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Application of Scenario Technique Analysis for Anticipating Future Impacts of Service Robots

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ABSTRACT: This paper explores the employment implications of integrating service robots in waste management. Using the scenario technique method, 14 critical influencing factors were identified and analyzed to develop a Best-Case, Worst-Case, and Trend scenario. A SWOT analysis was used to identify implications and develop measures. The findings indicate that service robots can enhance working conditions and enable service expansion but pose risks like job displacement without proper education and reskilling. The study underscores the need for regulatory frameworks, workforce adaptation, and education to ensure socially sustainable robotic integration.

KEYWORDS: Social responsibility, Early design phases, Uncertainty, Scenario technique, Service Robots

1. Introduction

Service robots (SR) are increasingly prominent due to labor shortages, cost efficiency, and demand for task automation (Müller et al., 2022). Advances in autonomy, sensors, and AI drive their versatility across various sectors, handling tasks from repetitive to complex. The rise in sales and research highlights the global interest in robotics for daily use (Statista Market Insights, 2024). As defined by ISO 8373, SR serve personal or professional purposes outside traditional industrial automation, directly or indirectly assisting humans (International Organization for Standardization, 2021). In personal settings, SR perform tasks such as domestic cleaning, personal care, and social interaction. Professionally, SR support industries like logistics, healthcare, agriculture, hospitality, and public safety (Müller et al., 2022). While professional SR potentially improve job quality by reducing physically demanding tasks, concerns about job displacement and workplace security persist (Bhargava et al., 2021; Paluch et al., 2020; Mitra and Das, 2022). The potential impacts depend on various evolving factors and pending strategic decisions, resulting in different possible trajectories. This uncertainty is further amplified by the long transition to SR, during which influence factors may continue to diverge. To address this, this paper applies the scenario technique (ST) to analyze the impact of SR on waste management employees, using the MARBLE SR developed at TU Berlin as a use case. It examines task changes, value chain shifts, key influence factors, and implications across different scenarios, identifying potential challenges and opportunities. The findings enhance understanding of SR's impact on employment, informing adoption discussions, guiding research, and supporting sustainable workplace integration.

2. State of the Art and Problem Definition

2.1. Service Robots

SR are transforming a multitude of industries driven by a global push for automation to address labor shortages and enhance efficiency. The market is projected to generate 30.63 billion euros in revenue by 2024, with the United States, China, and Germany leading (Statista Market Insights, 2024). In waste management, SR improve urban cleanliness and reduce labor demands. Examples include DustCart and

DustClean from the EU-funded DustBot project, designed to collect waste, clean streets, and monitor air quality (Ferri et al., 2011; ROBOTECH srl, n.d.). Other innovations include ROARy, a Volvo Group project combining drones and autonomous robots for waste collection (Volvo Group, 2016), and Angsa Robotics' AI-driven robot for picking up small litter on grass and gravel surfaces (Aviaspace Bremen, 2020). The MARBLE robot autonomously navigates to empty public litter-bins, aiming to reduce the physical burden on human workers while enhancing efficiency and sustainability (Göhlich et al., 2022). MARBLE's product-infrastructure service system can be expanded to include various service elements such as assistance vehicle motherships, fleets, and optimized routes based on litter-bin fill levels (Gupta and Göhlich, 2024). While service robots like MARBLE offer clear operational benefits, they also raise concerns about employment and labor conditions. Automating low-skilled tasks may reduce demand for these roles, with mixed perspectives in the literature(Paluch et al., 2020; van der Schoor and Göhlich, 2023). This paper aims to address these issues through the case of MARBLE, employing a suitable foresight method to systematically analyze potential developments and evaluate their implications.

