Fraunhofer IPA

KI Fortschrittszentrum LERNENDE SYSTEME UND KOGNITIVE ROBOTIK

Robot Safety in Industry 4.0 – Trends, Challenges and Future Opportunities

Executive Summary

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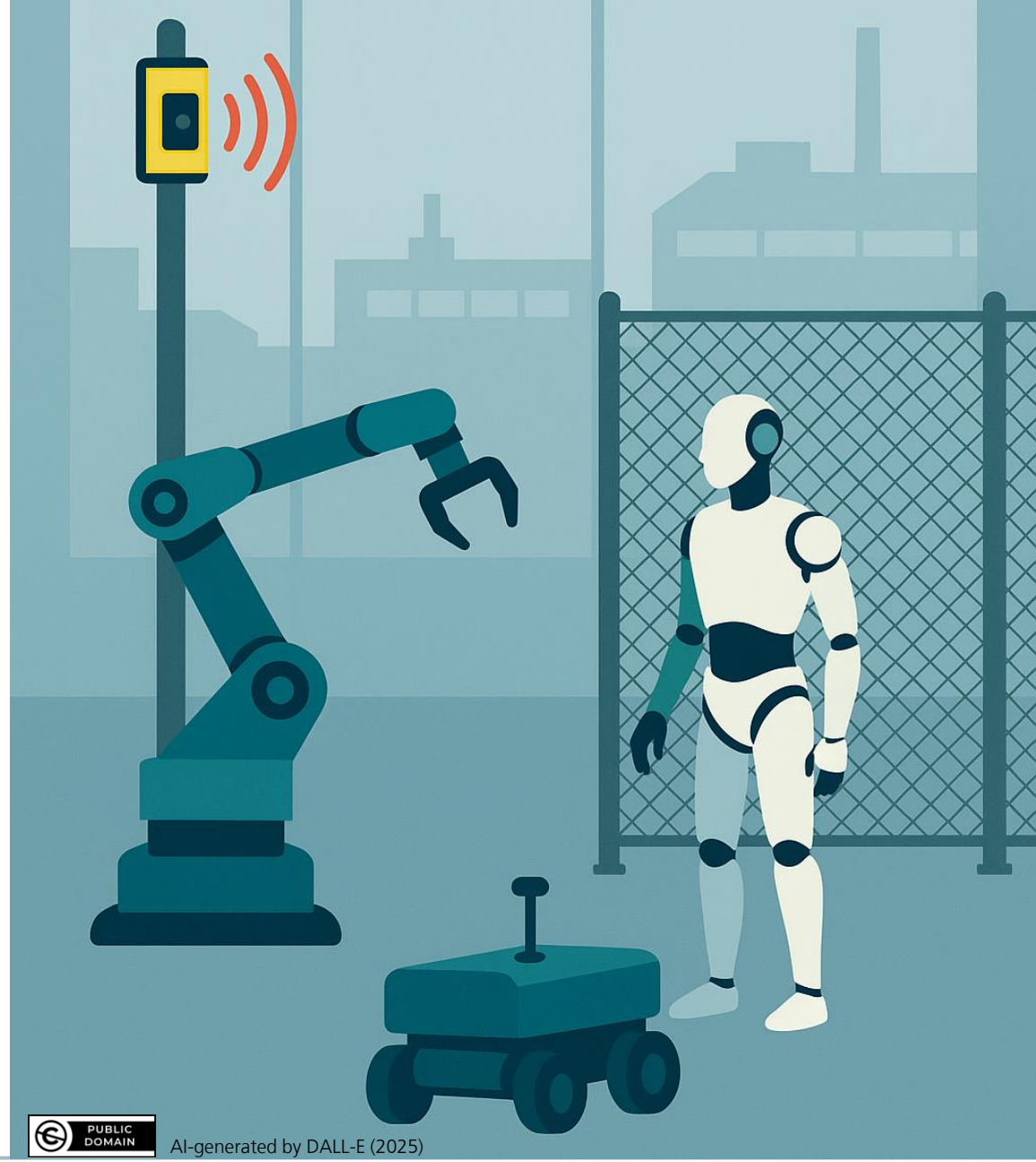
Introduction

As Industry 4.0 brings robots out from behind their fences to work alongside humans, the nature of industrial safety is fundamentally changing. Are today's safety measures and tools adequate for this new era of cognitive, AI-driven, and even humanoid robotics?

