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Ethics in manufacturing: a decision-making perspective

Greta Bozzelli[a,c], Eric Lutters[a,b], Rajkumar Roy[c*], Neha Shakelly[d], John W. Sutherland[d], Masayuki Nakao[e]

[a]*Department of Design, Production and Management, University of Twente, The Netherlands,*
[b]*Department of Industrial Engineering, Stellenbosch University, South Africa*
[c]*School of Science and Technology, City St George's, University of London, United Kingdom*
[d]*School of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN, USA*
[e]*Department of Engineering Synthesis, University of Tokyo, Japan*

* Corresponding author. *E-mail address:* r.roy@city.ac.uk

Abstract

The integration of ethical considerations in manufacturing systems has become increasingly an issue of concern for industries over the last decade. This paper proposes a comprehensive systematic framework for ethical decision-making in manufacturing systems, addressing the gap between theory and practical implementation. Following an extensive literature review and analysis by the CIRP Collaborative Working Group on Ethics in Manufacturing, a survey was conducted of CIRP members in February 2024. The study revealed that while practitioners demonstrate awareness of ethical considerations, there remains a significant disconnect between recognition and systematic implementation. The research identifies fragmented approaches across different areas such as environmental responsibilities, labour practices, and AI and automation; this highlights the need for a holistic and systematic framework for ethics in manufacturing. In response, this study proposes a dynamic ethical decision-making framework that develops along three main phases: problem definition, problem resolution, and evaluation. The framework is designed to provide consistent ethical support across all manufacturing areas while addressing cultural disparities that often lead to differences in ethical considerations across regions. While preliminary validation against existing literature shows promising results, ongoing case studies are being conducted to further verify the framework's applicability across various manufacturing sectors. This research contributes to the field by offering a systematic approach that is both comprehensive and adaptable to evolving manufacturing challenges.

Keywords: Manufacturing Ethics, Ethical Decision-Making, Ethical Reasoning, Technology Advancement

1. Introduction

1.1. Context

Ethics in manufacturing systems has become an increasingly important topic as industries adopt advanced technologies and encounter novel challenges in domains such as automation, sustainability, and human-robot collaboration. The incorporation of ethical considerations is no longer a peripheral concern but a core responsibility to be addressed. The considerations play fundamental roles at the strategic, tactical, and operational levels, and it is incumbent upon companies to address these issues across such levels. The ethical standards set by a company must reflect the actions of each of its constituent parts, encompassing each factory, department, work cell, and individual employee. The core problem lies not in the lack of awareness, but in the incompleteness of a comprehensive framework that guides ethical decision-making across all levels of manufacturing operations. Often, ethical challenges are addressed on an *ad hoc* basis or through isolated efforts that are not integrated across the entire organization. This results in fragmented solutions, hindering companies from establishing a cohesive ethical approach and ensuring consistency.

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1.2. Purpose and Scope (include the research questions)

The objective of this research is to establish a systematic framework for ethical decision-making in manufacturing systems, with the aim of bridging the gap between ethical awareness and practical implementation. The study addresses two primary research questions:

1. What is the current state of knowledge regarding the ethical decision-making processes thar are employed in the context of manufacturing systems?
2. What methodologies can be employed to systematically address and integrate ethical reasoning across all levels of manufacturing processes?

1.3. Structure of the Paper

The paper begins with an introduction, followed by a comprehensive literature review, which examines existing research on ethics in manufacturing, identifying key themes and gaps in current knowledge. The following chapter presents the findings from the CIRP Collaborative Working Group Ethics Survey, offering insights into the current landscape of manufacturing ethics. Subsequently, the section on gap identification analyses the discrepancies between theoretical knowledge and the practical implementation of ethics in manufacturing. The paper then proposes an ethical decision-making framework designed to address the identified gaps and challenges.

The final chapters evaluate the proposed framework and outline future validation steps through case studies. This structure ensures a thorough exploration of the topic while maintaining a focus on practical implementation strategies.

