timely interventions. On the other hand, without attention to accuracy, ethics, interoperability, and usability, the same technologies may exacerbate risks or entrench inequalities in access to decision-support tools.

2. Literature Review

Scholarship on wearable technologies has developed rapidly, ranging from technical reviews to evaluations of clinical and organizational applications. Early work focused on medical monitoring and rehabilitation. Pantelopoulos and Bourbakis (2010) [35] surveyed sensor-based health systems, highlighting their diagnostic potential but also reliability and integration challenges. Patel *et al*. (2012) [36] discussed rehabilitation uses, stressing technical feasibility without addressing decision-support contexts.

As consumer adoption expanded, attention shifted to fitness and lifestyle monitoring. Piwek *et al*. (2016) [38] critically assessed consumer-grade devices, noting problems of accuracy, adherence, and privacy. Dias and Cunha (2018) [9] classified wearable health devices but offered largely descriptive accounts with limited engagement on how continuous data streams support real-time decision-making.

Recent reviews recognize convergence with mobile health and artificial intelligence. Huhn *et al*. (2022) [25] identified opportunities for personalized monitoring but emphasized methodological inconsistencies across studies. Ghadi *et al*. (2025) [21] examined AI-enabled remote patient care, acknowledging predictive potential while pointing to unresolved interoperability and governance issues. Importantly, most reviews treat ethical questions as peripheral. Sharon (2017) and Mittelstadt (2017) [43, 32] argue that self-tracking raises concerns about autonomy, fairness, and surveillance, yet these issues remain underexplored in technical analyses.

Cross-domain comparisons are also scarce. Occupational safety research emphasizes proactive risk detection through smart helmets and fatigue monitors (Jacobs *et al*., 2019; Chen *et al*., 2022) [13], while sports medicine literature highlights performance optimization and injury prevention (Akenhead & Nassis, 2016; Tamura, 2024) [1, 45]. Defense studies focus on situational awareness in extreme environments (Bonato, 2010; Hossain & Muhammad, 2016) [10, 24]. Despite these advances, few reviews synthesize insights across sectors or critically link wearables to decision science frameworks such as Decision Support Systems (DSS), Internet of Things (IoT), or the Data-Information-Knowledge-Wisdom (DIKW) hierarchy. This article addresses these gaps by integrating theoretical models with empirical evidence across healthcare, occupational safety, sports, and defense. By foregrounding debates on accuracy, interoperability, ethics, and equity, it contributes a cross-sectoral critique of how wearables shape real-time decision support ecosystems.

3. Theoretical and Conceptual Framework

The integration of wearable technologies into real-time decision support can be explained through established theories in decision sciences and information systems. Traditional Decision Support Systems (DSS) emphasize the interaction between data, models, and user interfaces to aid decision-making under uncertainty (Di Matteo *et al*., 2020) [18]. Wearables extend this paradigm by acting as continuous sensing devices that feed dynamic and individualized data streams into adaptive DSS, enabling real-time analytics and context-aware decision-making. Within the Internet of Things (IoT) framework, wearables are situated as nodes in interconnected networks where information is exchanged across sensors, mobile devices, and cloud-based platforms. This aligns with socio-technical systems theory, which stresses that decision support effectiveness depends not only on technology but also on the organizational and human factors that govern its use (Baxter & Sommerville, 2011) [7]. Complementary frameworks further illustrate how raw wearable data become actionable knowledge. Complex Event Processing (CEP) explains the transformation of continuous sensor signals into meaningful events, such as detecting arrhythmias from ECG patches or identifying falls from accelerometers. In healthcare, Clinical Decision Support (CDS) models show how wearable-derived datasets enhance diagnostic precision and personalize treatment recommendations. The data-information-knowledge-wisdom (DIKW) hierarchy adds a conceptual layer by clarifying how sensor data evolve into higher-order insights that guide decision-making. Together, these perspectives frame wearables as integral components of decision-making ecosystems where technical, clinical, and organizational elements converge. Figure 1 provides a conceptual illustration of this process. It depicts how wearable sensors capture physiological signals, transmit them through patient-mobile and patient-clinician interactions, and feed into cloud-based data analysis. The output generates diagnostic results and integrates user feedback, showing how wearables function as intermediaries between individuals, healthcare providers, and computational infrastructures (Liu *et al*., 2024). This schematic exemplifies the theoretical principles of DSS, IoT, and DIKW in practice, situating wearables as both technical devices and enablers of socio-technical decision-making systems. Importantly, this framework also underpins the central purpose of this article: to critically assess how wearable technologies can be integrated into real-time decision-support ecosystems across healthcare, occupational safety, sports, and defense. By linking theory to application, the analysis moves beyond descriptive accounts to evaluate how continuous data streams are transformed into actionable, reliable, and ethically governed decisions. DSS, IoT, and DIKW justify the central research question of this article: how can wearable technologies be integrated to provide reliable, ethical, and actionable real-time decision support?

