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STUDY OF HUMAN-ROBOT COLLABORATION IN SMART FACTORIES: ILLUSTRATIONS USING DELHI-NCR BASED FACTORIES

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Abstract
Human-Robot Collaboration (HRC) is reshaping various industries by merging human adapt- ability, decision making skills, and dexterity with the accuracy, efficiency and cost effectiveness of robotic systems. This research explores how the integration of HRC influences efficiency of operations in factories, workforce dynamics, and technology adoption in manufacturing envi- ronments. Focusing on a range of factories from fully manual to those with lots of automation, this study analyses the opportunities and challenges presented by collaborative robotics in real world industrial settings. The research methodology was primarily qualitative, supported by some quantitative data, and involved conducting structured interviews and surveys with per- sonnel and high level staff across four factories in the Delhi-NCR region. The data collection focused on aspects such as labor challenges, order tracking, automation barriers, sustainability efforts, and future technology plans. By comparing experiences from different automation con- texts, the study identifies patterns and contrasts in how factories manage the balance between manual processes and collaborative technologies. The results show that the automation levels show a spectrum of contrasting differences. In factories solely functioning manually, there are difficulties with order tracking inefficiencies, high labor costs, and low sustainability. These oper- ations are over reliant on outdated and inefficient systems and it is difficult to scale production. Semi-automated facilities are in between, combining high-end tools and CNC machines with labour and manual variations. There have been some gains in accuracy and reduced manual effort, but there are still barriers. Despite the differences between factories and their industries, there were some major emerging cross-cut cutting themes: the need for automation strategies, human-centric design and custom yet scalable infrastructure. Researchers have emphasized that successful Human-Robot Collaboration (HRC) does not only depend on technologically imple- menting automation. Successful HRC depends on retraining, ergonomics and cost management. In summary, human-robot collaboration has the potential to be transformative in regions like Delhi NCR, but its success is reliant on technology, labor practice, and long-term adaptability.

Keywords: Human-robot, Automation, Artificial Intelligence.

1 Introduction

Human-Robot Collaboration (HRC) defines systems where the human and the robot are working side by side on a joint task, in which the advantages of humans (for example; human adaptability, human imagination, human context-based decision-making) and robots (for example; robotic sensitivity, robotic strength, robotic endurance) are combined[1]. It shifts the role of robots from master-slave servomechanism, doing manually operated jobs to sophisticated robotic systems with human-like intelligence, that can operate under human monitoring.

HRC is primarily focused on the safe, intuitive, interactive, and adaptive nature of the collab- oration made possible by the combination of human creativity, decision-making, and dexterity, along with robotics precision, endurance over time, and efficiency. HRC is performed with these human-robot teams working together to get the job done as opposed to robots in automation occupying separate, isolated spaces [24, 25]. Such activity is on increase in industries such as manufacturing, healthcare, logistics, and services where robots are working as 'co-workers' in collaboration and support of human workers as opposed to replacing human workers. HRC uses a combination of sophisticated sensing, real-time communication, machine learning, and ergonomic design to establish the conditions needed to ensure robots can understand, and there- fore respond appropriately to the actions and intentions of humans [2, 3].

HRC appeared as a term and idea when it was discovered that fully automated systems, which replaced human action, were incapable of performing tasks that required actions based on a shifting and impermanent set of conditions which required flexibility, creativity, conscious intention and a human-centric approach. In investigating this, research and practice began to advance with HRC in mind rather than HRI (human-robot interaction).

The opportunities for collaboration were more obvious in sectors where customization de- mands also increased and products became more complex to manufacture. Often, in these situations, automation could not keep pace. HRC provides a mechanism to support that op- portunity—robots for the most repetitive, accurate, or heavy lift tasks, while humans can focus on tasks requiring judgment and dexterity. The automotive industry has been an early and visible example of this collaborative human-machine effort. For example, collaborative robots or "cobots" would handle the components that were heavy or repetitive, while humans ac- complished oversight quality on the job, and handled more intricate assembly processes. This human-in-the-loop model improved productivity while also reducing the ergonomic risk to hu- mans. As HRC began to be deployed in factories, another issue came to light: safety. The traditional robotics approach is to isolate humans and machines physically. However, in col- laborative settings, this is not possible and introduces new safety risks relating to potential undesired unintended human-robot interactions. Industry and academia began to investigate how collaboration could focus on ways to have a robot safely operate around a human. A key innovation along these lines is the force-limited cobot, highly instrumented, containing advanced sensors, compliant actuators, and force-limiting controls[4, 5, 6].

