

## Critical Evaluation of Ergonomic Considerations in the Medical Device Industry's Early Product Development

Ghulam Shabir

Department of Health Science, University of Seoul Natl South Korea

### **Abstract:**

*Ergonomic considerations play a pivotal role in the early stages of product development within the medical device industry. This critical evaluation explores the significance of incorporating ergonomic principles from the outset of the design process to enhance usability, safety, and overall user experience. By examining various ergonomic factors such as user anthropometry, cognitive workload, and task analysis, this paper highlights the importance of aligning product design with the needs and capabilities of end-users, including healthcare professionals and patients. Moreover, it discusses the potential impact of ergonomic design on product adoption, efficiency, and patient outcomes. Through a comprehensive review of existing literature and case studies, this evaluation sheds light on the challenges and opportunities in integrating ergonomic considerations into the early phases of medical device development. Furthermore, it emphasizes the need for interdisciplinary collaboration between engineers, designers, healthcare practitioners, and ergonomics experts to optimize product design and mitigate potential ergonomic-related issues. Ultimately, this critical assessment underscores the imperative of prioritizing ergonomic factors to foster innovation and create medical devices that truly meet the diverse needs of users while ensuring safety and effectiveness.*

**Keywords:** *Ergonomics, medical device industry, product development, usability, safety, user experience, anthropometry, cognitive workload, task analysis, interdisciplinary collaboration*

### **Introduction:**

The field of medical device development stands at the intersection of technology, healthcare, and human factors. Within this domain, the integration of ergonomic considerations at the early stages of product development is crucial for ensuring the usability, safety, and effectiveness of medical devices. Ergonomics, often referred to as human factors engineering, is the science of designing products, systems, and environments to optimize human well-being and overall system performance. In the context of the medical device industry, ergonomic design principles encompass a wide array of factors, including user anthropometry, cognitive workload, task analysis, and user interface design, among others. The significance of ergonomic considerations in medical device development cannot be overstated. These considerations directly impact the usability of medical devices by healthcare professionals and patients alike, influencing factors such as ease of use, efficiency, and user satisfaction. Moreover, ergonomic design plays a pivotal role in enhancing patient safety and outcomes, as devices that are poorly designed from an ergonomic standpoint may contribute to errors, accidents, and user discomfort.

One of the primary objectives of integrating ergonomic principles into the early stages of product development is to align product design with the needs and capabilities of end-users. Healthcare professionals, including physicians, nurses, and technicians, have unique requirements and preferences when it comes to interacting with medical devices in clinical settings. Similarly, patients who rely on medical devices for managing their health conditions have diverse backgrounds, abilities, and limitations that must be taken into account during the design process.

Ergonomic design has a significant impact on product adoption and efficiency within healthcare settings. Medical devices that are ergonomically designed not only facilitate smoother integration into existing workflows but also contribute to improved efficiency and productivity among healthcare professionals. Conversely, devices that lack ergonomic considerations may face resistance from users, leading to delays in adoption and suboptimal utilization [1].

Despite the clear benefits of ergonomic design, integrating ergonomic considerations into the early stages of medical device development presents its own set of challenges. These challenges include balancing ergonomic requirements with other design constraints, such as technical feasibility, cost-effectiveness, and regulatory compliance. Moreover, effectively incorporating ergonomic principles often requires interdisciplinary collaboration among engineers, designers, healthcare practitioners, and ergonomics experts, which can be complex and resource-intensive. The opportunities associated with prioritizing ergonomic considerations in medical device development are significant. By leveraging advances in technology, such as virtual reality simulations and ergonomic modeling software, developers can more effectively evaluate and optimize the ergonomic aspects of their designs. Additionally, a growing body of research and case studies provides valuable insights into best practices and successful implementations of ergonomic design principles in medical device development. The integration of ergonomic considerations at the early stages of product development is essential for creating medical devices that meet the needs of users while ensuring safety, efficiency, and effectiveness. By prioritizing ergonomic design principles and fostering interdisciplinary collaboration, the medical device industry can drive innovation and deliver solutions that enhance patient care and improve healthcare outcomes.