2.2. Foresight

Foresight research explores possible, desirable, and probable future developments while recognizing the inherent unpredictability of the future (Göpfert, 2022). In business, it supports proactive decision-making, fostering innovation and competitiveness(Durst et al., 2014). Key methods include the Delphi Method and Scenario Technique (ST). Delphi refines predictions through expert consensus (Niederberger and Deckert, 2022), while ST constructs diverse, coherent scenarios to identify risks and opportunities, especially under uncertainty (Schwarz-Geschka, 2014). ST proves to be a valuable tool for supporting organizations in decision-making under uncertainty and complexity. It enables the development of strategies that are not only effective in a single possible future but also robust against various potential developments (Gausemeier et al., 1998). ST has become an integral part of product development, enabling early detection of market needs, opportunities, and risks, guiding product design accordingly (Graeßler et al., 2022). ST can also be used for the assessment of possible implications of future products. For instance, (Pulkka and Simanainen, 2022) used ST to evaluate two EU employment scenarios: one with automation-driven mass unemployment and another with reduced unemployment from technological benefits. (Gruetzemacher et al., 2020) surveys AI practitioners on the potential for extreme labor displacement by AI. Results suggest a significant possibility of AI automating up to 90% of tasks within 25 years. (Derbyshire and Giovannetti, 2017) combine scenario planning and forecasting using an adapted Intuitive Logics approach to model market acceptance and product diffusion, enhancing decision-making in New Product Development (NPD) under uncertainty. (Lu et al., 2020) reviews the impact of SR on customers and employees, analyzing customer trust frameworks (e.g., anthropomorphism) and employee adaptation theories (e.g., task replacement). The study underscores the need for research to explore long-term integration effects. The referenced studies highlight the appropriateness of ST for exploring the complex nature of the impact of technological change on employment. Furthermore, they underscore the lack of studies focusing on the social sustainability impacts of SR.

3. Methodology and Application

3.1. Theoretical Basis of the Methodology

Geschka's explorative method is widely used in ST for generating diverse future scenarios, essential for addressing complexity and uncertainty. (Schwarz-Geschka, 2014). Unlike deductive approaches, which rely on predefined frameworks, Geschka's inductive method captures a broader range of possibilities by analyzing interactions between key influence factors. The method follows eight steps, starting with defining the topic and identifying critical and non-critical influence factors, which are then transformed into projections. A consistency analysis evaluates projection compatibility to create coherent scenarios (Schwarz-Geschka, 2022). Finally, actionable measures are developed, enabling organizations to adapt strategies, ensuring readiness for plausible futures and resilience to change (Schwarz-Geschka, 2014).

3.2. Case Study: Service Robot MARBLE

The use case service robot MARBLE (Mobile Autonomous Robot for Litter Emptying) has been developed by Technische Universität Berlin and the Berlin waste management company BSR, designed for autonomously emptying the litter-bins on the streets of Berlin (Göhlich et al., 2022). MARBLE also aims to reduces energy consumption, CO_2 emissions, and improves employees' working conditions (Kohl et al., 2020). To achieve the overall service goal, the Smart Product Service System (SPSS) incorporates the service robot MARBLE alongside additional infrastructure such as an assistance vehicle, smart litter-bins, and an operation management service. As illustrated in Figure 1, this SPSS framework facilitates the integration and interaction of these service elements into the municipality BSR's service system. The automated litter-bin emptying process necessitates the inclusion of all SPSS elements.

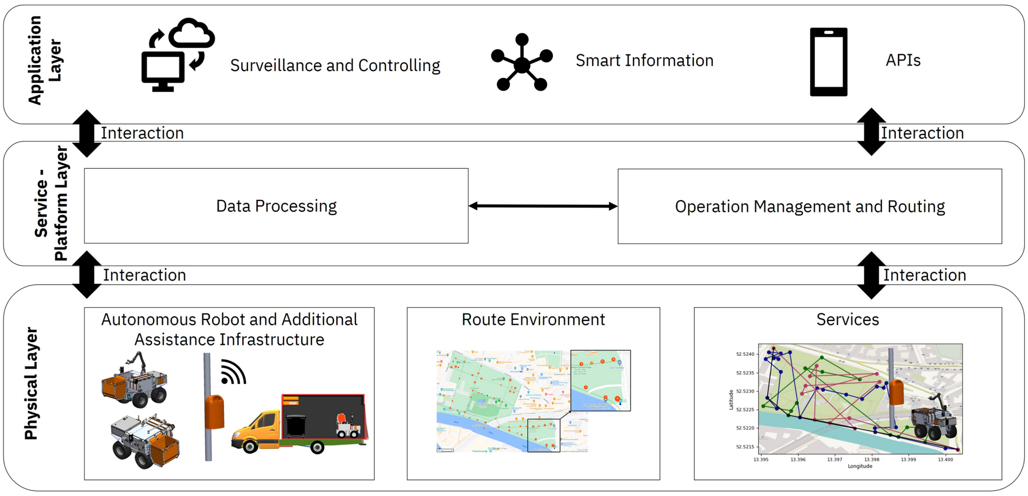

Figure 1. Smart product service system framework and system layers for use-case MARBLE