These cobots are engineered to recognize humans and slow or reduce their force based on human presence, thereby reducing the risk of harm [7, 8]. This work has led to the development of standards such as ISO/TS 15066, which provides force and speed limits for collaborative robots in shared settings. Safety has also led to innovations in adaptive and intelligent behav- iors of robots. In addition to safety features, new cobots are becoming increasingly context aware, meaning they sense their environment and provide a dynamic response to it. Artifi- cial Intelligence (AI) facilitates modifying the motion path, speed, and applied force based on real-time feedback, which helps increase safety and efficiency [9]. Tesla factories are a poster child for how this works: their adaptive robotics change behaviour based on the proximity and behaviours of other human workers, enabling them to work alongside each other peacefully and securely [10]. Such advancements are accompanied by multimodal human-robot interfaces, which allow for communication using speaking, gesture and vision—tools that create interaction in a familiar manner with less cognitive load on human worker. A further area of effective HRC concerns the ergonomics of workstations for humans. As humans remain integral to smart factories, it will be important for collaborative work areas to be created for human comfortable use and efficient operation. Poor ergonomics can disrupt productivity and safety—especially in prolonged collaborations. It has been shown that when effective principles of ergonomics are employed in the design of a human-robot collaborative ergonometric workstation, productiv- ity improves and human fatigue and injury are reduced [11]. For example, Employers like the Toyota Motor Corporation have engaged with the evidence presented to them and altered their work environments in such a way as to actually provide height adjustable workstations and to use collaborative robots that tailor services to different users to offer a level of individualized engagement or result efficient processes[11, 12].

Despite this level of advancement, there may be still be a number or roadblocks that prevent or slow quiet the implemnetation of this level of HRC at smart factories. One continuing story is effective communication between humans and robots. Although multimodal interfaces allows sophisticated communication across a number of methods the transmission of speech or gesture and its resultant miscommunication are very much still a possibility, an outcome which can result in not only inefficiencies but also torsional risks for the engaged workers. Additionally, task allocation—the determination of what task components are performed by a human (or robot)—is particularly convoluted when manufacturing workflows can be extremely dynamic [13]. The cost, technical complexity, and time associated with retrofitting a factory and adapt- ing to collaborative technologies is another major limitation for adopting HRC practices. This challenge is particularly pronounced for SMEs that may not have enough resources or techni- cal capabilities to apply and organize maintenance over such systems. Beyond the practical aspects, there are social and ethical factors including fears about job redundancy, altered skill requirements by HRC technologies, and target anxiety around working with intelligent machines [14, 15]. According to research, acceptance of collaborative robots relied heavily on an examina- tion of their safety, and to a lesser extent, on the transparency with which they operate, and the amount of control the human operator retains. When humans feel in control, and understand the operations of the collaborative robot, trust and acceptance significantly increased; demon- strating the importance of human-centric design in hardware, software, and as an organizational part of implementing HRC [16].

In conclusion, the existing literature illustrates that human-robot collaboration is not merely a technological integration but a multidimensional transformation involving safety, ergonomics, communication, and organizational culture. Each area builds upon the previous advancements, creating a continuous feedback loop of development. While promising, the realization of truly collaborative smart factories requires addressing persistent challenges that span technical, op- erational, and human-centered domains [17, 18, 19].

In order to understand the present scenario better, a study was designed to visit several factories and their warehouses in the Delhi-NCR and capture data to understand the level of automation, HRC, hurdles faced due to lack of automation and the organizations' willingness and readiness to adopt automation in the warehouses. The warehouse's primary hurdles are labor dependency, outdated order tracking, and resistance to automation due to cost and re- training concerns. However, planned investments in AI-driven order management and ERP solutions aim to address these gaps. Customer feedback highlights reliability in product quality but frustration with delayed updates and manual errors. Moving forward, integrating targeted automation while upskilling workers could enhance efficiency, scalability, and transparency, po- sitioning the warehouse for growth in a competitive industrial market.he lack of automation leads to inefficiencies, errors, and scalability constraints, though future plans include adopting AI and ERP systems to modernize operations. Despite some metal recycling efforts, sustainabil- ity initiatives remain minimal, with energy efficiency taking a backseat to production demands [26, 27, 28, 29]. In this work, we are excited to analyze how sales of warehouses have been impacted by the incorporation of human-robot collaboration. By collecting the data of some real-life semi-automated and automated warehouses, we will discuss how it impacted the effi- ciency of the factories along with some pros and cons. What are the challenges that are faced by the employees of manual warehouses compared to the automated warehouses are also dis- cussed, and in the end we will discuss how we can improve these challenges by incorporating human-robot collaboration.

This research paper is organized as follows: Section 1 is the introduction, followed by Section 2, which describes the methodology of the given work. Section 3 discusses the interpretation of qualitative data that I have collected during the visits to the warehouses, along with the training and workforce data. Section 4 discusses the results and conclusion from the study, along with some limitations of this work.