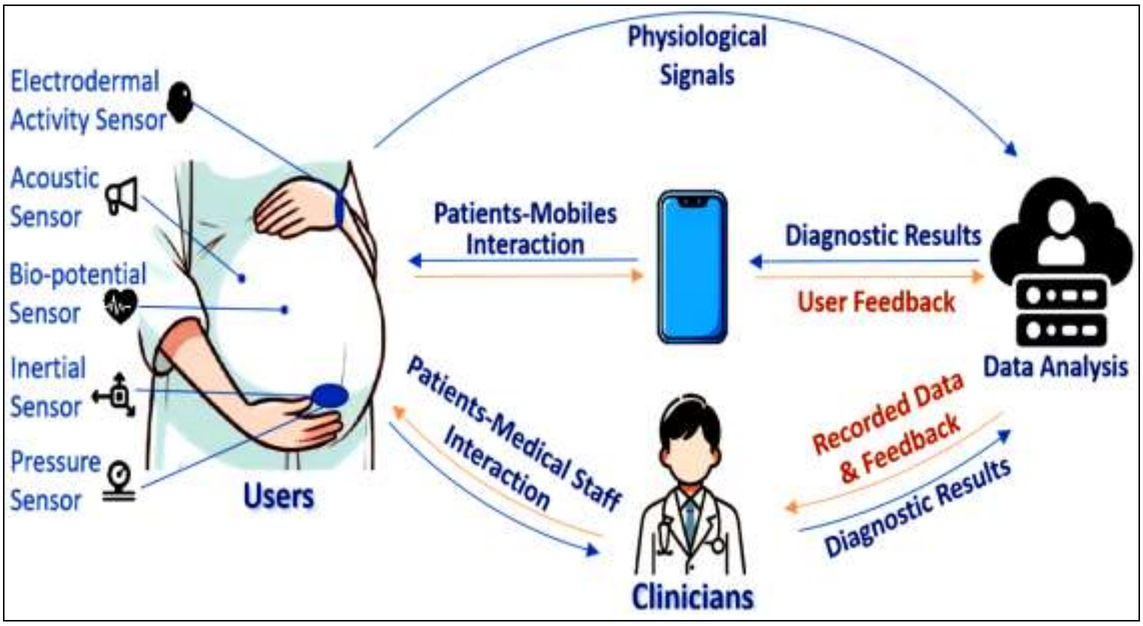

Fig 1: Conceptual Representation of Patient-Wearable-Clinician Interaction in Real-Time Decision Support

4. Applications of Wearable Tech in Real-Time Decision Support

Wearable technologies have advanced far beyond their initial role as consumer wellness tools, becoming central to real-time decision support in healthcare, occupational safety, sports, and defense. By continuously collecting physiological, behavioral, and environmental data, wearables generate insights that support timely interventions. Their contribution lies not only in personalization but also in enabling predictive and preventive decisions in high-stakes environments.

4.1 Healthcare

Healthcare is the most mature domain for wearable-enabled decision support. Continuous glucose monitors (CGMs) alert patients and clinicians to hypoglycemia or hyperglycemia in real time, improving insulin management and reducing complications (Shah & Garg, 2019) [41]. Cardiac patches and smartwatch-based ECG sensors detect arrhythmias, allowing early interventions that prevent strokes (Steinhubl *et al*., 2018; Perez *et al*., 2019) [44, 37]. During the COVID-19 pandemic, smart rings and wristbands that monitored oxygen saturation supported remote patient monitoring, reducing hospital congestion while maintaining clinical oversight (Annis *et al*., 2020). These examples illustrate how wearables extend care beyond hospital walls, aligning with precision medicine and proactive disease management.

