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Function Allocation in Human-Machine Teaming: A Systematic Review

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Abstract

With the rapid advancement of intelligent technology, humans and machines are increasingly collaborating as teams to complete tasks. In recent years, research on human-machine teaming (HMT) has gained significant scholarly attention. However, most studies focus on HMT applications from a technical perspective. This study synthesizes existing research on HMT, specifically emphasizing function allocation. A combination of bibliometric and thematic review approaches was employed. The literature search identified 149 papers for bibliometric analysis, and network analysis was conducted to examine co-authorship patterns. Additionally, thematic analysis was performed on 17 selected studies. Findings indicate that research on HMT function allocation centers around five key aspects: integration and coordination, trust and cooperation, approaches to function allocation, functional allocation design frameworks, and human safety considerations. This review provides insights into the state-of-the-art research on function allocation in HMT by integrating theoretical and empirical perspectives, offering guidance for optimizing task assignments in human-in-the-loop smart systems. Future research can focus on identifying mechanisms linking human-machine team inputs to output variables within specific function allocation contexts.

Keywords

Human-machine teaming, function allocation, systematic review, bibliometric analysis

1. Introduction

With advancing intelligent technology, humans and machines collaborate on task execution, creating opportunities to explore factors for successful teaming. Human-machine teaming (HMT) applies human-human team principles to human-cyber-physical teams, where humans and autonomous agents interact, complement each other, and work toward shared goals. Therefore, a clear understanding of function allocation is essential. Key considerations include task design, task allocation (e.g., deterministic vs. dynamic, human-centered, or efficiency-based), and teamwork factors (e.g., communication, collaboration synergy, trust, and role clarity) influencing allocation. Conducting a systematic literature review offers a comprehensive exploration of this research topic [1, 2]. Bibliometric analysis, the statistical analysis of bibliographic data commonly focused on citation analysis of publications, examines the state of research in a specific field [3]. On the other hand, thematic analysis provides qualitative insights into different aspects of the area. The objectives of this study are to: (1) investigate research on function allocation in human-machine teaming has evolved and its current trend, (2) conduct a bibliometric analysis of the research conducted in this field, (3) identify any emerging trends in the current research, (4) visualize various relationships, and (5) identify common themes in research in this field.

2. Problem Description

Research in the domain of human-machine teaming has gained significant attention in recent years. However, the existing body of literature remains fragmented and lacks a cohesive perspective on HMT. Most studies are rooted in the fields of computer science and control engineering, primarily emphasizing technical aspects while overlooking broader human-centered considerations. This study presents a comprehensive literature review focused specifically on function allocation within HMT. It identifies key concepts related to HMT and function allocation and provides a systematic review that integrates bibliometric and thematic analyses to map the current state of research in this area.

3. Methodology

Relevant research papers were identified based on specific inclusion criteria: (a) involvement of at least one machine agent and one human, (b) presence of a human-machine team, (c) interdependent teamwork toward a common goal, and (d) discussions on function allocation in HMT. The following search algorithm was followed: “Human-machine teaming” OR “Human-agent teaming” OR “Human-technology teaming” OR “Human-computer teaming” OR “Human-robot teaming” OR “Human-AI teaming” AND “Function allocation” OR “task allocation” OR “function assignment" OR "task assignment" OR "role assignment". Web of Science was utilized as the database for the timeline between 2000-2024 and 10058 papers were found. A refined search was performed to select the articles to be included in the sample and 5467 were identified. Then, 149 articles that are related to HMT and are written in English were selected. The abstract review revealed 17 papers were identified for a comprehensive analysis. Figure 1 presents the flowchart for the records sourcing, screening, and selection procedure. Bibliometric data was analyzed for co-authorship, co-occurrence, co-citation, and bibliographic coupling to visualize collaboration patterns and identify influential researchers, potential collaborators, and emerging research areas in HMT. The thematic analysis involved reviewing the selected papers to identify common themes, which were categorized into five key topics. These themes were examined according to the research objectives outlined earlier.