To answer this question, this study aims to identify the key safety challenges and opportunities presented by these emerging technologies. We did this by surveying and interviewing 203 industry experts across Europe in winter 2024, including end-users, system integrators, and robot manufacturers.

Here are the key takeaways.



AI-generated by DALL-E (2025)

Introduction
Technologies Surveyed

Fraunhofer IPA/Photo: Rainer Bez

Stationary Cobots

Stationary Cobots are collaborative robots* fixed in one location, designed to work alongside humans in a shared workspace.

Fraunhofer IPA/Photo: Rainer Bez

Mobile manipulators

Mobile Manipulators are cobots integrated on a mobile base, allowing them to move and execute tasks across different locations.

Fraunhofer IPA/Photo: Aulon Bajrami

Humanoids

Humanoids are robots designed to mimic human form and movement, capable of performing tasks in environments built for humans.

*Collaborative robots definition: Industrial robots that are designed and intended for collaborative use, in compliance with ISO 10218-2

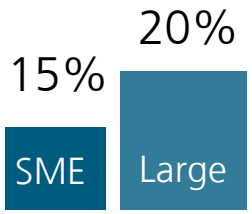
Key findings

91%

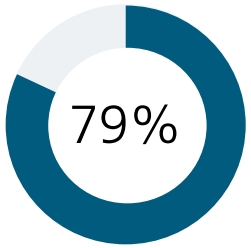
of participants already realized robotic technologies beyond traditional industrial robots

#1

Safety is the number one concern for deploying robotic technologies.



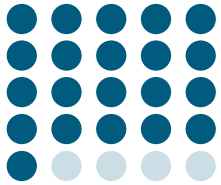
of the engineering costs for robotic applications are incurred from safety compliance, mainly for the risk assessment and risk reduction.



of participants find the need for a tool that guides the risk assessment process.

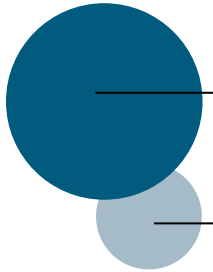
53%

of participants find current safety technologies inadequate for risk reduction of fenceless robotic technologies, citing poor economic feasibility, limited situational awareness and difficulties in handling parts/tool.



87%

of participants are unsure how to safely deploy humanoids or see additional safety challenges.



59%

of participants recognize the use of AI in predictive maintenance as beneficial for enhancing safety.

22%

of participants find AI-enabled technology useful for situational awareness.

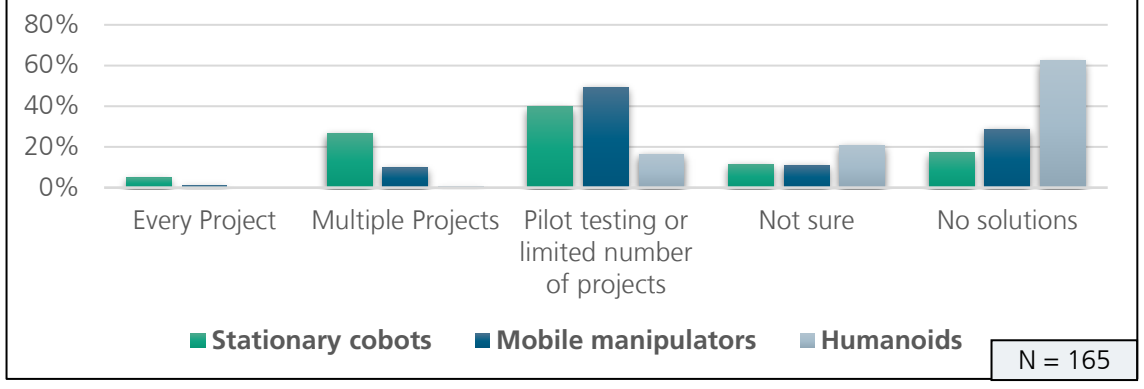
1. The Shift to Fenceless Robotics is Accelerating