2. Literature Review

2.1. Existing Literature

The body of knowledge built upon literature research provides relevant insights into the current integration of ethics within manufacturing systems. However, although current literature identifies the necessity for the integration of ethics in manufacturing, the approach remains fragmented and lacks an overall and systematic implementation model. Existing studies focus on specific aspects and fields of application (e.g. Environmental Responsibilities, Labor Practices, Automation, AI, etc.…), remaining sectorised among these areas.

The field of ethics in manufacturing systems has garnered considerable attention in recent years, with researchers exploring a range of aspects related to ethical decision-making in design and manufacturing processes. This literature review aims to provide an overview of the current state of knowledge regarding ethical considerations in manufacturing. The growing body of literature provides valuable insights into the current state of knowledge and presents potential approaches and examples for integrating ethical reasoning systematically within manufacturing systems.

2.2. Relevant Insights

The advent of Industry 4.0 has introduced novel ethical challenges in the context of manufacturing. There have been identified several ethical issues invoked by the implementation of smart factories and advanced manufacturing technologies.[1] These include concerns related to data privacy, job displacement, and the need for ethical guidelines in the development and deployment of Industry 4.0 solutions. The authors propose a set of ethical rights and duties that must be exercised by stakeholders in the implementation of Industry 4.0, underscoring the importance of aligning technological advancements with ethical responsibilities. While this framework provides a solid foundation, its broad nature may require further refinement for specific industry applications. In a similar vein, another study highlights the growing pressure on organisations to transition towards more sustainable manufacturing models and the imperative for frameworks to assess performance on sustainability and ethics. [2] This approach offers a comprehensive assessment tool, but its complexity may pose implementation challenges in practical settings. Recent research in related fields offers valuable insights. A study by Xiong et al. (2023) based on ethical decision-making for self-driving cars presents an innovative approach that could be adapted to manufacturing contexts. [3] Here, a method for the systematic incorporation of ethical considerations into the domain of AI decision-making processes is proposed. This approach addresses challenges such as the balancing of competing ethical priorities and operating within uncertain environments. Although there is a focus on autonomous vehicles, it demonstrates a quantitative approach to the implementation of ethical frameworks in real-world technological systems. Such methodologies could potentially be adapted for use at a higher level in manufacturing environments, where AI and autonomous systems are increasingly developing.

The ethical considerations about manufacturing systems, particularly in the context of human-robot collaboration, have also gained significant attention as the industry progresses towards more advanced technologies. Another illustrative framework is proposed by Callari et al. (2024), centred around human-robot collaboration in manufacturing, emphasizing the need for a human-centric approach that considers influences extending beyond the specific context of human-robot dynamics on the shop floor.[4] The paper presents a few potential limitations or challenges that can be addressed, such as the Eurocentric perspective and the evolving technology, which may introduce new ethical challenges not fully addressed by this framework. Overall, the study aligns with the broader trend towards Industry 5.0, which prioritizes human-centric, sustainable, and resilient considerations in manufacturing. [5] The integration of ethics in manufacturing systems must be systematic and comprehensive. It is crucial to consider ethical implications from the earliest stages of technology adoption and design, especially given the potential for privacy concerns and data misuse associated with continuous monitoring of employees' performance. [6, 7]

2.3. Justification for future exploration

The state of knowledge in the field of manufacturing is rapidly evolving, with researchers and industry experts recognising the need for interdisciplinary approaches to address the complex ethical challenges posed by advanced manufacturing technologies. [4, 7] Literature reveals a growing recognition of the importance of integrating ethics into manufacturing systems, particularly in the context of Industry 4.0 and the emerging Industry 5.0 paradigm. [5]

Although current research provides valuable insights into specific ethical challenges and potential approaches, there is a clear need for a more comprehensive and systematic implementation model. The studies highlight various ethical considerations, including data privacy, job displacement, human-robot collaboration, and sustainable manufacturing practices. Approaches such as the ethical framework for human-robot collaboration, adaptation of ethical decision-making models to specific areas, and integration of ethical considerations in technology deployment offer promising directions. However, these approaches remain largely fragmented across different areas of application.