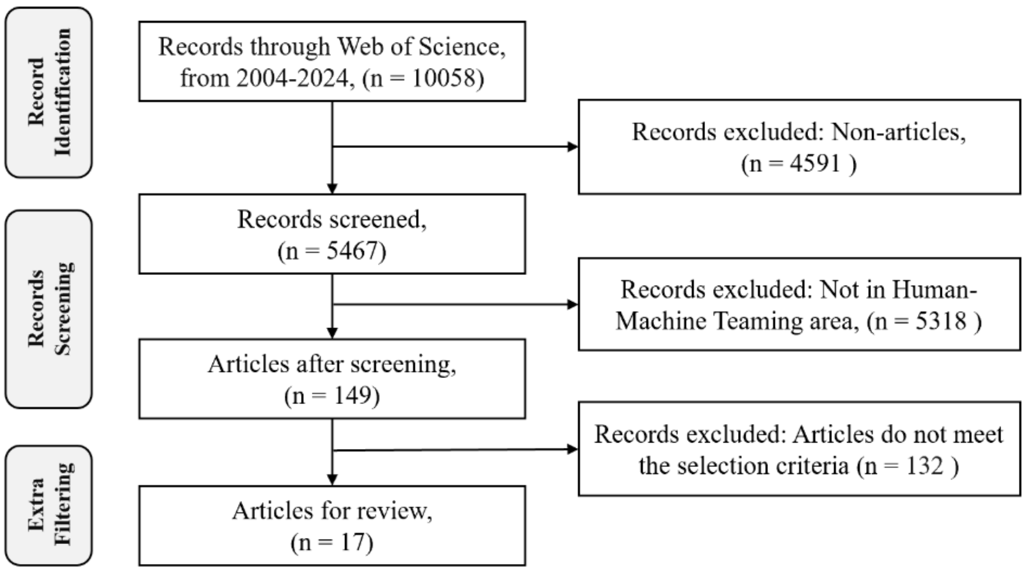

Figure 1: Flowchart of the records sourcing and selection procedure.

4. Results

4.1 Bibliometric and Network Analysis

Co-authorship: The co-authorship analysis helps to identify the authors who performed collaborative research with each other. Findings, as presented in Figure 2 (left), indicate that the most prominent author is Haibin Zhu [4]. All represented authors have at least four collaborations in HMT and function allocation research. Dongning Liu [5] is also one of the prominent researchers in this area and has co-authored at least four articles with two others. Figure 2 (right) presents a density visualization of co-authorship in the HMT research area. By looking at the density visualization, we can estimate the size of the collaboration team of the authors.

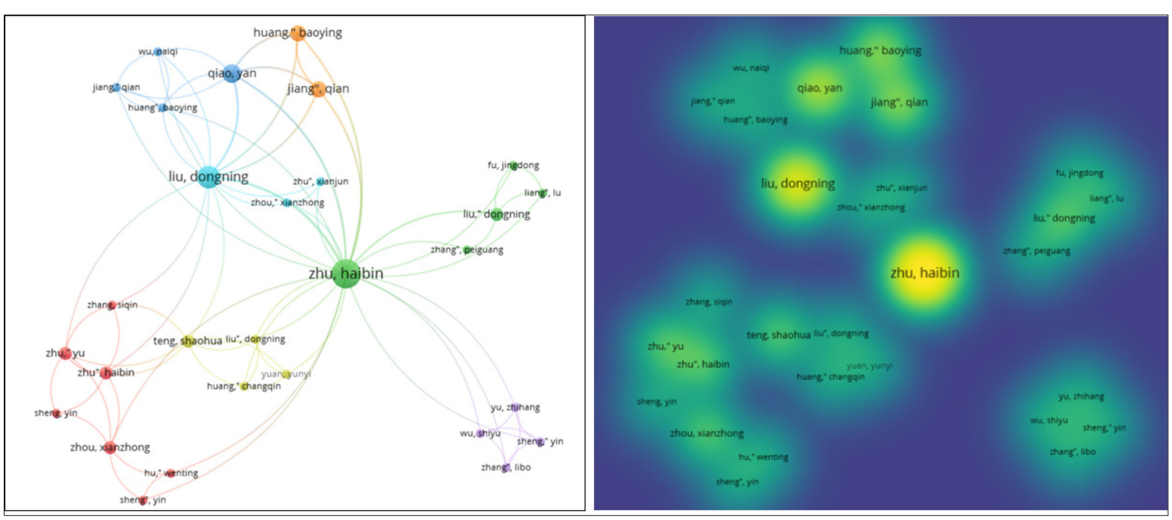

Figure 2: Co-authorship on HMT functional allocation: Network visualization (left) and density visualization (right).