2 Methodology

To explore practices of human-robot collaboration in smart factories, the present study followed a mixed-method survey-based approach [20, 21, 22, 23]. Primary data were garnered using a structured questionnaire filled in through a survey across chosen automated and semi-automated factories in the Delhi-NCR area. The questionnaire was framed to gather information regarding the level of robot integration, type of collaborative task, views of the employees, challenges encountered, and perceived advantages of human-robot interactions. The second round of ques- tionnaires was more focused on training and workforce data from the warehouses to better understand the parameters related to age, education qualifications, types of training provided, gender distribution, etc.

2.1 Research Design:

This qualitative case study employs Human-Robot Collaboration (HRC) occurring within the Indian manufacturing and warehousing sectors. The study seeks to understand the contex- tual implications of workforce experience, operational complications, automation adoption, and socio-technical issues that arise as robotics are incorporated within factory workplace domains. Large-scale quantitative studies often focus on productivity rates, incidence rates, or other ef- ficiency types of measures. Qualitative methods provide the depth necessary to encapsulate the nuances of human- robot interaction and the ability of organizations to respond to trans- formational change; specifically utilizing questionnaires and interviews with organizational key informants.

2.2 Data Collection Approach

Data was collected primarily through structured questionnaires administered during factory visits. The questionnaire was designed to get detailed information within six areas of focus:

General Data- Ownership, size, year established, industry sector not covered, the primary functions of warehouse/factory.

Workforce and Employee Experience - size and structure of workforce, skills/skill levels, training access or exposure, difficulties experienced in daily tasks, employee well-being or other items.

Automation and Technology - type of automation/automation maturity (manual, semi-automated, fully automated), developments in robotics, barriers to automation use or integration.

Performance and Efficiency - customer feedback, commonly relied key performance indicators (KPIs), pain points in operations, energy efficiency use.

Production and Scalability – Scalability of current operations, challenges in workforce expansion, ability to integrate new technologies at scale, and readiness for Industry 4.0 transitions.

Additional Insights – Perspectives on sustainability, environmental practices, expansions, and innovative initiatives aimed at balancing manual labor with automation.

The intended audience for the questions included factory managers, human resources of- ficers, and department managers—authors of the open questions, who had direct operational knowledge and oversight for on-site employee deployment and implementation of technology. Each survey also included open-response reflections (about barriers to re-skilling their employ- ees, changing workforce culture to adopt technology) as well as factual responding (about the size of their workforce, levels of automation).

2.3 Data Collection

A multiple case study design allowed comparisons of stakeholders with different levels of au- tomation readiness, with an opportunity to more clearly define the barriers, familiarity with working practices, and design structure that presented itself across the stakeholder group as a whole. To demonstrate a broad spectrum of experiences within the Indian industrial sector, five factories were purposively chosen:

Factory 1: Metaval Engineering Pvt. Ltd.
Sector: Heavy engineering/manufacturing and pipeline fittings. Status: Fully manual pro- cesses. Key insight: Total dependence on human labor; beginning to explore integrated ERP solutions and potential AI development.

Factory 2: Kadence Automation and Robotic Systems
Sector: Robotics integration and automation systems. Status: Highly automated and tech- nology advanced. Key insight: The pinnacle of HRC implementation with the additional chal- lenge of scaling knowledge- worker upskilling with rapid innovation.

Factory 3: Matrix Cutting Tools Pvt. Ltd. Sector: Industrial cutting tool manufactur- ing. Status: Semi-automated processes (CNC-based production). Key insight: Demonstrated the opportunities and barriers of semi-automated processes, with continual ROI concerns and shortages of skilled people.

Factory 4: Sarita Handa Exports Pvt. Ltd. Sector: Luxury home textiles and décor. Status: Semi-automated, artisan-heavy employment model. Key Insight: Tension be- tween automation and preserving traditional craft-based production methods. By selecting cases spanning metal fabrication, robotics integration, machine tools, and textiles, the study situates HRC not in an isolated high-tech context, but across diverse industrial ecosystems.

Factory 5: IFP Petro Products Pvt. Ltd. Sector: Lubricants, greases, and petrochem- ical products. The warehouse is run today largely by a labor-intensive staff, with most tasks like drum filling, sealing, stacking, palletizing, and documentation done manually. Although some simple machines are utilized for blending and sealing, these also need manual operators, and the lack of a fully integrated ERP or WMS system keeps administrative personnel busy with register-based record-keeping. This configuration reflects dependence on an average-sized workforce, with floor employees and clerical workers alike involved in vital components of main- taining routine operations.

2.4 Data Analysis Approach

Both deductive and inductive methods were used to code the questionnaire data thematically. The initial coding was guided by predefined categories (automation level, scalability, efficiency, safety, and training). From textual responses, other themes (such as artisan resistance, client demands for customization, and organizational barriers to digital adoption) surfaced inductively.