This integration within the actual service process will impact BSR employees, and this study generates various scenarios to explore possible impacts. The used methodology is detailed in Section 3.3.

3.3. Application of the Methodology

This section presents the empirical approach of applying Geschka's eight-step ST (Illustrated in Figure 2) to investigate the following research questions:

1. What factors influence employment when using SR? Which of these factors can be considered significant? What future projections can the significant factors take? (4.1)
2. What do the factor projections look like in best-case, worst-case, and trend scenarios? (4.2)
3. What opportunities and risks for employment conditions could arise from the use of the MARBLE service robot in litter-bin emptying? (5)

The scenario development follows 8 steps according to (Schwarz-Geschka, 2014)

1. **Structuring and Defining the Topic:** This phase defined the research focus on analyzing the potential impacts of SR, particularly MARBLE, on employment in the service sector. The scope was set to 2030 with an outlook to 2040.
2. **Identification of Influence Factors:** A literature review identified 17 preliminary factors. These were validated during a three-hour expert workshop, resulting in the addition of 13 new factors. A subsequent relevance analysis narrowed the list to 25 factors with medium to high relevance.
3. **Descriptor Formulation and Projections:** Descriptors were formulated for each influence factor, with experts specifying optimistic, pessimistic, and neutral projections up to 2030 and 2040 in a one on one interview format.
4. **Impact Analysis:** Using a quantitative matrix approach, experts assessed the relative impact of each factor. In an offline survey, they rated influence strengths independently. Out of the 25 factors, 14 were selected as significant which would serve as the primary drivers within the scenario structure. Next, a consistency analysis was carried out. In this step, experts identified compatible projections of significant factors to ensure internal scenario consistency. Using the software INKA4, 177 scenarios were developed based on the consistency ratings. The final selection was made based on the consistency score and representativeness by the core team of researchers.
5. **Scenario Development and Narrative Creation:** Raw scenarios were refined into detailed environmental scenarios by incorporating less critical factors and crafting meaningful narratives.

6. **Analysis of Trend Breaking Events:** Potential trend breaking events were identified and integrated into the scenarios. This allowed for adjustments in case of unforeseen influences.
7. **Implications of the scenarios:** Each scenario yielded actionable insights for BSR, highlighting opportunities and risks.
8. **Strategic Planning:** This final phase provided strategic recommendations for adapting to possible outcomes, facilitating strategic planning for BSR and other companies in the field.

The selection of experts for the workshops was carefully conducted to ensure the participation of professionals specializing in the development and research of service robots, as well as experts in their application domains. Emphasis was placed on including only individuals with recognized in-depth technical knowledge, rather than merely affected stakeholders, as is common in acceptance-focused formats. Experts were recruited through direct outreach and professional networks, encompassing specialists from municipal institutions, companies engaged in service robotics, and a technical university. Given the time-intensive nature of such formats, securing participation posed significant challenges. Experts with extensive domain knowledge often have demanding schedules, requiring long lead times for coordination and making it difficult to find suitable dates. Despite these challenges, eight experts ultimately participated, including two representatives from municipal institutions, one representative from a service robotics company, and five researchers from different departments of a technical university.
The expert engagement process was structured into three distinct phases. First, a three-hour workshop was conducted, during which experts collaboratively refined the identified influence factors. This was