Keywords Co-occurrence: Co-occurrence analysis revealed relationships and patterns between keywords occurring within a specific collection of articles. By identifying the frequently co-occurring keywords, dominant themes and emerging trends within the analyzed text can be mapped out and the central focus areas and intellectual landscape of research can be identified. Figure 3 presents the clusters of keywords that occurred together in at least four articles, and it is noticeable that task allocation, task analysis, and role-based collaboration are the most common keywords.

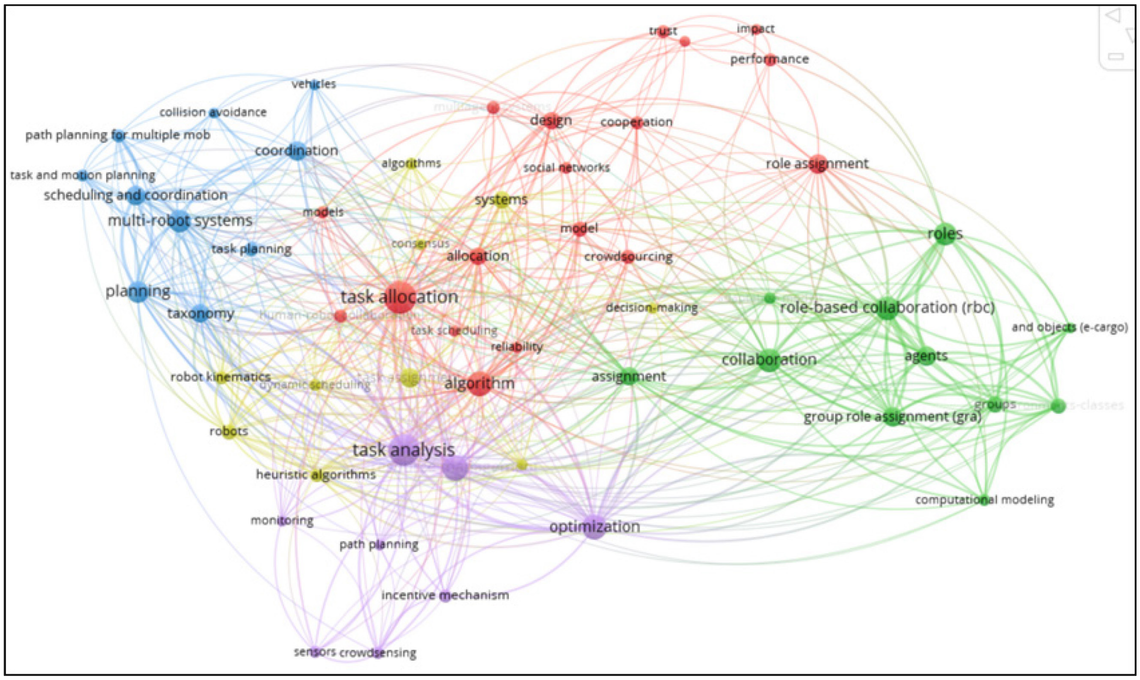

Figure 3: Keyword co-occurrence in HMT functional allocation.

Bibliographic Coupling: Bibliographic coupling occurs when two articles share common references in their bibliographies, indicating a thematic similarity between the documents. The strength of the coupling increases with the number of shared references. Figure 4 with different sizes of bubbles, Zhao (2016) with 31 others shared 11 references, De Wever (2010) with 18 others shared 10, Zhu (2013) with 11 others shared 9, Zhang (2016) with 11 others shared 7, and Jin (2018) with 3 others shared 5 references. Exploring the corresponding articles revealed that the methodological approach towards task allocation in HMT is the most emerging topic that overlaps in referencing.