After that, a cross-case comparison was carried out with an emphasis on:

Similarities between industries (e.g., high capital costs of automation, training challenges).

Differences (such as artisan-heavy industries and reluctance to automate versus robotics companies and excitement).

HRC maturity indicators, such as digital order tracking, AI integration, or the presence of cobots.

In order to validate the accounts of the participants, responses were cross-checked, where appropriate, using publicly available company data, industry reports, and sustainability reports. Both factory visits and interviews were done with the appropriate permissions taking by the respective companies. Respondents were informed that the research was for academic purposes, engagement was voluntary, and that they could skip questions. Sensitive information related to employee distribution, financial outlay in automation and customer details is reported in aggregated form to ensure confidentiality.

3 Interpretations of Qualitative data

In this work, we have visited four warehouses, all of them located in the close approximate of Delhi-NCR. Their names are as follows: Metaval Engineering Pvt. Ltd., Kadence Automation and Robotic Systems, Matrix Cutting Tools Pvt. Ltd., and Sarita Handa. While automation levels vary in all the visited factories and have been summarized in the Table 1, all warehouses face challenges balancing labor, technology, and scalability. Kadence leads in automation but must manage complexity, whereas Metaval and Sarita Handa need targeted technology adoption. Employee training and phased automation are critical for sustainable growth.

On visiting the Metaval Engineering Pvt Ltd that is a fully manual warehouse in Farid- abad, India, specializing in metal pipeline fittings for industries like oil and gas and energy. We have found that the warehouse is praised for product quality, but its reliance on manual processes creates challenges in labor management, order tracking, and customer communica- tion. Employees face moderate-to-high difficulty in labor-intensive roles, with training limited to basic techniques and safety skills. The lack of automation leads to inefficiencies, errors, and scalability constraints, though future plans include adopting AI and ERP systems to modernize operations. Despite some metal recycling efforts, sustainability initiatives remain minimal, with energy efficiency taking a backseat to production demands.

Metric	**Metaval Engineering**	**Kadence Automation**	**Matrix Cutting Tools**	**Sarita Handa**	**IFP Petro Products Pvt Ltd**
Industry	Metal pipeline fittings	Robotics & Automation	Industrial cutting tools	Luxury home textiles	Petrochemical industry
Automation Level	Fully Manual	Fully Automated	Semi-Automated	Semi-Automated	Semi-automated
Primary Challenges	Labor & Order Tracking	Custom Integration	ROI on CNC Investment	Artisan Labor Shortage	Space optimization and cross-contamination risks
Future Automation Plans	AI & ERP Systems	Industry 4.0 Expansion	CNC Upgrades	Packaging Automation	RFID systems, custom automation solutions

Table 1: Overview of Workforce and Automation in Selected Factories

The warehouse's primary hurdles are labor dependency, outdated order tracking, and resistance to automation due to cost and retraining concerns. However, planned investments in AI-driven order management and ERP solutions aim to address these gaps. Customer feedback highlights reliability in product quality but frustration with delayed updates and manual errors. Moving forward, integrating targeted automation while upskilling workers could enhance efficiency, scalability, and transparency, positioning the warehouse for growth in a competitive industrial market. The data for automation and technology for all the warehouses have been summarized in the Table 2. This table will give us better insights into warehouses' current focus, what barriers they are facing, and what can be done in the near future.

Factory	**Sector**	**Workforce Size**	**Current AI/Robotics Use**	**Impact Expected**
Metaval Engineering	Precision Engg.	250	None	^ Efficiency, cost savings
Kadence Automation	Industrial Auto.	500	Manufacturing line with robotics integration	^ Safety, _ Downtime
Matrix Cutting Tools	Tooling/Metal	300	Basic automation	^ Precision, ^ Throughput
Sarita Handa	Textiles	1200	Manufacturing line with Automated machinery, IoT sensors, ERP	^ Efficiency, profit & global trade
IFP Petro Products	Lubricants, greases, and petrochemical products	90-100	No AI or robotics currently deployed	Efficiency Gains, Safety Improvements, Scalability

Table 3: This table gives the overview of Workforce Size, Current AI/Robotics Utilization, and Impact Expectations Across Various Manufacturing Factories

Table 3: This table gives the overview of Workforce Size, Current AI/Robotics Utilization, and Impact Expectations Across Various Manufacturing Factories

All the above-mentioned warehouses face distinct operational challenges shaped by their industry and level of automation. For example, Metaval Engineering struggles with labor- intensive processes and inefficient manual order tracking, leading to delays and errors. If we can address these challenges, which obviously require tailored solutions, such as phased automation, upskilling programs, and hybrid manual-automated workflows to enhance efficiency without compromising core operations.