The shift towards fenceless robotics is gaining momentum, with 71% participants (combined every project, multiple projects and pilot testing) already deploying stationary cobots, as illustrated in the bar chart. For mobile manipulators nearly 50% have initiated pilot testing. An industry-wise breakdown reveals that over 75% of respondents across all sectors recognize high potential in both stationary cobots and mobile manipulators.

90% of Small and Medium Enterprise (SME) participants find high potential in mobile manipulators, with 65% already pilot testing them. On the other hand, more than 70% of participants from large manufacturing companies are already pilot testing mobile manipulator in their facilities.

Investment in humanoids remains cautious, with respondents mostly from aerospace and logistics seeing high potential in the technology.

How likely is your facility to invest in fenceless robotics within the next 2 years?



N = 165

75%

of participants from each industry sector see high potential in stationary cobots and mobile manipulators for increasing productivity, while only 35% see the same in humanoids.

N = 165

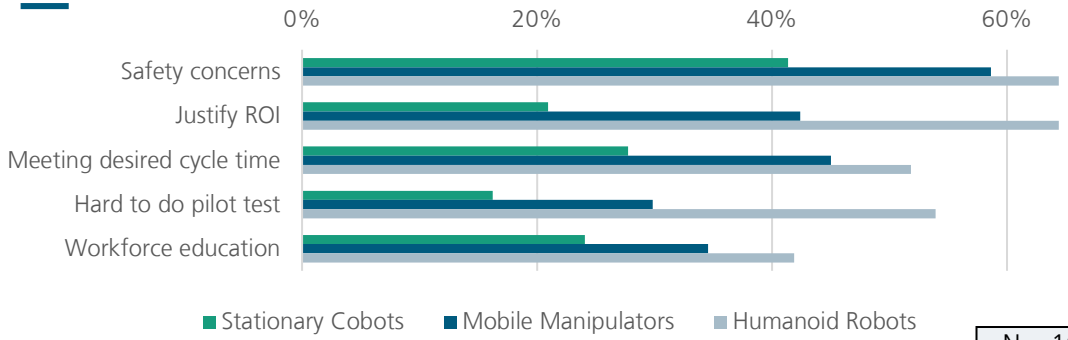
2. Safety is a Top Concern

Despite the increasing adoption of robotic technologies, safety is still seen as the primary concern across all robot types with more than 41% of participants highlighting the concern as shown in the bar chart.

Beyond safety concerns, other key challenges cited by experts include operational and economic barriers like meeting the key performance indicators (KPIs) and justifying the return-on-invest (ROI)—most notably for humanoids.

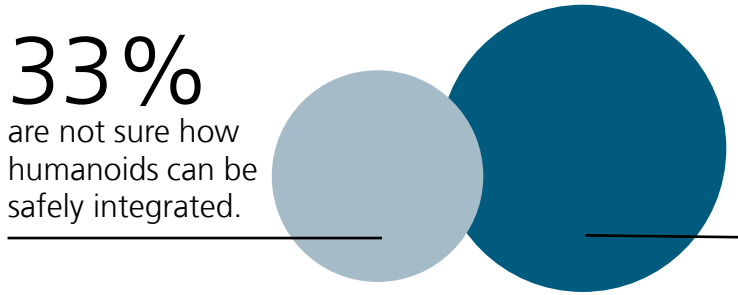
For mobile manipulators, over 36% of participants cite two major adoption barriers: deploying the application and adapting the existing industrial environment.