4.2 Occupational Safety and Industry

Wearables are increasingly deployed to prevent accidents and protect worker health in industrial settings. Fatigue-detection devices in mining and transport measure blink duration, head movement, and heart rate variability to issue early alerts that reduce accident risks (Chang *et al*., 2023; Choi *et al*., 2018) [12, 34]. Gas-detection wearables in chemical industries provide continuous monitoring of toxic exposures, enabling evacuation before thresholds are exceeded (Chen *et al*., 2022) [13]. Construction workers use posture-monitoring exoskeletons and inertial sensors to prevent musculoskeletal injuries by detecting unsafe lifting patterns (Antwi-Afari *et al*., 2017) [4]. Figure 2 illustrates selected wearable systems designed for industrial safety, highlighting their integration into broader occupational health and risk management strategies.

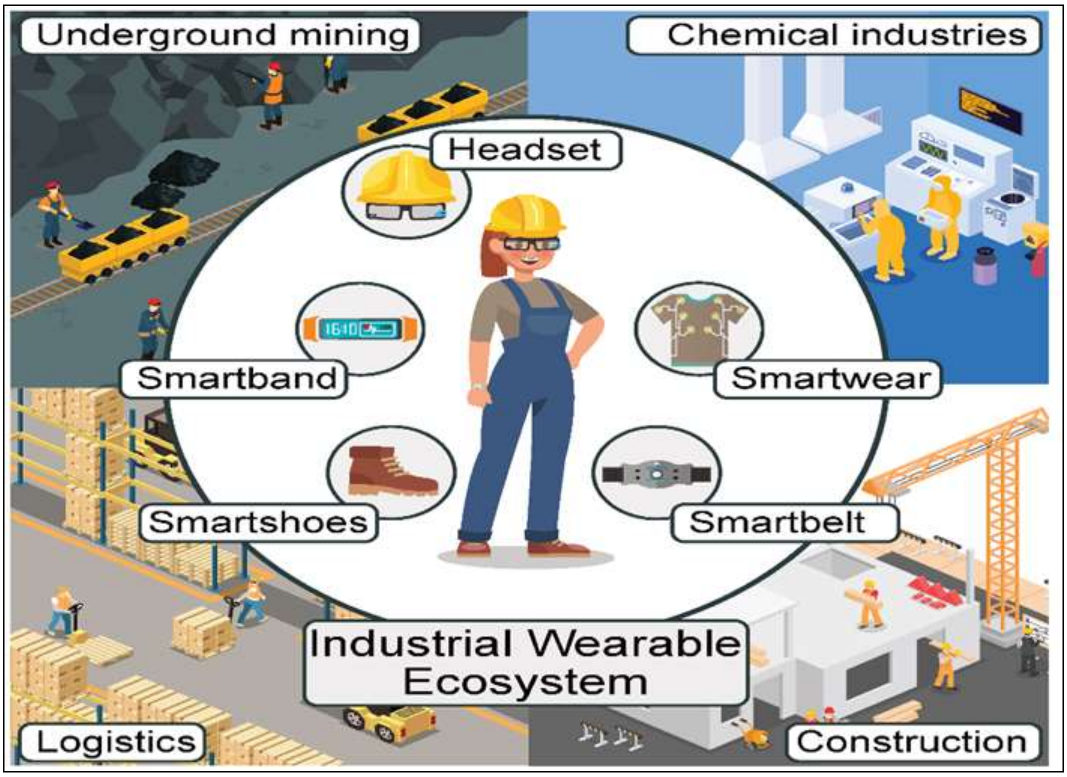

Fig 2: Wearable's for Industrial Work Safety

4.3 Sports and Human Performance

The sports sector demonstrates how wearable data are used to optimize performance and reduce injury risk. GPS-enabled vests and accelerometers track workload, speed, and fatigue, allowing coaches to adjust training intensity and avoid overtraining injuries (Akenhead & Nassis, 2016) [1]. Hydration sensors and thermoregulation monitors prompt interventions to prevent heat-related illnesses (Nuccio *et al*., 2017) [33]. In competitive play, coaches rely on real-time wearable data to make tactical decisions, such as substitutions guided by fatigue indicators (Cummins *et al*., 2013) [17]. These applications illustrate the shift from intuition-driven to data-informed decision-making in elite performance contexts.