Factory	Current Tech	Barriers	Future Plans
Metaval Engineering	None	High costs, employee retraining	AI-driven ERP
Kadence Automation	CNC machines, PLC systems, part assembly-mechanisms	Human robot collaboration, cost-effectiveness	Collaborative robots (cobots)
Matrix Cutting Tools	Semi-automated cutters and tools	High maintenance costs, limited adaptability	Full-scale robotic cutting line
Sarita Handa	ERP, digital monitoring, customized automated machines	Skilled labor shortage, data migration	Smart textile inventory management
IFP Petro Products Pvt Ltd	Automatic barrel filling, QR coding and labeling,	Regulatory compliance, Lack of skilled manpower and ERP	Warehouse Digitization, process automation

Table 2: Technologies in use, challenges and strategic future plans for automation in the selected factories.

3.1 Interpretations based on Training and Work-force data

Kadence Automation And Robotic Systems: Founded in 2018, Kadence Automation and Robotic Systems is a company dedicated towards bringing innovative solutions in the field of industrial automation and robotic integration. Operating over three stations and employing more than 300 shop-floor workers, the firm also works on one or two shifts daily lasting 8-10 hours. Kadence serves as a driving force for system integration within the automation sector and is leading the way into the new era of robotics-based manufacturing. The main parameters, like workforce distribution, gender distribution, age, qualification details and training types of this company, have been summarised in the below-given figures, Figure 1, Figure 2 and Figure 3.

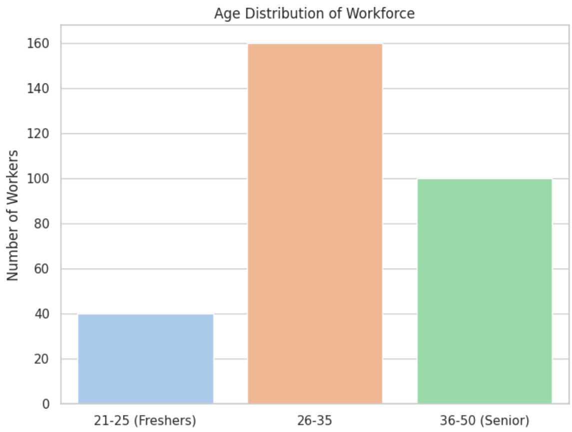

Figure 1: The given plot shows the age distri- bution of workforce in the company.

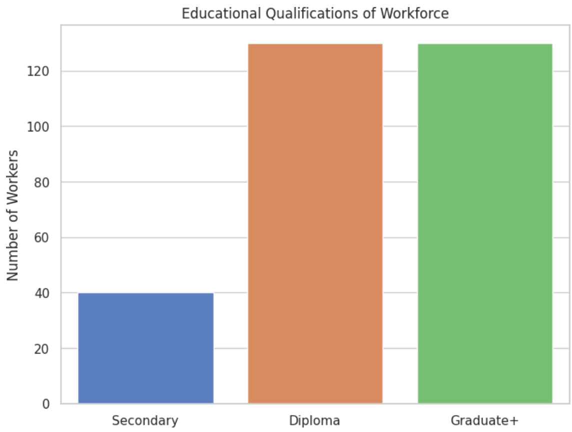

Figure 2: Education Qualification distribution in the company

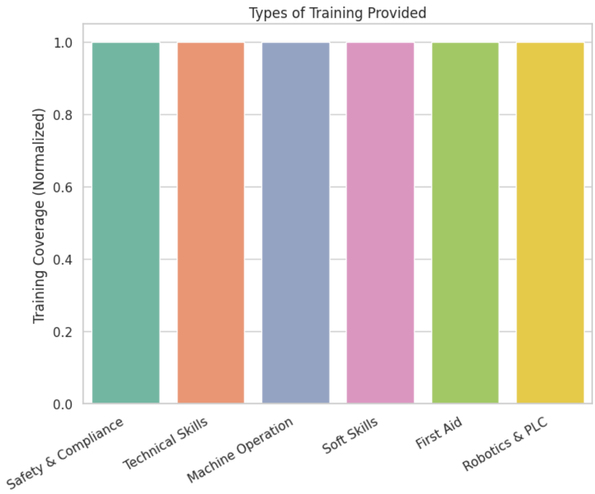

Figure 3: Types of difference training provided in the company

Training and skills development are at the core of Kadence's workforce strategy. Training is provided by the company on a regular basis, quarterly or as required, on technical and job- related skills, safety, soft skills, operating machines, and integration of robotics, including PLC programming and associated software. All employees are required to attend these sessions, and in-house trainers, external organizations, or OEM-specific trainers provide the training. The majority of training modules take 1 to 3 days and usually end with internal or external certification. Feedback processes and productivity assessment have shown that training has benefited the performance of employees.