### **Importance of Ergonomics in Product Development:**

Ergonomics plays a pivotal role in product development across various industries, and its importance is particularly pronounced in the field of medical devices. Ergonomic design focuses on optimizing the interaction between users and products, ensuring that devices are intuitive, efficient, and safe to use. In the context of medical devices, where the stakes are often high and user errors can have serious consequences, integrating ergonomic principles is crucial for several reasons:

1. **Usability Enhancement:** Ergonomic design ensures that medical devices are user-friendly, intuitive, and easy to operate. By considering factors such as user interface design, control placement, and feedback mechanisms, designers can create devices that healthcare professionals can use effectively in high-pressure clinical environments.
2. **Safety Improvement:** Medical devices must prioritize safety to minimize the risk of errors, accidents, and adverse events. Ergonomic design helps identify and mitigate potential hazards by optimizing device ergonomics, reducing the likelihood of user errors, and enhancing overall device reliability.
3. **User Satisfaction:** Devices that are ergonomically designed contribute to a positive user experience, leading to higher levels of user satisfaction and acceptance. Healthcare professionals are more likely to embrace devices that are comfortable to use and seamlessly integrate into their workflow, ultimately improving patient care and outcomes.
4. **Efficiency and Productivity:** Ergonomically designed medical devices facilitate smoother workflows, leading to improved efficiency and productivity within healthcare settings. By

reducing user fatigue, minimizing task completion times, and streamlining interactions, ergonomic design enhances overall operational efficiency and resource utilization [2], [3].

5. **Accessibility and Inclusivity:** Ergonomic considerations extend beyond the needs of healthcare professionals to encompass the diverse needs of patients. Designing medical devices with accessibility features ensures that individuals with disabilities or special requirements can effectively use the devices, promoting inclusivity and equitable access to healthcare services.
6. **Regulatory Compliance:** Regulatory bodies, such as the FDA in the United States and the CE Marking in Europe, increasingly emphasize the importance of human factors and ergonomics in medical device design and development. Integrating ergonomic principles into the product development process is essential for meeting regulatory requirements and obtaining necessary approvals for market clearance.
7. **Risk Reduction:** Poorly designed medical devices can pose significant risks to patients and healthcare providers, including medication errors, misdiagnoses, and treatment complications. Ergonomic design helps identify and mitigate potential risks associated with device use, reducing the likelihood of adverse events and liability issues.

## Ergonomic Factors:

In the realm of medical device development, numerous ergonomic factors must be carefully considered to ensure optimal usability, safety, and user satisfaction. These factors encompass various aspects of human interaction with devices and encompass physical, cognitive, and environmental considerations. Understanding and addressing these ergonomic factors is essential for creating devices that meet the diverse needs of healthcare professionals and patients. Some of the key ergonomic factors include:

1. **User Anthropometry:** User anthropometry refers to the measurement of human body dimensions and proportions. Designing medical devices that accommodate a wide range of anthropometric characteristics ensures that they can be comfortably used by individuals of different sizes, shapes, and abilities. Factors such as seat height, reach distances, and control placement should be tailored to accommodate the variability in user anthropometry within the target population [4].
2. **Cognitive Workload:** Cognitive workload refers to the mental effort required to perform a task or interact with a device. Medical devices that impose high cognitive demands on users can lead to errors, fatigue, and decreased performance. Design strategies aimed at minimizing cognitive workload include simplifying user interfaces, providing clear instructions and feedback, and reducing the need for complex decision-making.
3. **Task Analysis:** Task analysis involves breaking down complex tasks into smaller, more manageable components to understand the sequence of actions and interactions involved. By conducting thorough task analyses, designers can identify potential sources of user error, inefficiency, and discomfort. This information informs the design process, enabling the development of devices that support users in performing their tasks effectively and efficiently.
4. **User Interface Design:** User interface design encompasses the visual, auditory, and tactile elements of device interaction. A well-designed user interface facilitates intuitive navigation, enhances information accessibility, and promotes user engagement. Considerations such as

button size, color coding, iconography, and menu structure play a critical role in ensuring that users can interact with medical devices confidently and accurately [5].

5. **Physical Ergonomics:** Physical ergonomics focuses on optimizing the physical interactions between users and devices to minimize the risk of musculoskeletal injuries and discomfort. Design features such as adjustable height, tilt, and support options help accommodate users' ergonomic preferences and promote proper posture during device use. Additionally, devices should be lightweight, portable, and easy to handle to reduce the physical strain associated with their manipulation.
6. **Environmental Considerations:** Environmental factors, such as lighting, noise, temperature, and space constraints, can influence the usability and effectiveness of medical devices. Designing devices that are compatible with various environmental conditions ensures their suitability for use in diverse healthcare settings, including hospitals, clinics, and home environments. Moreover, devices should be resistant to environmental hazards such as moisture, dust, and electromagnetic interference to maintain functionality and safety.