What challenges do you expect when utilizing robotic technologies in your facility?



N = 165

Can humanoids be used safely in your facility?*



*13% of the participants mentioned that humanoids can be safely integrated without additional challenges

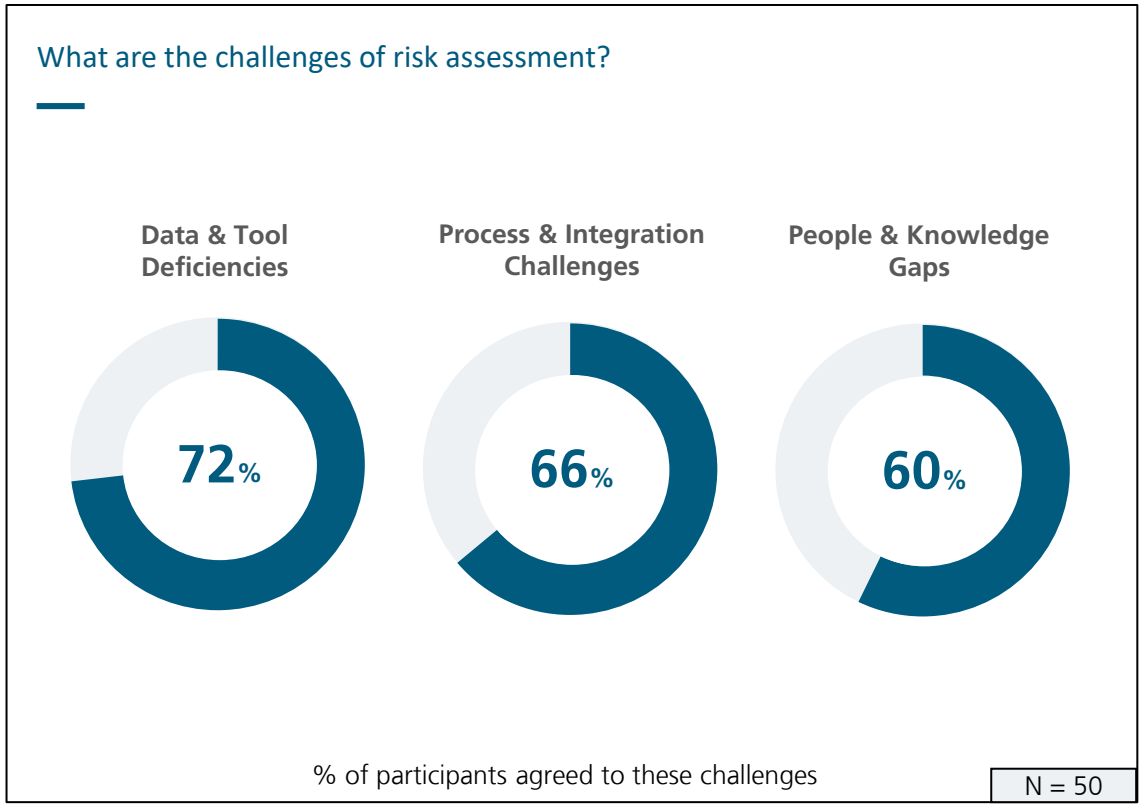
N = 97

3. Risk Assessment is a critical Bottleneck

In order to deploy industrial robotic applications in the European Union (EU), a safety compliance process is required to meet regulatory standards. Interviewed experts report that safety compliance for fenceless applications in large companies can account for over 20% of the engineering effort, largely due to the risk assessment and risk reduction phases.

The survey reveals key challenges in risk assessment. Data and tool deficiencies (72%) lead, driven by lack of tools, limited data, and difficulty keeping up with safety standards. Process and integration challenges (66%) show struggles in balancing safety with performance goals. People and knowledge gaps (60%) reflect a shortage of experts and high hiring costs. These issues highlight the need for better tools that streamline the processes and also embed expert-level safety knowledge.