3. Survey

3.1. Purpose of the survey

The purpose of the survey conducted on CIRP Collaborative Working Group on Ethics in Manufacturing, is to assess the current state of ethical awareness, understanding, and application within the manufacturing sector. By gathering insights from industry professionals, the survey aims to identify prevalent ethical issues, evaluate familiarity with existing ethical frameworks, and highlight areas where ethical training and decision-making tools may be lacking. This survey serves as a foundational step toward bridging the gap between ethical recognition and practical implementation, ultimately contributing to more responsible and ethically grounded manufacturing practices.

3.2. Survey methodology

The survey was conducted during the inaugural meeting of the CIRP Collaborative Working Group on Ethics in Manufacturing, held on February 21, 2024, during the CIRP winter meetings in Paris. A total of 45 participants submitted results that were deemed suitable for analysis; of these 45, almost all participants responded to all questions.

The survey comprises a range of question types to elicit a diverse set of insights. These include multiple-choice questions, which address topics such as familiarity with ethical frameworks, fields of application and confidence in understanding ethical considerations. Additionally, there are open-ended questions, which provide detailed accounts of ethical dilemmas encountered in manufacturing as well as recommendations for enhancing ethical practices in this sector. Finally, rating scales were employed to assess the level of familiarity with ethical frameworks and confidence in understanding ethical considerations.

3.3. Survey results

The results of the survey indicate that the majority of practitioners have a moderate familiarity with ethical frameworks, which range from established engineering council codes to newer directives addressing emerging technologies. However, this familiarity often lacks depth and systematic application in daily practice.

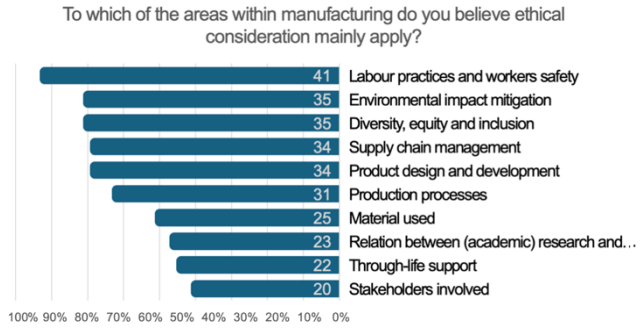

Figure 1. Manufacturing area for ethical application

Figure 1 illustrates the areas within manufacturing where respondents indicated that ethical considerations are primarily applicable. The top three areas identified were Labour practices and worker safety (41%), Environmental impact mitigation (35%), and diversity, equity, and inclusion (35%). While these ethical considerations are acknowledged as important, they are often treated as secondary concerns rather than integral components of the design process. This is particularly evident in how organisations approach ethical decision-making. [8]

Figure 2. Ethical ambitions perceived about manufacturing

The second chart (fig. 2) provides insight into the current understanding and application of ethical considerations in manufacturing environments. The top three responses, namely Ethical Frameworks, Compliance with Regulations, and Ethical Training and Education (each at 22%), indicate that there is a foundational awareness of ethics within manufacturing systems. Nevertheless, other pivotal domains, such as Ethical Leadership (15%) and Ethical Decision-Making Tools (13%), are comparatively less emphasised. This indicates that although there is a certain degree of awareness of ethical frameworks, the practical tools and leadership skills essential for ethical decision-making may not be as systematically integrated as they could be. Further survey questions reveal a considerable deficit in formal education and training on ethical considerations in

manufacturing. Indeed, only 25% of respondents had received training on ethical considerations in manufacturing. Despite the awareness of ethical issues, the lack of systematic training suggests that many professionals may not have the necessary tools or frameworks to make informed ethical decisions. This finding reflects a significant challenge in the current state of knowledge regarding ethical decision-making in manufacturing systems. While professionals may recognise ethical concerns, the absence of structured training limits their ability to address these issues in day-to-day operations. In conclusion, the CIRP survey reveals a complex landscape in which manufacturing ethics intersects with multiple domains of professional practice. While engineering professionals demonstrate awareness of ethical considerations, there appears to be a significant discrepancy between the recognition and implementation of these topics.

4. Identification of gaps

4.1. General overview

The comparative analysis between the literature review findings and the CIRP survey results reveals several gaps in the current state of ethical implementation and decision-making in manufacturing systems. These gaps address both theoretical and practical levels. This section aims to uncover specific areas where ethical frameworks and industry practices diverge, providing a foundation for targeted improvements. By identifying these gaps, we can clarify where current ethical knowledge falls short in guiding real-world decision-making, allowing for a more detailed and effective approach to ethical integration in manufacturing.