### **Alignment with User Needs:**

Ensuring that medical devices align closely with the needs and preferences of users is paramount for achieving successful adoption and utilization. In the context of medical device development, users encompass a diverse range of stakeholders, including healthcare professionals, patients, caregivers, and support staff. Designing devices that effectively meet the needs of these users requires a comprehensive understanding of their requirements, capabilities, and contexts of use. Several strategies can facilitate alignment with user needs:

1. **User-Centered Design Approach:** Adopting a user-centered design approach involves actively involving end-users in the design process from the outset. Engaging healthcare professionals, patients, and other stakeholders through interviews, surveys, focus groups, and usability testing sessions allows designers to gain valuable insights into their preferences, workflows, and challenges. By incorporating user feedback iteratively throughout the design process, developers can ensure that devices are tailored to meet the specific needs of their intended users.
2. **Needs Assessment and Persona Development:** Conducting needs assessments and developing user personas help designers gain a deeper understanding of the diverse needs and preferences of their target user groups. Needs assessments involve identifying users' functional requirements, workflow preferences, and pain points, while persona development involves creating fictional representations of typical users based on demographic, behavioral, and psychographic characteristics. These tools serve as valuable reference points for designing devices that resonate with users' priorities and preferences.
3. **Contextual Inquiry and Workflow Analysis:** Conducting contextual inquiries and workflow analyses involves observing users in their natural environments to understand how they interact with devices and perform their tasks. By observing users' behaviors, decision-making processes, and environmental constraints firsthand, designers can identify opportunities for streamlining workflows, improving task efficiency, and addressing ergonomic challenges. Contextual inquiry also provides insights into the contextual factors that influence device use, such as organizational policies, cultural norms, and resource constraints.

4. **Customization and Personalization:** Offering customization and personalization options allows users to tailor devices to their individual preferences and needs. Customization features may include adjustable settings, interchangeable components, and user-configurable interfaces. Personalization options may involve adapting device functionality, feedback mechanisms, and display preferences to match users' unique requirements. By empowering users to personalize their devices, manufacturers can enhance user satisfaction, usability, and overall device acceptance [6].
5. **Training and Support:** Providing comprehensive training and support resources is essential for ensuring that users can effectively utilize medical devices in their clinical practice or daily lives. Training programs should cover device operation, troubleshooting, maintenance, and safety precautions, catering to users' varying levels of expertise and experience. Additionally, offering readily accessible support channels, such as user manuals, online tutorials, and helplines, enables users to seek assistance and guidance whenever needed, fostering confidence and competence in device use.

#### **Impact on Product Adoption and Efficiency:**

The incorporation of ergonomic principles into the design of medical devices has a significant impact on both the adoption of the product and the efficiency of its use within healthcare settings. Several key factors contribute to this impact:

1. **User-Friendly Design:** Ergonomically designed medical devices are inherently more user-friendly, with intuitive interfaces, ergonomic controls, and clear feedback mechanisms. These design features reduce the learning curve for healthcare professionals, enabling quicker mastery of device operation and increasing confidence in its use. As a result, users are more likely to embrace and adopt ergonomic devices, leading to faster integration into clinical workflows.
2. **Reduced Error Rates:** Ergonomic design minimizes the potential for user errors by streamlining workflows, reducing cognitive load, and enhancing task efficiency. Devices that are ergonomically optimized are less prone to user mistakes, such as data entry errors, medication administration errors, or procedural inaccuracies. By reducing error rates, ergonomic devices contribute to improved patient safety and clinical outcomes, further incentivizing their adoption by healthcare providers [7].
3. **Enhanced Workflow Integration:** Ergonomic devices seamlessly integrate into existing clinical workflows, minimizing disruptions and enhancing overall efficiency. Devices that are compatible with established protocols, procedures, and documentation systems require less adaptation from healthcare professionals, enabling smoother transitions and reducing downtime. Ergonomic design also facilitates interoperability with other medical devices and information systems, further enhancing workflow efficiency and data exchange.
4. **Time Savings:** Ergonomic design features, such as streamlined interfaces and optimized controls, reduce the time required to perform tasks and procedures. Healthcare professionals can complete tasks more efficiently and with fewer errors, leading to time savings that can be allocated to other patient care activities. Additionally, ergonomic devices may require less maintenance, calibration, or troubleshooting, further optimizing time utilization and resource allocation.