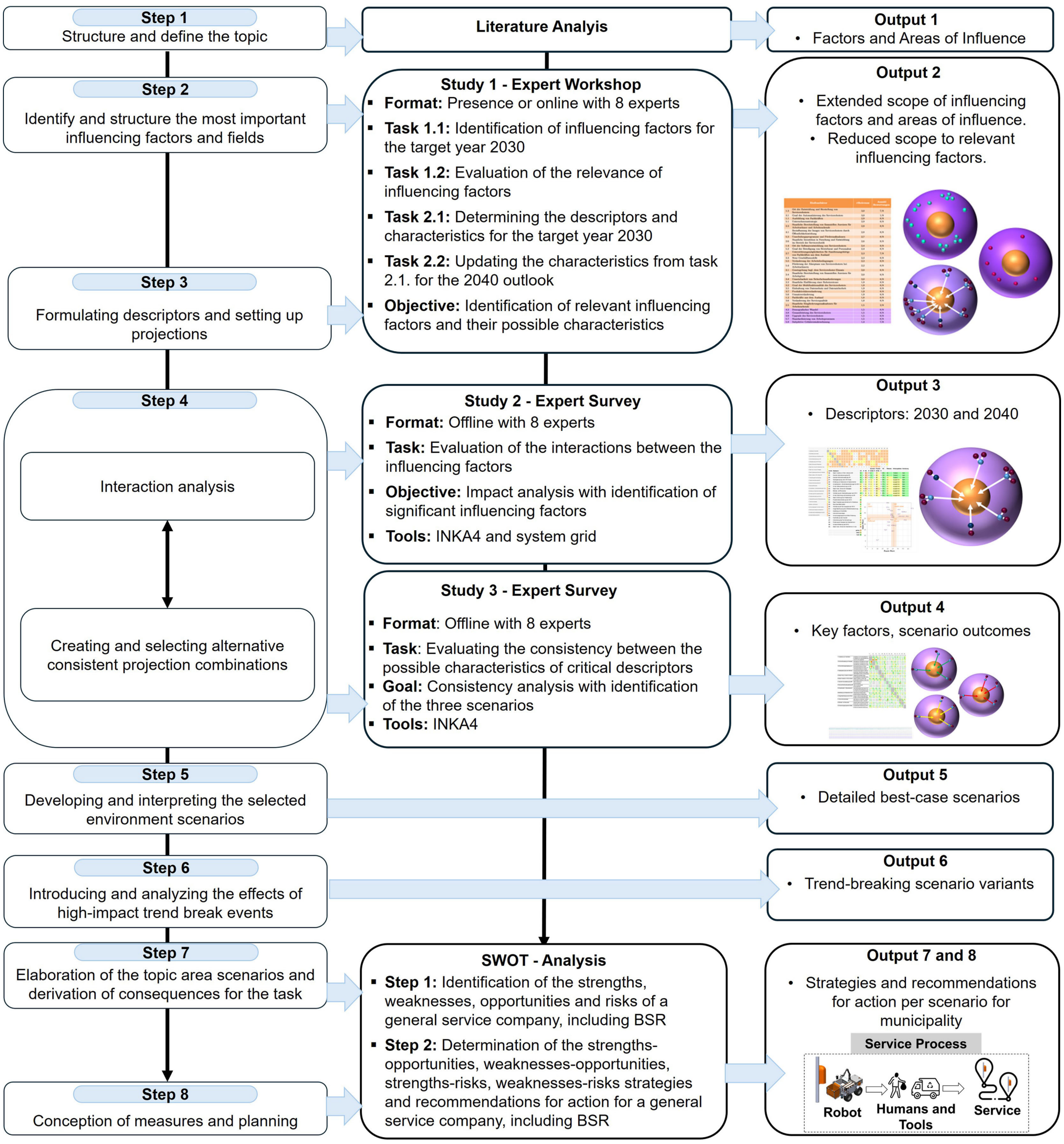

Figure 2. Scenario technique methodology applied to MARBLE's SPSS

followed by an offline survey in which the experts assessed the strength of influence for each factor. Finally, a second offline survey was carried out to analyze the consistency of their assessments. Scenarios were selected based on their internal consistency and representativeness. The INKA4 software supported precise filtering and pairing of assumptions, resulting in three primary scenarios (Best-Case, Worst-Case, and Trend) with distinct characteristics.