While manufacturing professionals demonstrate awareness of ethical considerations, there is a significant gap between theoretical knowledge and practical implementation. [9] The survey indicates that most practitioners have only moderate familiarity with ethical frameworks, and this knowledge often lacks depth and systematic application in daily operations. [10]

4.2. Addressing the identified gaps

In the identified context of manufacturing ethics, current frameworks often present a collection of best practices and guidelines that, while valuable, tend to offer discretionary principles rather than fostering a deeper understanding of ethical dilemmas and their resolution processes. Furthermore, existing ethical frameworks in manufacturing are frequently constrained to specific domains, such as sustainability, human rights, automation and AI, and lack a comprehensive approach that encompasses the entire manufacturing landscape.

To address these limitations, the authors propose the development of a systematic approach with the intent of integrating ethics universally across all stages of manufacturing, from initial design conceptualisation to through-life engineering, and finally discarding.

5. Proposal of conceptual framework for ethical decision-making

The proposed diagram (fig. 3) is a dynamic ethical decision-making framework designed to assist stakeholders in the resolution of ethical dilemmas. It differs from traditional approaches by avoiding rigid rules or codes of conduct in favour of a dynamic thinking support tool or decision-making diagram. The primary objectives of this proposed framework are twofold:

- To provide consistent ethical support across all areas of manufacturing, thereby ensuring a unified approach throughout the entire process, rather than relying on different frameworks for distinct sections of the same manufacturing operation.
- To ensure a more globally applicable and culturally sensitive approach to manufacturing ethics, by addressing cultural disparities. Such disparities become apparent in comparing, for example, ethical standards in either European or Asian contexts...

The objective is to implement a comprehensive and adaptable ethical reasoning framework, to enhance the overall ethical decision-making process in manufacturing contexts. This will be achieved by promoting consistency and addressing cultural differences, as well as facilitating a deeper engagement with ethical considerations across all levels of aggregation in manufacturing environments. The proposed framework adopts a holistic approach, which encompasses the entire design process, from initial problem definition to subsequent resolution and evaluation. These three steps are situated within a given context, which exerts a direct and indirect influence on the entire process.

The framework starts with the identification of the ethical dilemma. This stage focuses on understanding the context in which the ethical dilemma arises, including factors like stakeholders involved, cultural norms, and the specific field of application. By clearly defining the ethical dilemma and identifying the conflict, this stage ensures that all relevant aspects of the problem are recognized early on.

The framework then delves into the second phase, Problem Resolution, which involves analysing the potential outcomes of each ethical choice. In this phase the decision-making process takes place. The analysis considers: personal point of view, ethical principles, and existing frameworks (e.g., laws, guidelines, or moral codes). The inclusion of alternative decisions ensures that multiple options are considered before settling on a final course of action. After making a decision, the consequences of that decision are evaluated. Both the chosen decision and any alternative decisions lead to their respective consequences.

Finally, the evaluation step assesses the outcomes to determine whether the ethical issue has been satisfactorily resolved and if they align with ethical standards.

5.1. Evaluation of the proposed concept

The conceptual framework is designed to present a systematic tool to facilitate the integration of ethical