Under the risk reduction, more than 40% of the participants reported using laser scanners, light curtains, robot's axes and space limitation safety measures. On the other hand, less than 5% mention the usage of robot skin and ultra-sonic sensors.



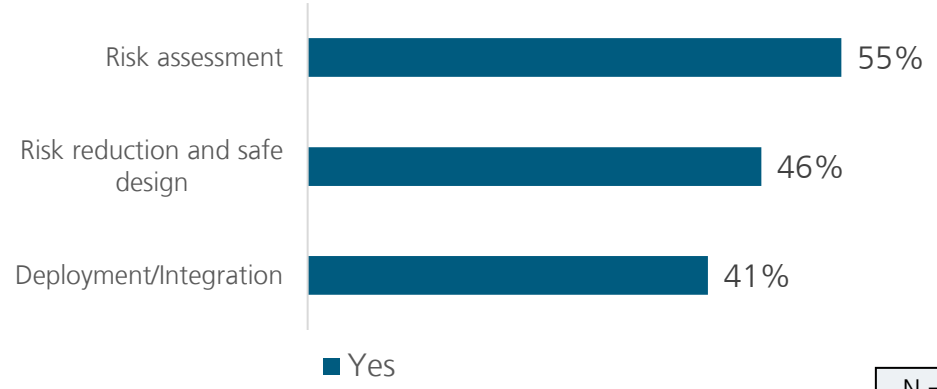
4. Demand for Smarter Safety Tools

More than 72% of participants identify the need for smart tools to accelerate the safety compliance process. Requested features include accurate force and pressure estimation during the application design phase (83%), automatic safety measure configuration (81%), guided support for risk assessment (79%), accurate estimation of RoI (76%), and automatic hazards identification from 3D models (73%).

Additionally, interviewed experts identify the need for pragmatic approaches focusing on likely human behaviors rather than theoretical scenarios.

Accordingly, as shown in the bar chart, over half of the respondents (55%) believe smart tools can significantly reduce engineering effort in risk assessment. 46% see similar benefits in risk reduction and safe design, while 41% expect improvements during deployment and integration. This highlights the growing trust in smart tools to streamline safety compliance, especially in early project phases.

Can Smart tools reduce the engineering effort of safety compliance process by half?



N = 110

79%

of participants find the need for a tool that guides the risk assessment process.

N = 95

5. AI: Enabling Next-Gen Safety

A majority of participants (53%) who has experience with risk assessment find current safety technologies inadequate for risk reduction of fenceless robotic technologies, with 83% unsure how to deploy humanoids safely. This technology gap is driven by poor economic feasibility, limited situational awareness and difficulties in handling parts/tool. To overcome these limitations, over half of the experts are pointing to AI-enabled safety systems as the key solution.

The bar chart indicates strong confidence in the potential of AI to enhance safety in industrial settings. 59% of respondents identify high potential in using AI for predictive maintenance and real-time risk alerts, signalling a clear industry demand for more intelligent and adaptive safety systems.

On the other hand, 31% of the participants view AI-enabled wearable trackers as ineffective for preventing fatigue-related accidents.

From the free-text responses, more than one in five experts (22%) highlighted the need for AI-enabled sensors that can distinguish people from objects.