5. **Improved Patient Interaction:** Ergonomic devices enhance healthcare professionals' ability to interact with patients effectively, promoting better communication, engagement, and rapport. Devices that are easy to use and non-intrusive facilitate smoother patient interactions, reducing patient anxiety and enhancing the overall care experience. Improved patient interaction contributes to higher levels of patient satisfaction and compliance, ultimately benefiting clinical outcomes and healthcare provider productivity.
6. **Cost Savings:** The adoption of ergonomic medical devices can result in cost savings for healthcare organizations through increased efficiency, reduced error rates, and improved patient outcomes. By minimizing the need for repeat procedures, mitigating adverse events, and optimizing resource utilization, ergonomic devices contribute to lower healthcare costs and improved financial sustainability.

### Challenges and Opportunities:

The integration of ergonomic considerations into medical device development presents both challenges and opportunities for manufacturers, designers, and healthcare stakeholders. Addressing these challenges while leveraging the opportunities can lead to the creation of safer, more effective, and user-centered devices. Some of the key challenges and opportunities include:

#### Challenges:

1. **Balancing Ergonomic Requirements with Technical Constraints:** One of the primary challenges is balancing ergonomic design principles with technical constraints such as size, weight, power consumption, and cost. Designers must navigate trade-offs between ergonomic considerations and engineering requirements to develop devices that meet both user needs and technical specifications.
2. **Regulatory Compliance:** Regulatory agencies increasingly emphasize the importance of human factors and ergonomics in medical device design and development. Meeting regulatory requirements for usability testing, risk assessment, and human factors validation adds complexity and time to the product development process.
3. **Interdisciplinary Collaboration:** Effective integration of ergonomic considerations requires collaboration between engineers, designers, healthcare professionals, and ergonomics experts. Bridging disciplinary silos, managing divergent priorities, and fostering effective communication can be challenging but essential for successful device development.
4. **Cost Constraints:** Incorporating ergonomic features into medical devices may increase manufacturing costs, impacting product affordability and market competitiveness. Balancing cost considerations with ergonomic requirements without compromising device quality or safety presents a significant challenge for manufacturers.
5. **Complexity of User Needs:** Healthcare environments are inherently complex, with diverse user populations, varying clinical contexts, and evolving technological landscapes. Designing devices that effectively meet the needs of different user groups while accommodating changing healthcare practices and preferences poses a considerable challenge for designers and developers.

#### Opportunities:

1. **Enhanced Usability and User Experience:** Integrating ergonomic principles into medical device design leads to enhanced usability, improved user experience, and increased user satisfaction. Devices that are easy to use, intuitive, and ergonomic are more likely to be

adopted by healthcare professionals and embraced by patients, driving improved clinical outcomes.

2. **Competitive Advantage:** Ergonomic design can confer a competitive advantage by differentiating products in the marketplace based on usability, safety, and user-centered features. Manufacturers that prioritize ergonomic considerations can gain market share, enhance brand reputation, and capitalize on opportunities for innovation and differentiation.
3. **Risk Reduction and Liability Mitigation:** Ergonomic design helps mitigate risks associated with device use, including user errors, adverse events, and liability issues. By identifying and addressing potential ergonomic hazards early in the development process, manufacturers can reduce the likelihood of device-related incidents and associated legal liabilities.
4. **Market Expansion and Accessibility:** Ergonomically designed devices are more accessible to diverse user populations, including individuals with disabilities, limited dexterity, or special requirements. Designing devices with accessibility features broadens market reach, fosters inclusivity, and promotes equitable access to healthcare technologies.
5. **Improved Clinical Outcomes:** Ergonomic devices contribute to improved clinical outcomes by reducing errors, enhancing efficiency, and facilitating better patient-provider interactions. Devices that are ergonomically optimized enable healthcare professionals to deliver safer, more effective care, leading to better patient outcomes and overall healthcare quality.