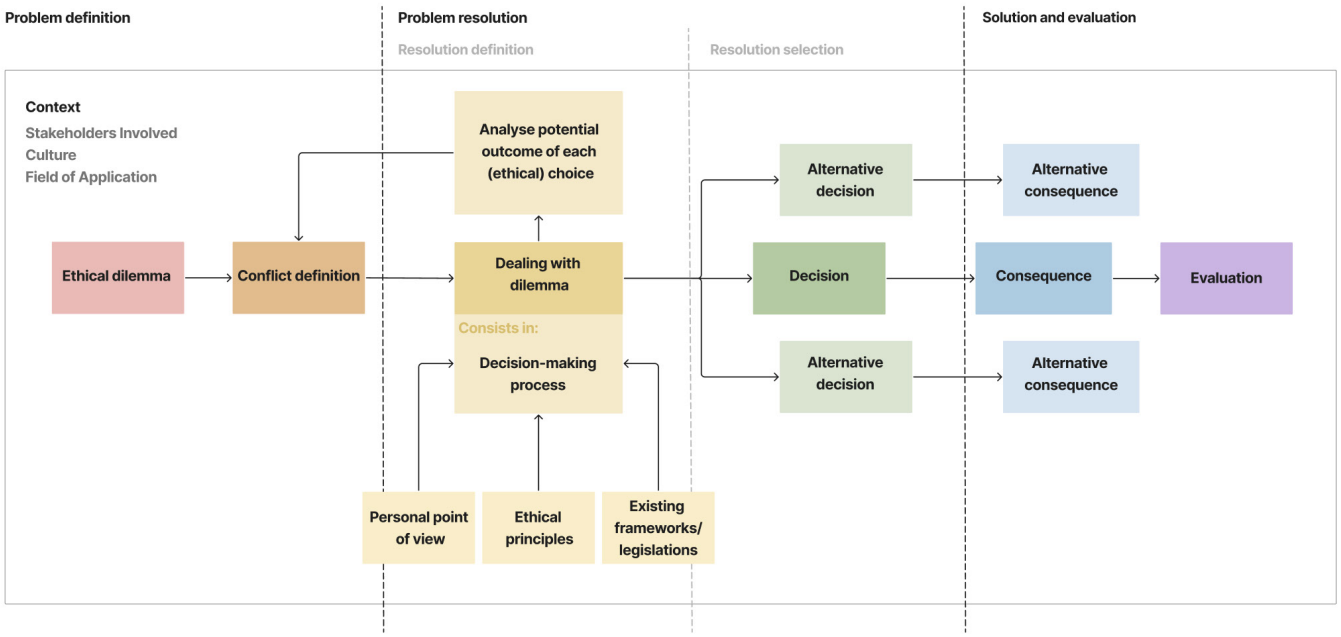

Fig. 3 Proposed conceptual framework for ethical decision-making in manufacturing systems

considerations within the context of manufacturing systems. On the one hand, it encourages a comprehensive understanding of the context in which ethical issues may arise, which is crucial for addressing such issues in a manner that is sensitive to the specific cultural and industrial context. On the other hand, it is important to consider how the effectiveness of this stage depends heavily on how well stakeholders can identify and articulate the ethical dilemma and its underlying conflict. Additionally, the reliance on subjective inputs, such as personal viewpoints, may result in the introduction of bias into the decision-making process, unless they are balanced by objective standards. The iterative process afforded by the holistic approach fosters accountability and continuous improvement, ensuring that decisions are not only made but also subjected to rigorous assessment for their impact. However, while this step is beneficial for reflection, it may prove challenging to fully anticipate or evaluate consequences in complex scenarios.

Overall, the framework is highly adaptable and promotes a dynamic approach to ethical decision-making. Its strength lies in its flexibility in accommodating various cultural contexts and in considering multiple perspectives before making a decision. However, its reliance on subjective factors could introduce inconsistencies if not managed carefully. Additionally, while it provides a structured approach, its effectiveness depends on how well users engage with each step of the process.

6. Future steps and validation

The next steps will be further verification and validation of the applicability of the proposed systematic framework. A preliminary validation of the framework is provided if tested against the body of knowledge gathered thus far. Indeed, no conflicting topics arise between the proposed framework and the ethical considerations identified by industry professionals in the survey, nor the insights collected from the literature review. However, the work done this far is insufficient to fully test the effectiveness of the framework's implementation.

6.1. Framework validation and refinement

A further validation process, based on expert interviews, has provided essential insights to improve the proposed ethical decision-making framework. Their insights have provided valuable feedback for refining and improving the framework. It was generally agreed that the framework addresses ethical decision-making effectively, particularly due to its clear structure and flexibility for various contexts. The strengths of the framework were highlighted, including its three-phase process and adaptability. However, several areas for improvement were identified. It was suggested that more detailed descriptions of each step should be provided to enhance user understanding. Additionally, it was recommended that the problem resolution phase be subdivided to improve clarity. The issue of responsibility within the framework was also raised, with a need for clarification on who would implement the steps. Further refinement was proposed by incorporating a stronger feedback loop from the evaluation phase to earlier stages, ensuring continuous improvement. The possibility of developing an interactive tool to support decision-making processes was also mentioned. These insights will be used to refine the framework, making it more robust and adaptable for practical application in manufacturing ethics.