4.4 Defense and Emergency Response: Defense and emergency response contexts demand rapid decisions under extreme conditions. Biometric sensors that monitor heart rate variability, stress, hydration, and core temperature help commanders assess troop readiness and optimize deployment cycles (Gao *et al*., 2016) [20]. For firefighters and disaster responders, smart helmets equipped with GPS, gas sensors, and thermal imaging provide real-time situational awareness, guiding safer navigation in hazardous conditions (Hossain & Muhammad, 2016) [24]. During large-scale emergencies, wearable biosensors transmit patient vital signs directly to command centers, enhancing triage and resource allocation (Mirjalali *et al*., 2021) [31]. Figure 3 illustrates the role of wearable systems in defense and emergency operations, where real-time monitoring directly translates into survival outcomes.

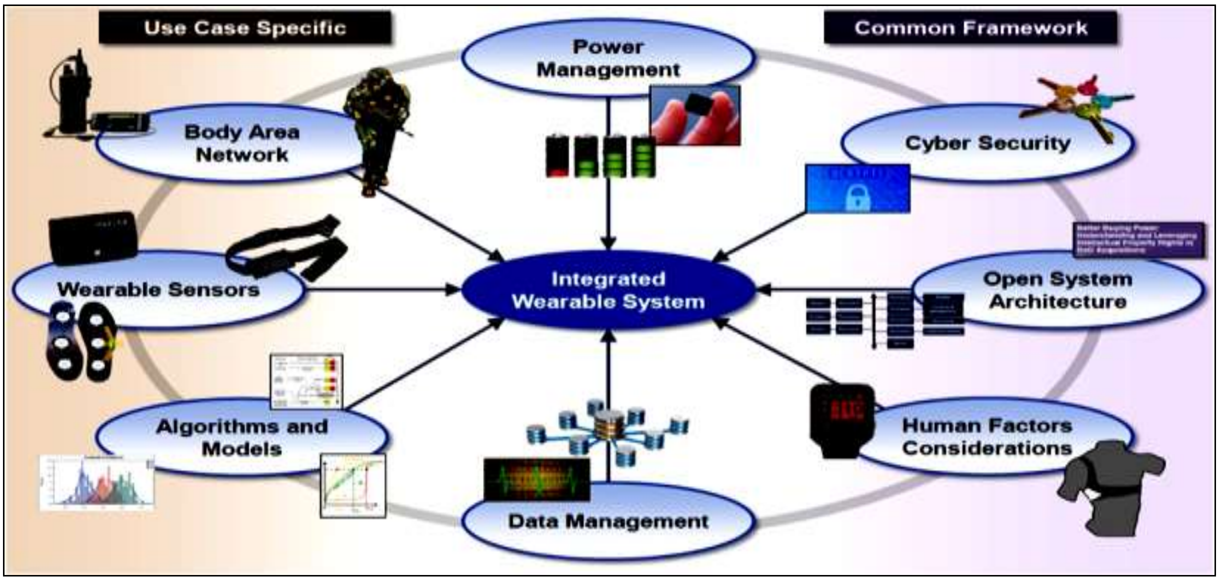

Fig 3: Role of Wearables in Defense/military system

Table 1: Comparative Applications of Wearables in Real-Time Decision Support

Domain	Example Devices	Decision Supported	Key Benefits	Key Challenges
Healthcare	CGMs, ECG patches, smart rings, wristbands	Diabetes alerts, arrhythmia detection, remote monitoring	Early intervention, reduced hospital burden, precision care	Accuracy variability, interoperability
Occupational Safety	Fatigue sensors, smart helmets, exoskeletons, gas monitors	Fatigue detection, hazard monitoring, ergonomics	Accident prevention, hazard alerts, worker wellbeing	Compliance, privacy, organizational readiness
Sports	GPS vests, accelerometers, hydration sensors	Training optimization, injury prevention, tactical substitutions	Enhanced performance, reduced injuries, informed coaching	Reliability in high-intensity settings
Defense & Emergency	Biosensors, smart helmets, triage monitors	Stress/fatigue monitoring, situational awareness, patient triage	Improved readiness, safer deployments, faster triage	Scalability, ethical governance, data security