4. Results

4.1. Description of influencing factors and theirs projections for 2030

In the following section, the 14 significant influencing factors with the highest relevance are introduced to address research question 1. The average relevance rating for each factor is indicated in brackets, using a scale from 0 to 3, where 0 represents “No Relevance,” and 3 denotes “High Relevance.” Additionally, two or three projections (indicated by the letters a, b and c) of each factor for the year 2030 are noted. The chapter also provides an overview of the results from the impact analysis. This analysis aims to estimate the extent to which the factors influence one another, thereby determining the inter-connectedness of the scenario field. A factor can either be driving, meaning it strongly influences other factors, or driven, meaning it is heavily influenced by others. Some factors may simultaneously exhibit both driving and driven characteristics, while others remain relatively independent.

1. **Location of Development and Manufacturing (3.0):** SR can be developed and manufactured domestically (a), both domestically and internationally (b), or entirely internationally (c). Experts unanimously rated this factor as highly relevant due to the potential for job creation, particularly in domestic manufacturing. The factor is balanced between being driving and driven.
2. **Degree of Automation (3.0):** SR may be fully autonomous (a) or operate cooperatively with humans (b). Experts emphasized the significance of automation levels in determining whether employees are displaced or retrained for collaborative work. The factor is highly driving, hence strongly influencing the scenario field.
3. **Education of Skilled Workers (2.9):** Training efforts may focus on high-skilled professionals (a), low-skilled workers (b), or no training at all (c). Experts highlighted the need for highly skilled workers and considered both hard and soft skills as critical for adapting to technological changes. The factor is predominantly driven but still has a high activity sum.
4. **Corporate Strategy (2.9):** SR may be employed as tools to support human labor (a) or as replacements (b). A employee-oriented strategy fosters smoother integration, while replacement strategies may cause resistance among employees. The factor is predominantly driven.
5. **Financial Incentives for Workers and Job Seekers (2.8):** Governments may provide effective financial incentives (a) or fail to do so (b). Experts stressed the importance of subsidies for training programs to encourage adaptation to robotics-driven job markets. The factor is highly driven.
6. **Public Image of SR (2.8):** The public perception of SR may be generally positive (a) or negative (b). Experts noted that curiosity about working with advanced technology may attract employees, while fear of being replaced by robots could deter interest in this field. The factor is balanced.
7. **Retraining and Support Programs (2.7):** Retraining programs may be effective (a) or inadequate (b). Experts considered reskilling initiatives critical for workforce transitions, focusing on developing both soft and hard skills to complement evolving job demands. The factor is driven.
8. **Government R&D Investments (2.6):** Governments may invest sufficiently in robotics R&D (a) or fail to do so (b). Investment drives innovation, creates opportunities for researchers and developers, and fosters business expansion into new markets. The factor has the highest active sum, exerting significant influence on the scenario field.
9. **Location of Software Development (2.4):** Software development may occur domestically (a), both domestically and internationally (b), or entirely internationally (c). Experts emphasized its role in ensuring data security, which influences the acceptance of SR. The factor is balanced.
10. **Involvement of Employee Committees (2.4):** Employee committees may actively support employees (a) or remain passive or absent (b). Active participation facilitates smoother transitions and ensures fair labor practices. The factor is balanced between being driving and driven.
11. **Legislation on SR (2.0):** Laws may support robot deployment (a), impose stricter regulations (b), or ban their use (c). Experts rated this as moderately relevant, with the potential to either facilitate or hinder robotics. The factor is balanced between being driving and driven.

12. **Implementation of Safety Standards (2.0):** Safety standards may be fully achievable (a), sufficiently manageable (b), or excessively restrictive (c). Experts viewed strict standards as both a technical challenge and a potential hindrance to investment. The factor is balanced.
13. **Degree of Multifunctionality (1.9):** SR may be highly multifunctional (a) or specialized (b). Multifunctional robots provide versatility but could displace employees, while specialized robots remain limited to specific tasks. The factor is driving.
14. **Data Security and Privacy (1.9):** Robots may operate in secure environments (a) or face data security challenges (b). Experts emphasized the importance of a secure environment for fostering acceptance. The factor is balanced between being driving and driven, yet with a high active sum.