For the future goals, extension of its training facilities further with the implementation of modular and blended e-learning and partnerships with certification organizations are the key areas for Kadence. Moreover, some other areas, like hands-on simulation laboratories and en- hanced digital communication and soft skills courses, are also important. Despite some major problems related to time limitations, budgetary restrictions, and sometimes low interest in non- core subjects, Kadence demonstrates strong commitment to upping the modernization of its workforce and catering to the increasing demand for human-robot collaboration in industrial settings.

Sarita Handa: Sarita Handa Exports Pvt. Ltd., a leading firm in luxury home furnish- ings based in Gurugram, Haryana, India, has built a strong reputation for integrating artisanal excellence with modern and automated production methods. The company operates across one to two shifts daily (8–8.5 hours each) and employs a large workforce of approximately 350-500 employees and 2500 contracted workers, comprising of artisans, home-based quilters, and sea- sonal shop-floor staff. Its product portfolio includes quilts, cushions, bedding, linens, drapes, and intricately embroidered and block-printed items.

Workforce distribution at Sarita Handa Exports reflects the company's focus on both tradi- tional craftsmanship and machine-based manufacturing. The workforce is primarily composed of skilled artisans and shop-floor operatives, many of whom have educational backgrounds rang- ing from eighth grade to higher secondary levels, aligning with industry practices for such roles. More technical roles such as machine handling and production are handed to workers with a diploma, and the design, management, quality and marketing are handled by graduates or higher. This distribution ensures that no one is over or underqualified for their job.

Training and skills development are central to Sarita Handa's human resource strategy. The company provides a range of skill training programs covering technical proficiencies such as machine operation (quilting, sewing, embroidery), workplace safety, and first aid. Training is often formalized, with certification reinforcing the attainment of standards. Assessment of pro- grams is systematic: every session is followed by feedback collection, and efficiency is measured using quality metrics, audits, certification rates, and production yield. Evidence suggests that training has led to improvements in worker productivity, as seen in reduced defect rates and increased order accuracy.

If we talk about the challenges, the company does face challenges, particularly in engaging workers on topics outside their core craft, such as compliance. Despite these challenges, Sarita Handa Exports is committed to expanding its training coverage, including plans to broaden its capabilities in printing, drapery, and wall-art, as well as to introduce new machinery and digital compliance systems. Upcoming initiatives also feature blended e-learning modules on safety, compliance, and soft skills, and building digital literacy for traceability and customized production pipelines. Overall, Sarita Handa Exports Pvt. Ltd. demonstrates a robust approach to workforce development, combining technical skill-building with a forward-looking commit- ment to digital transformation and worker well-being. This positions the company to maintain high standards of artisanal quality while embracing the evolving demands of the modern textile industry.

Matrix Cutting Tools: Matrix Cutting Tools Private Limited is an industrial SME fo- cused on the manufacture of precision cutting tools. The company operates from its main works in HSIIDC IMT, Faridabad, and typically runs one to two shifts per day, each lasting approx- imately 8 to 10 hours, to manage both production and testing requirements. The workforce includes a mix of permanent employees and around 20–50 contract or temporary workers, pri- marily engaged during periods of seasonal demand or for special, customized machining tasks. Support staff often consist of individuals with a high school education level, while the core technical, quality control, and R and D teams collectively have an average experience of 5–15 years, contributing significant domain expertise to daily operations. The visualization of work and gender distribution are given in Figure 4 and 5.

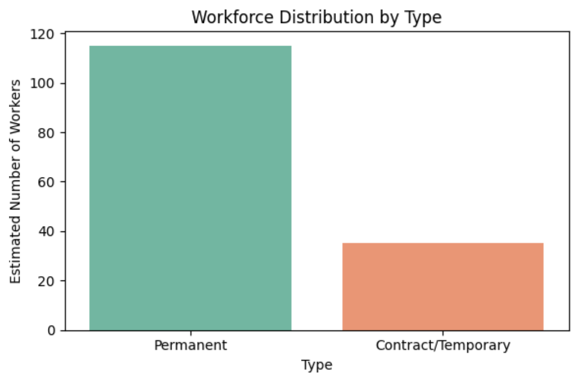

Figure 4: Work distribution in the factory

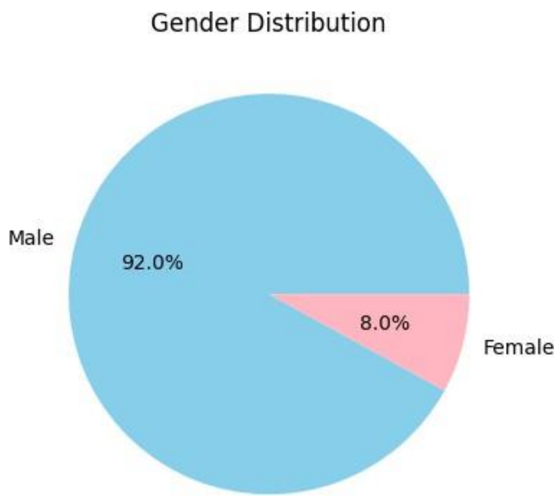

Figure 5: Gender distribution in the company

Training and skill development at Matrix Cutting Tools aids in balancing production dead- lines with the upskilling of employees. While regular training sessions are not always possible due to the production schedule, the management recognizes the importance of ongoing devel- opment—especially in technical skills, safety, and quality practices. Workers are periodically given training in line with advances in machining technology or quality control requirements, often conducted internally by experienced staff or external technical experts.