5. Discussion

The application of wearable technologies across healthcare, occupational safety, sports, and defense reveals several common patterns. A consistent trend is the movement from reactive monitoring toward predictive and preventive decision support. In healthcare, for instance, continuous glucose monitoring shifts diabetes care from episodic measurement to proactive intervention (Shah & Garg, 2019) [41]. In industrial safety, fatigue sensors and posture monitors provide anticipatory alerts that prevent accidents before they occur (Chang *et al*., 2023; Antwi-Afari *et al*., 2017) [12, 4]. Sports and defense sectors similarly demonstrate the value of prediction and personalization, with wearable data enabling tailored training, informed substitutions, and early detection of physiological stress (Akenhead & Nassis, 2016; Gao *et al*., 2016) [1, 20]. Across domains, the personalization of decision-making emerges as a defining feature: data streams are increasingly fine-tuned to individual physiological baselines, producing insights that are more actionable than generic guidelines.

Despite these advances, significant limitations remain. Accuracy and reliability are inconsistent across devices and contexts, with motion artifacts, environmental interference, and sensor placement affecting readings (Bent *et al*., 2020). This undermines confidence in clinical and industrial decision-making where errors carry high risks. Evidence is also uneven across domains. Healthcare benefits from large-scale clinical trials (e.g., Perez *et al*., 2019), whereas occupational safety and defense often rely on pilot studies or proprietary industry data that are not peer-reviewed. The context-specific nature of performance further complicates generalization; a wearable validated in controlled laboratory settings may not function with the same reliability in unpredictable real-world environments.

There are also ongoing debates and unresolved challenges. Privacy and data governance remain central concerns, as wearable devices capture intimate physiological and behavioral data that can be misused for surveillance or commercial exploitation (Sharon, 2017; Mittelstadt, 2017) [43, 32]. Equity is another issue: most large-scale studies are conducted in high-resource settings, raising concerns about global accessibility and the risk of exacerbating digital divides. Governance is contested between industry and academia, with technology companies often making optimistic claims that outpace the available scientific evidence. This tension highlights the need for independent validation, standardized regulatory frameworks, and interdisciplinary oversight that integrates engineering, clinical, ethical, and policy perspectives.

6. Opportunities and Transformative Potential

The integration of wearable technologies into decision-making processes presents a set of transformative opportunities that extend across healthcare, occupational safety, sports, and defense. Their potential lies not simply in monitoring, but in reshaping how decisions are informed and acted upon at individual, organizational, and population levels.

Personalization remains one of the strongest opportunities. Because wearables generate continuous and multimodal data, they allow insights to be tailored to individual baselines rather than population averages. In healthcare, continuous glucose monitors have enabled more accurate insulin dosing and improved glycemic control, while rehabilitation programs that incorporate wearable feedback achieve better adherence and recovery outcomes (Shah & Garg, 2019) [41]. In workplaces, personalization means fatigue alerts or ergonomic adjustments can be calibrated to each worker's age, health status, or workload. This individualized approach strengthens compliance and increases the relevance of decision-support interventions.

A second opportunity arises from predictive analytics. The high-frequency signals captured by wearables can be processed through machine learning models to identify early warning patterns. In clinical contexts, such models have been used to forecast sepsis onset, arrhythmias, and respiratory distress, allowing interventions before critical deterioration occurs (Ghiasi *et al*., 2022; Clifford *et al*., 2016) [22, 16]. In industrial environments, predictive analysis of motion and biosignals provides advance alerts of fatigue or cognitive decline, helping to prevent accidents in transportation, mining, and construction (Chang *et al*., 2023) [12]. This shift from reactive to anticipatory decision support fundamentally alters the timing and effectiveness of intervention strategies.

Wearables also enable population-level intelligence when data are aggregated. At this scale, patterns in community health, occupational risks, or hazard exposure can be identified. Notably, large-scale smart watch studies have uncovered previously undiagnosed atrial fibrillation, with direct implications for public health planning and resource distribution (Perez *et al*., 2019) [37]. For policymakers, such insights could support epidemic surveillance, workforce protection, and targeted allocation of healthcare services. The challenge is to balance these collective benefits with stringent privacy and governance standards.

Finally, the idea of hybrid intelligence emphasizes that wearables are designed to complement, not replace, human expertise. Automated alerts and continuous monitoring reduce cognitive burden, but decision-making remains rooted in professional judgment and ethical reasoning. In emergency response, biometric sensors may highlight rising physiological strain, yet the critical decisions on evacuation or tactical adjustments remain with trained personnel (Nuccio *et al*., 2017) [33]. This model preserves human agency while ensuring that complex, real-time data are translated into usable insights.