N = 64

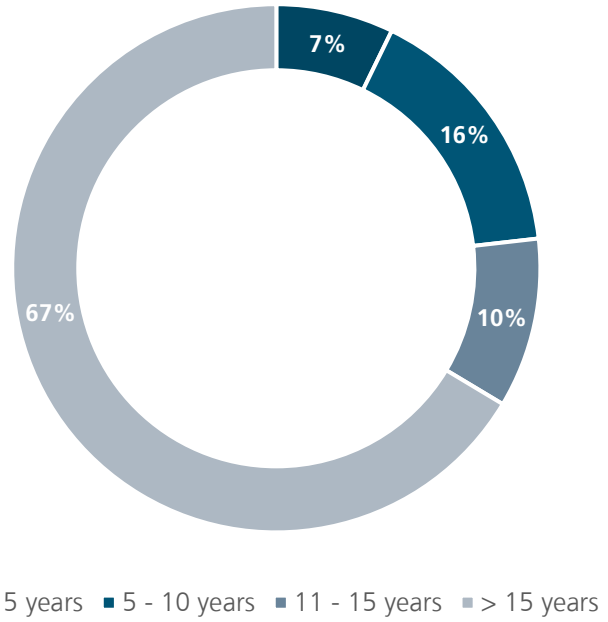
Conclusion

1 Technology Trend	The shift to fenceless robotics is accelerating, with participants actively deploying stationary cobots and pilot testing mobile manipulators. Investment in humanoids remains cautious, though some see high potential in specific sectors like aerospace and logistics.
2 Safety is a Top Concern	Safety concerns have been identified as the primary challenge in the implementation of fenceless robotic technologies. Additionally, difficulties in achieving key performance indicators (KPIs) and bridging technology adoption gaps are recognized as significant barriers.
3 Challenges in Risk Assessment	Risk assessments are challenged by time-consuming processes, lack of qualified personnel, and high expert costs. Participants also report limited tool support and design issues that hinder meeting key KPIs like cycle time, cost, and factory space usage.
4 Demand for Smarter Safety Tools	There is strong demand for smart tools to speed up risk assessments. Many participants agreed that features like guided support, automation, and accurate estimations can cut assessment time by half. Safety experts also emphasized need for more pragmatic approaches over theoretical scenarios.
5 Future Technology	There is a need to more advanced safety measures that can precisely identify, locate, and differentiate humans from objects. AI is emerging as the key enabler for these capabilities, while also enhancing safety through predictive maintenance, and real-time risk alerts. Furthermore, the safe integration of humanoids highlights the need for advanced safety strategies and clearer implementation frameworks.