4.2. Description of the Three Scenarios

This section focuses on the developed scenarios to answer research question 2. Using the values obtained through the consistency analysis, the INKA4 software generated 177 possible scenarios. These scenarios were subsequently refined through various logical evaluations, ultimately narrowing them down to one best-case, one worst-case, and one trend scenario.

Best case scenario: Germany on the path to global leadership in service robotics

By 2030, Germany has adapted its educational offerings in robotics, resulting in the training of predominantly highly qualified specialists in robotics and related fields. Also non-STEM educational programs have increasingly integrated robotics content, ensuring that all graduates are well-prepared for interactions with SR, which are becoming increasingly significant in the modern workplace. This widespread expertise fosters excellent conditions for domestic development and production of SR and associated software, maximizing value creation potentials and enhancing Germany's innovation capacity and global competitiveness. Companies in the service sector employ SR as multifunctional assistants designed for human-robot collaboration, necessitating qualified personnel. To meet these demands, companies provide regular, retraining programs, expanding employee skills. Labor councils oversee the deployment of these technologies to safeguard employee rights, ensuring all safety standards and data protection measures are upheld. Employees embrace retraining, relieved to be freed from unpleasant, repetitive tasks. Their enthusiasm boosts the image of service robotics careers and drives societal demand for robot-provided services through social networks. In response to growing customer demand, companies invest in additional robots to boost productivity and maintain competitiveness, potentially opening new business fields. Workers and job seekers with a strong interest in service robotics benefit from government financial incentives such as retraining opportunities and start-up grants, facilitating the creation of new, attractive employment opportunities. By 2040, SR operate fully autonomously in service sector companies, independently providing the services desired by customers. As part of corporate strategies involving the deployment of SR to support staff, employees are retrained and reassigned to roles along the company's value chain vacated by retiring baby boomers. Consequently, the transition to fully autonomous SR involves a shift in working conditions within service companies, without reducing the number of employees.

Trend scenario: Educational crisis as the cause of stagnation

By 2030, Germany's educational programs in robotics have been revised but fail to reflect current technological advancements. This has resulted in graduates being poorly qualified, exacerbating the existing skills shortage. Although there is a foundation for domestic development and production of SR and associated software, it is insufficient to conduct all production exclusively within Germany, leading to a mix of domestic and foreign manufacturing. Workers and job seekers are motivated by financial incentives such as qualification measures and start-up grants. The state invests in research and development in service robotics. SR in the service sector are primarily designed for joint service with employees and are specialized for specific tasks. This necessitates qualified personnel and implies the need for retraining employees to prepare them for upcoming human-robot collaboration. The new, varied, and less burdensome tasks lead to higher job satisfaction, and employees positively accept the changes in their roles. However, concerns arise about potential occupational hazards and data privacy, as companies cannot fully meet all safety requirements. Economic development in Germany is stagnating, caused to a high extend by outdated educational offerings and a lack of workplace safety. These challenges pressure the federal government to reform the education system and strengthen existing laws to ensure worker safety and protection. However, the societal image of SR remains generally positive.

By 2040, SR are no longer limited to specific tasks but operate multifunctionally and fully autonomously, eliminating the need for human-robot collaboration. Employees are retrained and reassigned to roles along the company's value chain that have become vacant due to the retirement of the baby boomers. The shift to multifunctional SR reduces the overall demand for robots, negatively impacting employment in their development and production. Overall, the transition to fully autonomous SR leads to altered working conditions in service sector companies and a slight decline in he number of employees.

Worst case scenario: Obsolete education jeopardize Germany's innovation and global competitiveness