7. Challenges and Limitations

The opportunities outlined above are tempered by persistent and multi-dimensional challenges. A first concern is data accuracy and reliability. Industry marketing often promotes wearables as seamless and precise, yet empirical evidence reveals frequent calibration errors, motion artifacts, and physiological variability that undermine trust. Heart-rate monitors can misread signals during vigorous exercise, while sweat-based biosensors are easily distorted by hydration levels (Gao *et al*., 2016) [20]. In decision-support contexts, such inaccuracies translate into false alarms or missed detections, creating risks that are rarely acknowledged in promotional claims.

Equally significant are issues of privacy, security, and ethics. Wearables generate continuous streams of sensitive data, raising questions of ownership, informed consent, and surveillance. While marketed as empowering tools, in practice they can expose users to coercive oversight by employers, insurers, or governments. High-profile data breaches underscore these vulnerabilities, while critics have warned that without robust ethical frameworks, wearables risk undermining the trust required for adoption (Topol, 2019; Sharon, 2017) [47, 43].

A third limitation is interoperability and system integration. The wearable ecosystem remains fragmented, with proprietary platforms and competing standards limiting connectivity with electronic health records, safety platforms, and national health databases (Hossain & Muhammad, 2016) [24]. Industry rhetoric often stresses scalability, but in practice integration costs and technical incompatibility slow adoption and restrict cumulative learning.

Finally, human and organizational factors constrain implementation. User compliance often declines over time due to discomfort, battery limitations, or information overload (Basch *et al*., 2016) [6]. Digital literacy gaps reduce accessibility, particularly in older or underserved populations. In workplaces, monitoring may be resisted as invasive or punitive. Organizational reluctance also reflects uncertainty about liability, workflow disruption, and unclear returns on investment. These factors illustrate that adoption is not purely a technical issue but one of socio-technical alignment. Figure 4 illustrates these multi-dimensional challenges, highlighting the interplay of technical, ethical, and organizational barriers.