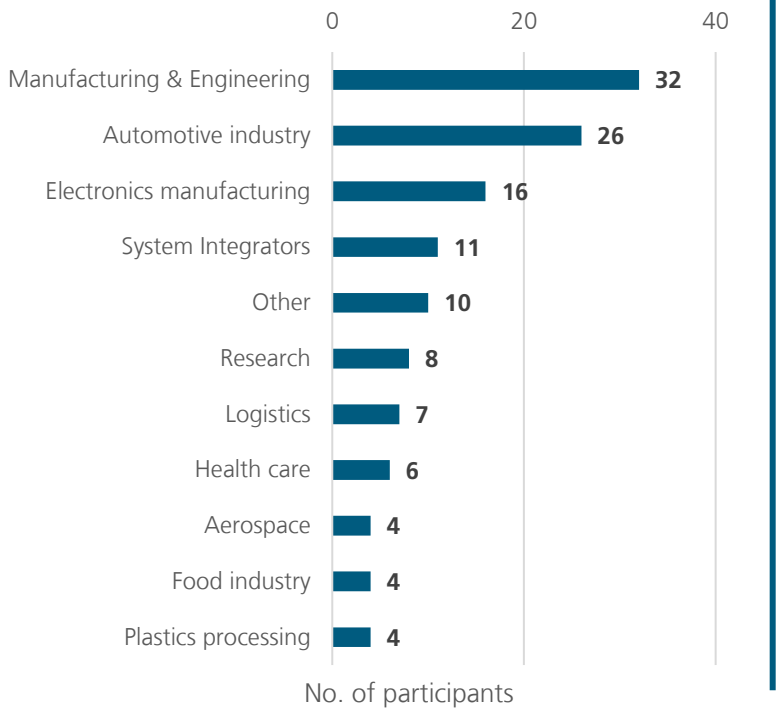
Methodology: Survey Demographics

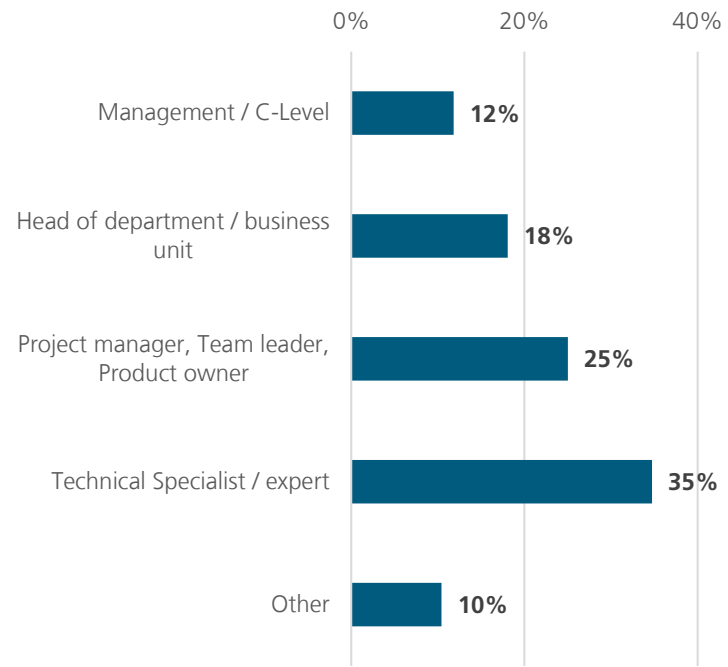
Total number of participants: 203

Experienced survey participants



Which industries survey participants belong to? What are their positions?