By 2030, the failure to update educational programs and curricula in robotics has severely damaged the industry's image and significantly reduced public interest in this field. Consequently, very few specialists are being trained domestically, increasing the necessity to recruit foreign experts. The shortage of highly qualified specialists makes it difficult for the government to create financial incentives for business expansions or start-ups, while at the same time there is no investment in research and development in the field of service robotics. Development and production of SR and associated software increasingly occur abroad. Service sector companies employ multifunctional and fully autonomous SR, often aiming to release "unqualified" personnel, without intervention from employee committees. This passive stance eliminates the need for retraining programs. Employment opportunities are drastically reduced, with only a few employees responsible mainly for monitoring and maintenance tasks. As a result, SR are increasingly perceived as a threat to jobs, deteriorating their public image. Strict safety requirements associated with the use of SR make it challenging for many companies to comply. Concerns about data protection and security cause employees to feel increasingly uncomfortable and unprotected. These safety deficits also displease customers, leading to a decline in demand for services provided by SR. Unemployment increases due to a lack of security, prompting the government to tighten laws governing the use of SR. By 2040, companies in the service sector continue to use fully autonomous and multifunctional SR. The conditions from a decade earlier have largely remained unchanged.

4.3. Trend-breaking Events

Unexpected, trend-breaking events can disrupt anticipated development paths and create new scenario variants. Drawing on literature and expert analysis, two key events have been identified: First, epidemics and pandemics, like the COVID-19 crisis, may drive increased adoption of SR to minimize human contact and curb infection risks, potentially reducing the demand for human service providers. Corporate strategies will be pivotal in determining whether technology complements or replaces human workers. Second, a ban on SR could arise from safety concerns, job losses, social unrest, or negative public sentiment. Such a ban could lead to missed employment opportunities for robotics specialists, brain drain, and setbacks in domestic development and production. Replacing robots with human labor might trigger layoffs in manufacturing and diminish interest in robotics education among citizens.

5. Possible Implications and Corresponding Measures

Based on the developed scenarios, opportunities and risks for employment conditions in waste management due to service robot implementation are identified to answer research question 3). To do so, a SWOT analysis is employed as a strategic tool to assesses internal strengths and weaknesses alongside external opportunities and risks. The SWOT analysis was conducted for all scenarios[1] but the findings are illustrated in table 1 only for the trend scenario, as it offers the most comprehensive insights. Subsequently, specific strategies and actions are proposed. These are based on the case study BSR but can be generalized for waste management in Germany. Given the paper's scope, a simplified analysis is conducted for the second step of SWOT to formulate strategic recommendations. The strategies developed include: strength-opportunity strategy: "leverage strengths to seize opportunities"; weakness-opportunity strategy: "enhance weaknesses to capitalize on opportunities"; strength-risk strategy: "apply strengths to mitigate risks"; and weakness-risk strategy: "reduce weaknesses to avoid risks." The following section will describe the opportunities and risks as well as the corresponding strategies.

[1] The findings for the best-case and worst-case scenarios are available at: Supplementary Material

Recommendations for the best-case scenario

In line with the Strengths-Opportunities strategy, companies should leverage their skilled workforce to expand service offerings, i.e. by enhancing their focus on sustainability and public engagement. For cost challenges, adopting a Weaknesses-Opportunities approach is recommended: Companies can consider implementing rigorous cost management measures to identify areas for optimization without compromising on employee benefits or training quality. By refining cost structures, organizations can ensure that the financial burden of new technologies is manageable.

Recommendations for the worst-case scenario

Applying a Strengths-Risks strategy, companies should reinvest cost savings from staff reduction into essential safety improvements and retraining programs. This approach would address safety concerns, improve employee security, and enhance workforce retention. Companies should also conduct regular safety audits to identify specific risks associated with robot deployment, ensuring compliance with regulatory standards and building a positive workplace environment. Transparent internal communication about the benefits, limitations, and safety measures of SR can also improve employee acceptance.