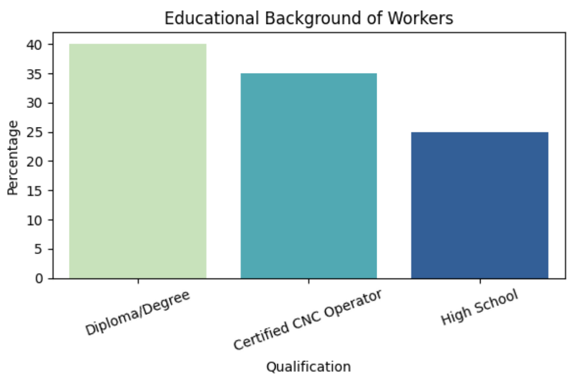

Figure 6: Education background of employees in the company

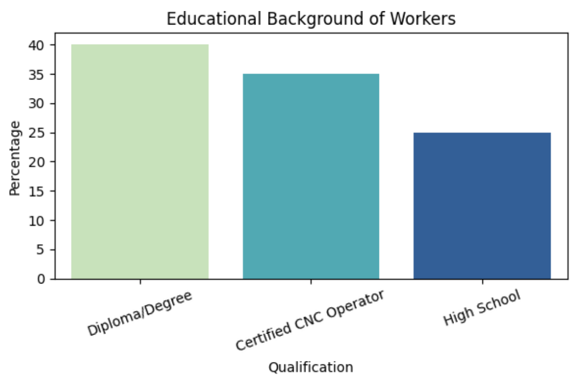

Figure 7: Education background of employees in the company

Recommended initiatives for enhanced training and workforce productivity involve increased training into production processes - that is, training workers across processes or machines, and providing more hands-on technical training sessions for less-skilled learners. There is also recognition of the value of certification in improving worker credibility and motivation. Nevertheless, there are still challenges, for example time constraints created by delivery dates, having a small budget for a formal training program, or less commitment from contract staff. Despite these drawbacks, Matrix Cutting Tools continues to pursue practical ways to upgrade its workforce, aiming to maintain high production standards and meet the evolving demands of the precision tooling market.

IFP Petro Products Pvt Ltd: This is a Sahibabad, Ghaziabad, Uttar Pradesh-based re-refining company that was founded in 1977. The factory re-refines used industrial and lubri- cating oils to manufacture industrial fuels and re-refined base oils. It has about 95 workers, two shifts of 8.5 hours each. There are approximately 60 permanent workers and 30–40 contract laborers, mostly male, with the age range of 25–55 years. The qualifications of the staff vary from engineering graduates and experienced technicians to high-school-educated support staff. However, this has no labor union, but the factory retains a balance of experienced and fresh recruits, with the majority having 5–15 years of experience.

This organization has put a huge importance on skill development and training, with quar- terly training programs on machine handling, safety, compliance, technical operations, and digitization, such as AI, IoT, and blockchain traceability. Training is made available for all employees, typically conducted by in-house experts, external agencies, or OEM trainers, and typically for 1–3 days per module. Employees become certified after training, and productivity improvement is seen, especially in compliance and safety. Challenges are round-the-clock oper- ations, limited budgets, and keeping employees interested in computer and technical modules. In the future, IFP plans to expand training to enable a new Greenfield refinery as well as dig- itization, with proposals including modular e-learning, partnerships with technology suppliers, simulation labs, and linking training outcomes with performance KPIs.

4 Results and Conclusion

This research probes the existing scenario of human-robot collaboration in different industrial environments by comparing four factories of Delhi-NCR: Metaval Engineering, Kadence Au- tomation, Matrix Cutting Tools, IFP Petro Products Pvt Ltd, and Sarita Handa Exports. These factories are analyzed from multiple perspectives, and we classified them into three types—manual, semi-automated, and automated—according to their usage of automation tech- nologies. These organizations are also involved in different industrial sectors, with varying mixes of workforce, business models, and technology readiness. The collected data and its interpre- tation show how automation maturity influences not only operational effectiveness but also training requirements for workers and planning strategy.