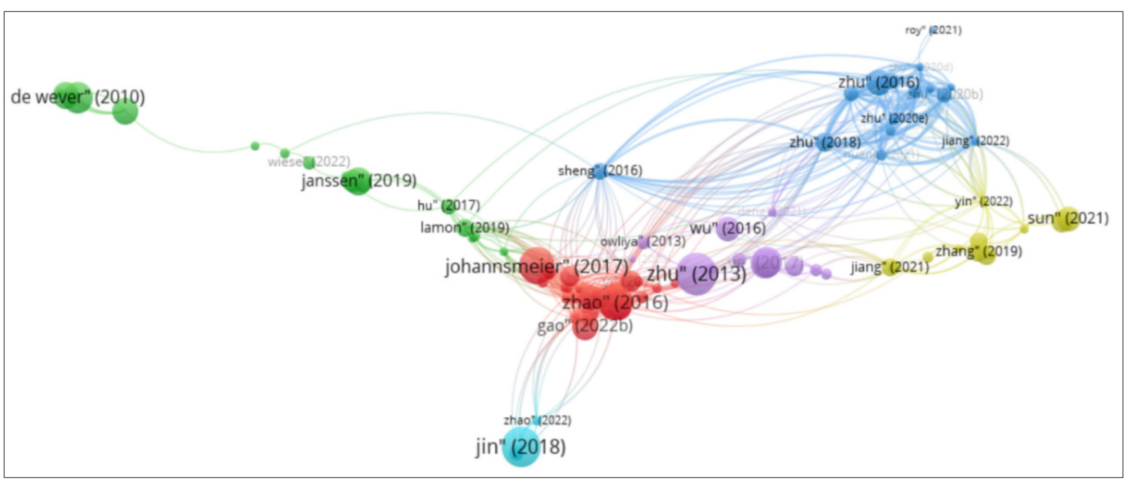

Figure 4: Network visualization of bibliometric coupling in HMT functional allocation research topic.

4.2 Thematic Analysis

Thematic analysis was conducted on 17 selected empirical studies to identify recurring patterns and conceptual insights on task allocation between humans and machines in collaborative systems. Findings were categorized into five key themes related to function allocation in HMT, as summarized in Table 1.

Table 1: Summary of thematic analysis of literature on HMT functional allocation research.

Themes	Authors	Findings
Integration and coordination	[6-9]	• Humans and machines should complement each other's weaknesses. • Shared decision-making between humans and machines for collaboration. • Both agents must act as team players and communicate effectively.
Trust and cooperation	[7, 8], [11, 12]	• Trust and transparency depend on actions and cooperation expectations. • Decision-making requires transparency in other's capacity and progress. • Explainable AI can build better trust between teammates. • AI may offer customized communication.
Approach to functionality	[8], [13-15]	• Machines may offer decision support in error-prone situations. • Machines enhance decision-making via proactive roles and data analytics. • Decision Support Systems (DSS) strengthen human control capabilities. • AI agents adapt actions based on human mental and functional state.
Design and frameworks for functional allocation	[16-20], [23-24]	• Coactive design optimizes human-machine collaboration. • Adaptive framework enhances operator performance, situational awareness, and workload balance in automated vehicle supervision. • HMT framework defines roles in adaptive cyber-physical-human systems. • Autonomous manager dynamically reallocates tasks based on workload. • Risk-based mechanism aids task allocation using risk estimation. • Markov decision process framework dynamically allocates tasks using trust and workload models, validated via simulation. • Joint activity design heuristics aid task allocation and workload evaluation.
Human safety	[25]	• Proposed user-centered design with situational awareness.

Integration and Coordination: HMT combines human creativity with machine intelligence [26]. Humans excel in contextual understanding and knowledge evolution but may lack domain expertise and exhibit biases. Machines, on the other hand, process vast data efficiently but struggle with contextual interpretation, sometimes leading to errors. By complementing each other's strengths, human-machine collaboration enhances performance. Human-centered Artificial Intelligence (AI) design was advocated to ensure seamless cooperation, where humans and machines support each other's limitations through shared knowledge [6]. Machines can assist decision-making by analyzing dynamic data and presenting multiple options, while humans provide contextual insights [7, 8]. Human, artificial, and shared decision-making were further defined emphasizing the need for structured collaboration to improve effectiveness [8]. However, effective integration relies on teamwork and machines must be designed as active team players capable of communicating and coordinating during human-machine interaction [9].