Table 1. SWOT-analysis for the Trend Scenario

Strengths	Weaknesses
• In the trend scenario, companies use internal retraining programs to mitigate skill gaps, enabling some employees to adapt to the demands of servicer obotics. • Although retraining is not comprehensive, it supports productivity as employees learn to manage robotic systems more effectively. • Robots reduce the burden of physically and mentally taxing tasks, which contributes to modest gains in employee satisfaction. • For the BSR, the introduction of MARBLE enhances waste collection processes by handling repetitive tasks, allowing staff to redirect their focus toward other service duties.	• However, the limited qualifications of the workforce continue to hinder the effective integration of robotic technology. • The BSR, like other organizations in this scenario, faces financial pressure from the costs associated with retraining and implementing new technologies. • Incomplete adherence to safety standards also creates a sense of insecurity among employees, negatively impacting morale and satisfaction. • As a public entity, the BSR is particularly sensitive to these challenges, as its commitment to public service requires a stable, well-supported workforce to maintain operational standards.
Opportunities	**Threats**
• Despite the challenges, companies can position themselves as modern workplaces, appealing to sustainability-focused employees interested in robotics and technological advancement. • For the BSR, this emphasis on sustainability presents an opportunity to strengthen its reputation as a progressive organization, potentially attracting skilled workers motivated by the chance to contribute to responsible projects.	• Persistent skills shortages and employee concerns over safety and job security limit the effectiveness of robotics and create potential barriers to successful integration. • For the BSR, these challenges could lead to turnover, as employees become dissatisfied with working conditions, ultimately undermining service quality and restricting the benefits of MARBLE's deployment.

Recommendations for the trend scenario

To maximize benefits, companies should adopt a Strengths-Opportunities strategy, focusing on expanding retraining programs to ensure employees are equipped to handle new robotic technologies. Additionally, a Weaknesses-Risks strategy is advisable to address persistent safety concerns and optimize cost structures. Safety audits and consulting services can help identify financial and safety improvements, allowing companies to balance expenses while protecting employee welfare. These measures can (re-) build employee confidence and foster a supportive work environment, enabling companies to sustain high service standards while embracing technological advancements.

6. Discussion and Outlook

The ST, following the approach by Geschka, has proven to be effective for analyzing and evaluating the impact of emerging technologies using the example of SR on the employment situation. The significant factors with high influence on the matter, along with their interactions and projections across different scenarios, were successfully identified, which allowed for a detailed assessment of risks and facilitated the development of clear action recommendations. This suggests that the ST is an effective method for identifying both opportunities and risks for social sustainability associated with new technological products and product-service systems early in the design process. Future research might explore the application of the ST in other sustainability domains, providing a basis for more comprehensive assessments and strategic planning. However, some limitations were identified regarding the practicality of the approach. The method heavily relies on expert knowledge and requires significant time commitments from participants, which can pose challenges in engaging a sufficiently diverse and representative group of experts. The workshops provided valuable in-depth insights and allowed for real-time resolution of questions but were constrained by the limited availability of participants—a common issue in time-intensive methodologies. Offline surveys helped to broaden participation and include a wider range of expertise; however, they introduced inconsistencies, likely due to varying levels of comprehension or interpretation of the questions. To overcome these challenges, a more integrated approach could combine workshops with asynchronous methods such as online surveys or follow-up discussions. This refinement would ensure methodological depth while improving accessibility, allowing for broader expert engagement and more consistent data collection. By addressing these limitations, the ST's applicability in the design process could be further enhanced, making it an even more effective tool for assessing the broader sustainability impacts of emerging technologies.

The findings of this study align with the broader debate on SR implementation introduced in the introduction, as they not only confirm the advantages but also highlight a range of risks, particularly concerning the social dimension of their implementation. For the case study of the service robot MARBLE, 14 key influencing factors were identified, forming the basis for three consistent scenarios. For each scenario, the implications for the case study were analyzed and possible countermeasures and strategies were developed. The findings suggest that robots like MARBLE can alleviate physically demanding tasks, create opportunities for expanding services and create new, more fulfilling tasks for workers. However, risks for working conditions such as physical and data security and job displacement, particularly for workers lacking reskilling opportunities, remain critical when appropriate countermeasures, proper training, and regulations are lacking. The worst-case scenario contrasts sharply with the best-case scenario, highlighting that without the ability to train specialists, the existing skills shortage worsens, entailing the replacement of human labor by SR. Additionally, the lack of domestic potential for research, development, and production of SR exacerbates the situation, especially risking compliance with security and data protection standards. This can be understood as a clear call to action. To ensure that the introduction of SR maximizes positive outcomes while minimizing negative consequences, the findings of this study highlight the need for investment in education and the development process. This includes prioritizing the education and training of qualified professionals, both in companies and academia, broadly supporting service robot development projects, particularly those focused on sustainable implementation, and placing a strong emphasis on safety standards.

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