6.2. Future directions

The proposed ethical decision-making framework aims to address the complexities of ethics within manufacturing systems. While still rudimentary, the framework is designed as a dynamic and evolving structure, aimed at helping companies and organizations navigate ethical dilemmas

effectively. A key aspect of this approach is its cyclic process of *adding value by receiving value*, ensuring that the framework continuously evolves based on user feedback and real-world applications. Companies can take advantage not only of the structured guidance the framework offers but also from its flexibility, which promotes the continuous alignment of ethical standards, offering a "moral compass" that adapts to changing contexts while preserving its foundational structure.

By adopting a research-by-design methodology, the framework priorities validation through real-world application, allowing for the collection of insights that improve and expand its effectiveness. It is not designed to provide definitive answers but instead offers a robust structure to guide decision-making, supporting organizations to find solutions related to specific context. The goal is to make the framework valuable even in its incomplete state, with the understanding that it will always improve through iterative use and refinement.

The framework and the process which led to its development also acknowledge that ethical decision-making is an ongoing journey rather than a fixed destination. As a matter of fact, the framework provides a tool rather than rigid routes, encouraging companies to adjust their course based on evolving challenges and priorities. This approach ensures that the framework remains useful, and adaptable, serving as a support for ethical decision-making in manufacturing as the industry continues to advance.

In manufacturing environments, the framework allows for conducting case studies to assess and verify its applicability. These studies can facilitate further testing versatility and applicability of the diagram in its current state, allowing for iteration and improvements. As case studies and surveys continue, the framework will be iteratively refined based on emerging insights, to expand its scope and applicability. It is also important to mention that although the value of the framework approach will become fully apparent following a period of rigorous testing, it already provides a structured approach for addressing ethical challenges in manufacturing. This makes it a viable tool for practical implementation in the context of manufacturing ethics.

7. Conclusions

The paper explores the critical need for integrating ethical considerations systematically into manufacturing systems. Through a comprehensive literature review, survey analysis, and the proposal of a novel conceptual framework, this study has addressed significant gaps in the current approach to ethics in manufacturing. The literature review revealed a growing recognition of ethical challenges in advanced manufacturing; however, it also highlighted the fragmented nature of existing approaches, which often focus on specific aspects or fields of application rather than providing a comprehensive framework. The CIRP Collaborative Working Group Ethics Survey conducted in February 2024 provided crucial insights into the current landscape of manufacturing ethics. While practitioners demonstrated awareness of ethical considerations, there was a notable discrepancy between theoretical knowledge and practical implementation. This finding underscored the need for a more systematic and comprehensive approach to address ethical decision-making in manufacturing contexts.

To address these shortcomings, the study proposed a dynamic ethical decision-making framework designed to assist stakeholders in resolving ethical dilemmas throughout the entirety of the manufacturing process. The framework's principal strengths are its holistic approach, and its capacity to accommodate a range of cultural contexts and manufacturing sectors. The proposed framework represents a significant step towards integrating ethics more effectively into manufacturing systems. By providing a structured yet adaptable approach, it aims to bridge the gap between ethical awareness and practical implementation, addressing the limitations identified in both the literature review and survey results. However, the effectiveness of this framework will ultimately depend on its practical application and further validation. Future steps include conducting case studies across various manufacturing sectors to test and refine the framework's applicability.

In conclusion, this research contributes to the field by offering a systematic approach to ethical decision-making in manufacturing that is both comprehensive and adaptable. As the manufacturing industry continues to evolve in response to technological advancements, such frameworks will become increasingly important in ensuring that ethical considerations are integrated seamlessly into all aspects of manufacturing processes. The proposed framework allows for research and implementation, creating opportunities for ethically conscious and responsible manufacturing practices in the era of Industry 4.0 and beyond.

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