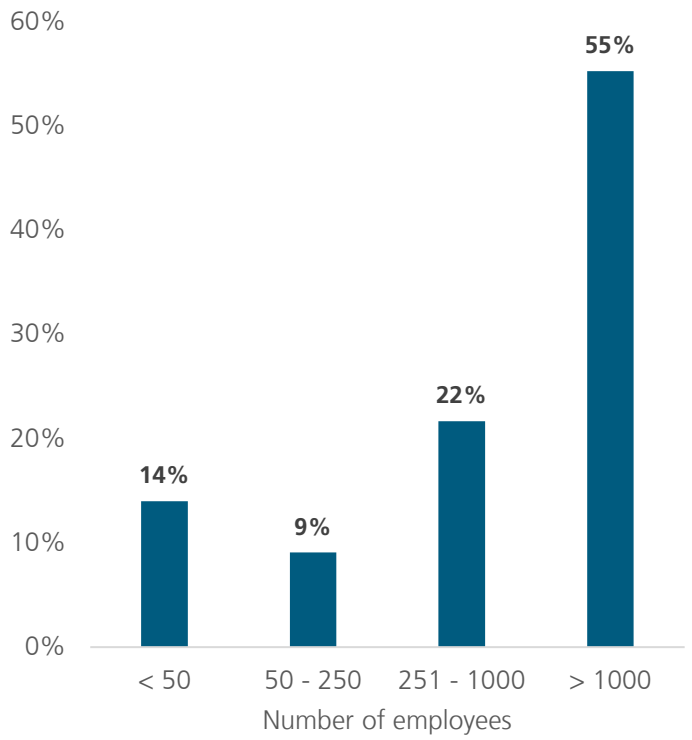


*Respondents who disclosed their organizational affiliation

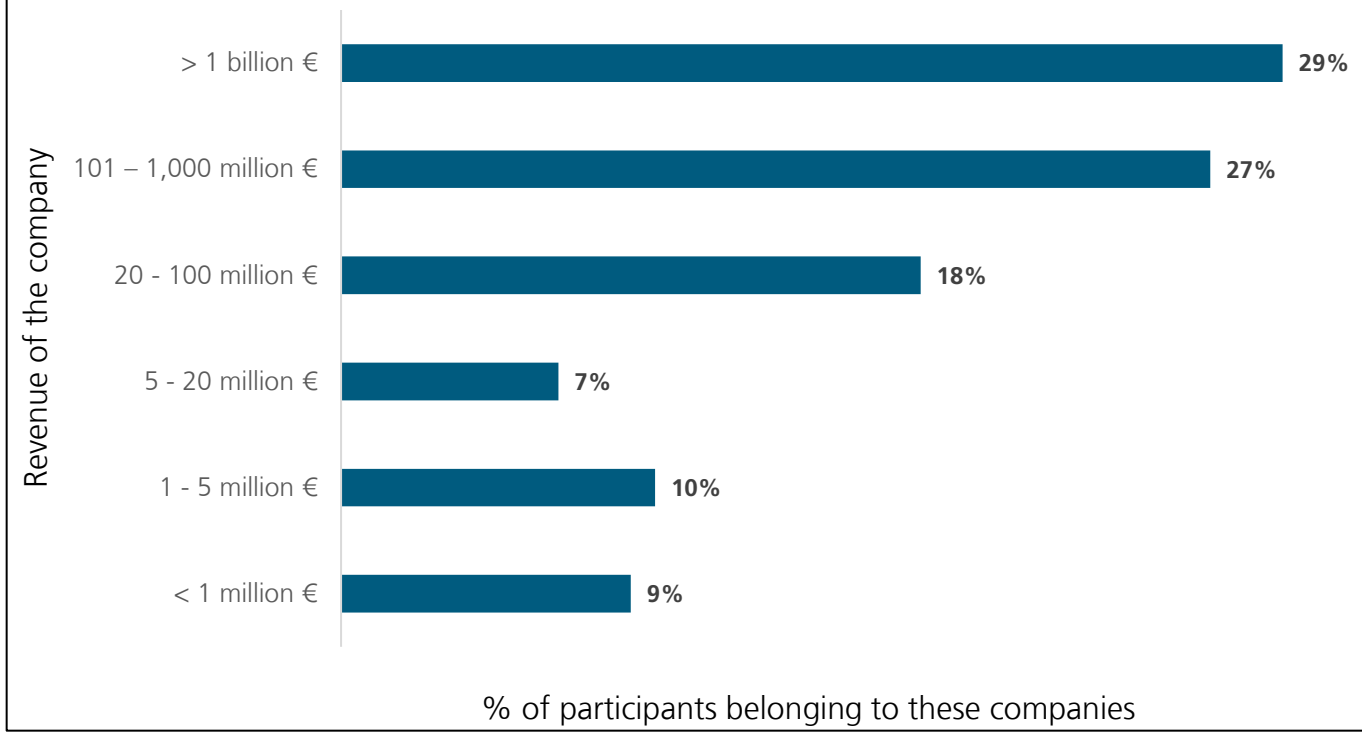
Methodology: Survey Demographics

Participants from diverse company sizes and revenues

Distribution by Company Size



Distribution by Company Revenue



Contact

M.Sc. Mohamed El-Shamouty

M.Sc. Mrunal Sompura

Robot Safety and Cobots
robo-safety-assist@ipa.fraunhofer.de

Fraunhofer IPA
Nobelstraße 12
70569 Stuttgart
Germany
www.ipa.fraunhofer.de

Fraunhofer IPA

Fraunhofer-Institut für Produktions-
technik und Automatisierung IPA

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Prof. Dr.-Ing. Thomas Bauernhansl. Prof. Dr.-Ing. Marco Huber, Dr.-Ing Werner Kraus

Autoren
Mohamed El-Shamouty, Mrunal Sompura, Aulon Bajrami, Theo Jacobs

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Kontaktadresse
Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA
Nobelstraße 12, 70569 Stuttgart
Telefon +49 711 970-3874
presse@ipa.fraunhofer.de
https://www.ipa.fraunhofer.de

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