Trust and Cooperation: Trust is crucial for effective human-machine collaboration, requiring transparency in machine decisions and rationales. Human trust in machines is influenced by their actions and adherence to cooperation expectations, making clear communication of responsibilities essential [10]. Ensuring transparency between humans and machines about each other's capacity and current state regarding progress toward achieving shared goals is important [8]. However, trust in fully autonomous systems is challenging, as their decisions may appear unclear to humans. EASE, an approach using statistical models and interpretable machine learning was proposed to improve trust, aligning with explainable AI concepts [11]. Similarly, Paleja [12] explored how AI can align human and machine mental models, enabling cobots to understand teammates, communicate effectively, and adjust autonomy levels as needed. This enhances mutual trust and enables dynamic task allocation.

Approaches to Function Allocation: Researchers have explored various approaches to function allocation in human-machine teaming, balancing automation with human decision-making. Machines handle repetitive and error-prone tasks, while humans provide insights and make informed decisions using machine-generated data. Autonomy structures vary from full automation to shared control, depending on system demands [20]. In highly dynamic fields such as aviation, error-prone tasks can be assigned to AI-powered machine agents to facilitate generating report narrations and identifying language patterns linked to error causal factors, enhancing safety analysis and decision-making [13]. Effective HMT models integrate automation with human oversight. Modern AI prioritizes interaction and decision support over full automation [22]. Machines can enhance decision-making through dynamic data analysis, while human creativity refines contextual manipulation [8]. Steen et al. [14] advocated for decision support systems (DSS) to maintain human control in operations such as drone management. Ewing et al. [15] explored AI's role in military systems, adapting actions based on human cognitive states. Achieving optimal performance requires careful allocation of tasks between human supervision, monitoring, and machine control.

Design and Frameworks for Function Allocation: Coactive design was proposed for analyzing human-machine interdependencies to optimize collaboration and task performance [16]. Based on the notion that in high-level automation, autonomous agents should handle information acquisition and analysis, while decision-making automation should remain moderate, a framework was developed and validated through simulation, demonstrating improved operator performance, situational awareness, and workload balance while avoiding over-reliance on automation [17]. An HMT framework was developed, demonstrating its effectiveness in defining adaptive roles in cyber-physical-human systems [18]. An autonomous task manager was built for redistributing tasks based on human workload and performance, also validated through simulation [19]. A risk-based framework was devised for function allocation based on autonomy levels [20]. A Markov decision process framework was proposed using trust and workload models to dynamically allocate tasks, successfully tested in simulation [23]. Cognitive systems engineering principles were applied to develop joint activity design heuristics for aiding task allocation in HMT and to evaluate performance, workload, and safety in different simulated allocation scenarios [24]. A scenario-based design method was introduced that incorporates human-in-the-loop simulations to enhance machine assistant functions, while also refining metrics related to performance, trust, and collaboration [25].

Human Safety: A mechanism was developed to categorize risk for HMT operations against levels of autonomy and machine functions [20]. It facilitates specifying the level of autonomy and appropriate allocation of functions based on risk estimation, thus enabling safe operation of humans and machines working closely as a team. Moreover, user-centered design of allocation process facilitates situational awareness and ensures safety [21].

5. Conclusions

While most studies examine HMT from a technical perspective, this review systematically analyzes research on HMT with a focus on function/task allocation perspective. Using selection criteria and systematic searches in Web of Science, bibliometric analysis was conducted on co-authorships, co-occurrence, and bibliographic coupling. A thematic analysis categorized findings into five key areas: integration and coordination, trust and cooperation, functional allocation approaches, design frameworks, and human safety. Mapping current research, theoretical frameworks, and empirical findings, identifying key researchers, and topics in HMT such as shared cognition, trust, and transparency, provided guidance on methodologies, analytical tools, and future research directions, particularly linking human-machine team inputs to outputs in function allocation. HMT has the potential to transform industries from healthcare to manufacturing, but effective function allocation, trust, and collaboration are essential for maximizing the benefits. This study offers insights to decision-makers, supporting engineered task allocation in intelligent systems, where humans and machines work as seamless teams.

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