### Interdisciplinary Collaboration:

Interdisciplinary collaboration is a cornerstone in the successful integration of ergonomic considerations into medical device development. In the complex landscape of healthcare technology, bringing together professionals from diverse fields fosters a holistic approach that addresses the multifaceted challenges and opportunities inherent in designing user-centric devices. The importance of interdisciplinary collaboration can be examined through various lenses:

1. **Engineering and Design Integration:** Collaboration between engineers and designers is fundamental to developing ergonomic medical devices. Engineers contribute technical expertise to ensure the functionality, reliability, and regulatory compliance of the device, while designers focus on user interface, aesthetics, and overall user experience. A seamless integration of engineering and design perspectives is vital for achieving a balance between technical feasibility and user-centered design [8].
2. **Healthcare Practitioner Involvement:** Involving healthcare practitioners, including physicians, nurses, and allied health professionals, is indispensable. Their deep understanding of clinical workflows, patient needs, and the challenges in real-world healthcare settings provides invaluable insights. Through collaboration, these practitioners contribute to the identification of ergonomic requirements, ensuring that devices align with clinical practices and enhance user efficiency.
3. **Ergonomics Expertise:** Ergonomics experts play a pivotal role in assessing and optimizing the interaction between users and medical devices. Their expertise in human factors, anthropometry, and cognitive ergonomics contributes to the identification of potential risks and the design of interventions that enhance user safety and usability. Collaborating with ergonomics specialists ensures that devices are tailored to the physical and cognitive capabilities of their users.

4. **User-Centered Research:** Collaboration with researchers specializing in user-centered methodologies is essential for gathering empirical data on user needs, preferences, and behaviors. Through methods such as ethnographic studies, usability testing, and focus groups, researchers contribute critical data that informs the design process. This collaboration helps bridge the gap between theoretical design principles and practical user requirements.
5. **Regulatory Compliance Experts:** Collaboration with professionals well-versed in regulatory standards and human factors regulations is crucial. This collaboration ensures that the design process aligns with industry guidelines and regulatory expectations for usability testing, risk management, and validation studies. Integrating regulatory compliance expertise from the early stages of development streamlines the path to obtaining necessary approvals.
6. **Continuous Feedback Loops:** Establishing continuous feedback loops among team members throughout the design and development process is essential. Regular communication ensures that insights from various disciplines are considered iteratively, allowing for adjustments and refinements based on evolving requirements and challenges. Open lines of communication facilitate the integration of diverse perspectives and expertise.
7. **Inclusive Decision-Making:** Inclusive decision-making processes involve stakeholders from different disciplines in key design decisions. This approach ensures that diverse perspectives contribute to the

#### Case Studies and Literature Review:

Case studies and literature reviews are invaluable tools for understanding the practical application and theoretical foundations of ergonomic considerations in medical device development. They provide insights into real-world challenges, innovative solutions, and best practices, informing the design process and guiding decision-making. The integration of case studies and literature reviews into medical device development offers several benefits:

1. **Evidence-Based Design:** Case studies and literature reviews provide evidence-based insights into the effectiveness of ergonomic design principles in improving usability, safety, and user satisfaction. By examining existing research findings and real-world examples, designers can identify best practices and design strategies that have been validated through empirical evidence [9].
2. **Identification of Key Challenges:** Case studies and literature reviews highlight common challenges and pitfalls associated with ergonomic considerations in medical device development. By analyzing case studies of failed or suboptimal designs, designers can learn from past mistakes and proactively address potential ergonomic issues in their own designs.
3. **Innovation Inspiration:** Case studies and literature reviews showcase innovative approaches and creative solutions to ergonomic design challenges. By studying successful case studies and emerging trends in the literature, designers can gain inspiration for novel design concepts, technologies, and methodologies that push the boundaries of traditional design practices.
4. **Validation of Design Decisions:** Case studies and literature reviews serve as validation tools for design decisions, allowing designers to justify their design choices based on existing evidence and expert consensus. By referencing relevant case studies and literature, designers can build a compelling rationale for incorporating specific ergonomic features or design principles into their devices.