Kadence Automation is a completely automated factory with effective training schemes and the pioneer in robotics integration and collaboration with humans. Metaval Engineering continues to rely solely on manual processes, which presents significant challenges in terms of scalability, workforce management, and technological integration. Matrix Cutting Tools and Sarita Handa are semi-automated models moderately successful in introducing technology to the backbones of artisan or skilled labor structures. Sarita Handa formalizes its training programs, while Matrix Cutting Tools emphasizes technical excellence through experienced personnel and periodic skill development workshops. However, IFP Petro Products Pvt Ltd is a semi-automated warehouse, and the workforce of this warehouse remains vital under the existing model, although prospective automation and digitalization are anticipated to minimize the need for manual labor, simplify operations, and reorient labor demands toward higher technical and supervisory functions.

In this work, we have given an effective comparison and visualization over varied qualitative parameters of all the factories. For this the data was normalized to a common range of 0 to 1. For automation level, we provided categorical values: 0 for manual, 1 for semi-automated, and 2 for fully automated, which we used directly in the bar chart to show relative automation, given in Figure 8. In addition, for training availability and functionality, qualitative descriptions from each case study were translated into approximate numerical values by perceived intensity: for example, Kadence, with well-documented, frequent training programs, was scored around 1.0, while Metaval, with no training infrastructure, was scored lower (around 0.5). Similarly, high challenge-operational plants were labeled with higher challenge values (e.g., 0.9 for Metaval), while lower issue plants (e.g., Kadence) were assigned lower values. This method of scaling allowed us to convert qualitative results into comparative graphics without sacrificing the relative differences between the factories. The comparative visualizations are given below in Figure 9.

The method has disadvantages even though it is a source of useful qualitative information about the dynamics of Human-Robot Collaboration (HRC) in smart factories. First, because the research only took a small number of factory cases, the findings are unlikely to completely represent India and broader industrial environment. In addition, the data was gathered man- ually via questionnaires and interviews, which can be prone to human error in both recording and documenting even though they can capture nuances of complex views. Since most of the data was qualitative, the researcher a and interviewers views played a part in the assessment of the data which could create a degree of subjectivity or bias in the analysis. The barrier to devel- oping adequate models related to human workers and collaborative robots within HRC settings comes from the lack of trustworthy quantitative measures such as cost-benefit analysis, efficiency rates, or metrics to quantify real-time productivity. Finally, some inefficiencies or challenges may not have been as salient since much of the data was based on self-reported data provided by business representatives. All of these limitations underscore the need for mixed methods or other quantitative research moving forward, even though the research provides considerable exploratory contributions.

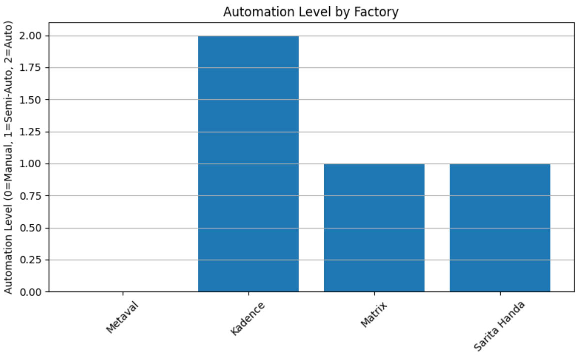

Figure 8: Automation level comparison of all the companies

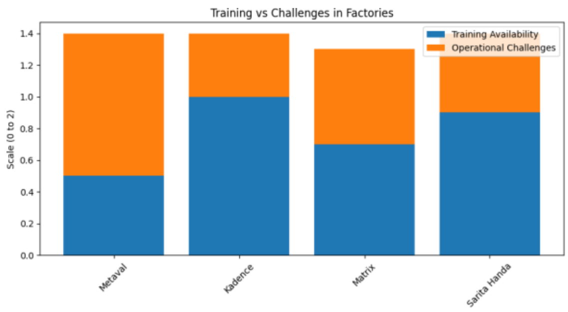

Figure 9: Training vs Challenges graph of all the companies

In each of the factories, we can observe a consistent pattern: effective automation and human-robot collaboration need more than investment in technology but also planned employee training, flexibility toward change, and planned upskilling. The future for these organizations is in embracing a phased model of automation, balancing technological progress with human capital development to achieve long-term scalability and efficiency.

This research concludes that Human-Robot Collaboration (HRC) is not an innovation in technology alone but is a socio-technical transformation of a complex nature needing to bal- ance human adaptability, training, and ergonomic needs with automation. Delhi-NCR factory diversity means successful robotics integration relies on tailored approaches to the abilities of the workforce, scalability of operations, and safety. While highly automated environments have some clear advantages in operational efficiency and consumer satisfaction, challenges such as dealing with custom components and deficits of specialist labor continue. Semi-automatic and manual plants underscore the paramount need for upskilling and flexible technology. Lastly, the revolutionizing power of HRC lies in its capacity to harmonize human ability with robotic precision, facilitating sustainable industrial growth that resists imminent innovation and labor transformation.

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