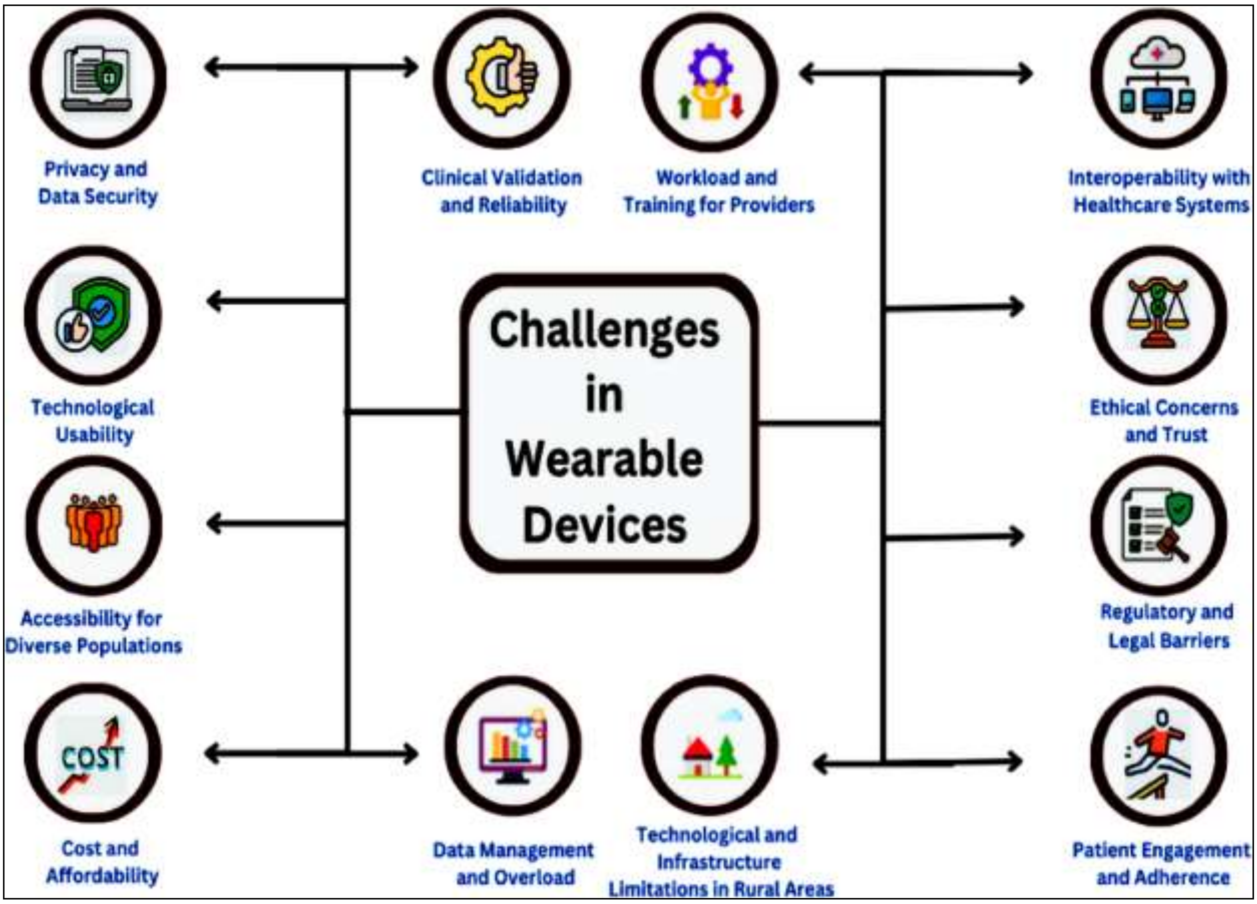

Fig 4: Multi-Dimensional Challenges of Wearable Decision Support

8. Future Directions

Addressing these limitations requires coordinated innovation and governance.

One priority is strengthening policy and regulatory frameworks. In the European Union, the General Data Protection Regulation (GDPR) provides baseline protections for personal data (Voigt & Von dem Bussche, 2017) [48]. In healthcare, medical device regulation by the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMA) has set standards for safety and efficacy (Rabbitts *et al*., 2021) [39]. However, current frameworks are uneven and underdeveloped in other sectors such as occupational safety and defense. Scholars argue that clearer standards on fairness, transparency, and accountability are essential to prevent misuse and foster trust (Mittelstadt, 2017) [32].

Another direction is fostering interdisciplinary collaboration. Research shows that wearable systems are most effective when engineers, clinicians, ethicists, and social scientists collaborate to address not only technical reliability but also ethical and social acceptability (Baxter & Sommerville, 2011; Kostkova *et al*., 2016) [7, 27]. This collaborative approach ensures that technological innovations are embedded within broader socio-technical systems.

A further priority is expanding the equity and global health agenda. Evidence from low- and middle-income countries (LMICs) demonstrates the challenges of wearable adoption due to infrastructure limitations, affordability constraints, and cultural barriers (Byass, 2018; Rawstorn *et al*., 2016) [11, 40]. Without deliberate strategies for equitable distribution, wearable-enabled decision support may exacerbate rather than reduce health and safety disparities.

Finally, scalability remains critical. Large-scale studies such as the Apple Heart Study have demonstrated both feasibility and the infrastructure demands of population-level wearable deployment for atrial fibrillation detection (Perez *et al*., 2019) [37]. Expanding these initiatives will require sustained investment and cross-sector partnerships to align technical, organizational, and ethical priorities.

8. Conclusion

Wearables are reshaping decision support by enabling personalization, predictive intervention, population-level intelligence, and hybrid human-machine collaboration. Their potential is evident across healthcare, occupational safety, sports, defense, and emergency response. Yet persistent challenges, ranging from accuracy failures and declining compliance to ethical risks and limited interoperability, demonstrate that their integration into decision-support ecosystems is far from straightforward. The path forward requires balancing technical innovation with governance, ethics, and inclusivity. Regulatory frameworks such as GDPR and medical device certification must be adapted to new applications. Interdisciplinary collaboration across engineering, clinical science, ethics, and policy is essential to translate pilots into sustainable infrastructures. Equally, a focus on equity is needed to ensure that wearable-enabled decision support benefits not only high-resource environments but also LMICs where health and safety burdens are greatest.

Future research should prioritize large-scale trials, the development of governance frameworks, and cross-disciplinary partnerships to ensure that wearable-enabled decision support advances responsibly and inclusively.

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