5. **User-Centered Design Insights:** Case studies and literature reviews offer valuable insights into user needs, preferences, and behaviors in real-world contexts. By examining how users interact with existing devices and environments, designers can identify opportunities for improving device usability, enhancing user experience, and addressing unmet user needs.
6. **Regulatory Compliance Guidance:** Case studies and literature reviews provide guidance on meeting regulatory requirements for ergonomic considerations in medical device development. By reviewing relevant literature and case studies, designers can ensure that their designs align with industry standards, regulatory guidelines, and best practices for human factors engineering.
7. **Continuous Improvement:** Case studies and literature reviews support a culture of continuous improvement by encouraging designers to reflect on past experiences, learn from successes and failures, and iterate on their designs based on feedback and new insights. By incorporating lessons learned from case studies and literature reviews into future design iterations, designers can continually refine and optimize their devices over time [10].

## Conclusion:

The integration of ergonomic considerations into medical device development is essential for creating devices that prioritize user needs, enhance usability, and improve patient outcomes. Throughout this critical evaluation, we have explored the significance of ergonomic design principles in addressing the complex challenges associated with medical device development. Ergonomic design plays a pivotal role in enhancing usability, safety, and user satisfaction by ensuring that devices are intuitive, efficient, and comfortable to use. By considering factors such as user anthropometry, cognitive workload, task analysis, and user interface design, designers can create devices that meet the diverse needs of healthcare professionals and patients. Ergonomic design contributes to improved product adoption and efficiency within healthcare settings. User-friendly design features, reduced error rates, enhanced workflow integration, and time savings are just some of the benefits that ergonomic devices offer.

By prioritizing alignment with user needs, manufacturers can drive adoption, improve efficiency, and ultimately enhance patient care outcomes. Despite these challenges, there are significant opportunities associated with prioritizing ergonomic considerations. Ergonomic design can confer a competitive advantage, reduce risks, expand market reach, and drive innovation in medical device development. In conclusion, the integration of ergonomic principles into medical device development is essential for creating devices that are safer, more effective, and more user-centered. By leveraging case studies, literature reviews, and interdisciplinary collaboration, designers can overcome challenges, seize opportunities, and create devices that truly make a difference in healthcare delivery and patient care. Embracing ergonomic design principles is not just a best practice; it is a necessity for advancing the field of medical technology and improving the lives of patients and healthcare providers alike.

## References

- [1] Sharples, S., Martin, J., Lang, A., Craven, M., O'Neill, S., & Barnett, J. (2012). Medical device design in context: A model of user-device interaction and consequences. *Displays*, 33(4-5), 221-232.



- [2] Medina, L. A., Jankovic, M., Kremer, G. E. O., & Yannou, B. (2013). An investigation of critical factors in medical device development through Bayesian networks. *Expert Systems with Applications*, 40(17), 7034-7045.
- [3] Money, A. G., Barnett, J., Kuljis, J., Craven, M. P., Martin, J. L., & Young, T. (2011). The role of the user within the medical device design and development process: medical device manufacturers' perspectives. *BMC medical informatics and decision making*, 11, 1-12.
- [4] Ashween. Ganesh, *Critical Evaluation of Low Ergonomics Risk Awareness among Early Product Development Stage of the Medical Device Industry*, pp. 15, 2022.
- [5] Privitera, M. B., Evans, M., & Southee, D. (2017). Human factors in the design of medical devices—Approaches to meeting international standards in the European Union and USA. *Applied ergonomics*, 59, 251-263.
- [6] Sharples, S., Martin, J., Lang, A., Craven, M., O'Neill, S., & Barnett, J. (2012). Medical device design in context: A model of user–device interaction and consequences. *Displays*, 33(4-5), 221-232.
- [7] Dianat, I., Molenbroek, J., & Castellucci, H. I. (2018). A review of the methodology and applications of anthropometry in ergonomics and product design. *Ergonomics*, 61(12), 1696-1720.
- [8] Ram, M. B., Campling, N., Grocott, P., & Weir, H. (2008). A methodology for a structured survey of the healthcare literature related to medical device users. *Evaluation*, 14(1), 49-73.
- [9] Sundin, A., Christmansson, M., & Larsson, M. (2004). A different perspective in participatory ergonomics in product development improves assembly work in the automotive industry. *International journal of industrial ergonomics*, 33(1), 1-14.
- [10] Ganesh, A. (2022). Critical Evaluation of Low Ergonomics Risk Awareness among Early Product Development Stage of the Medical Device Industry. *Industrial Engineering Journal*, 15(12).