White Paper

Cobot Application in Battery Manufacturing

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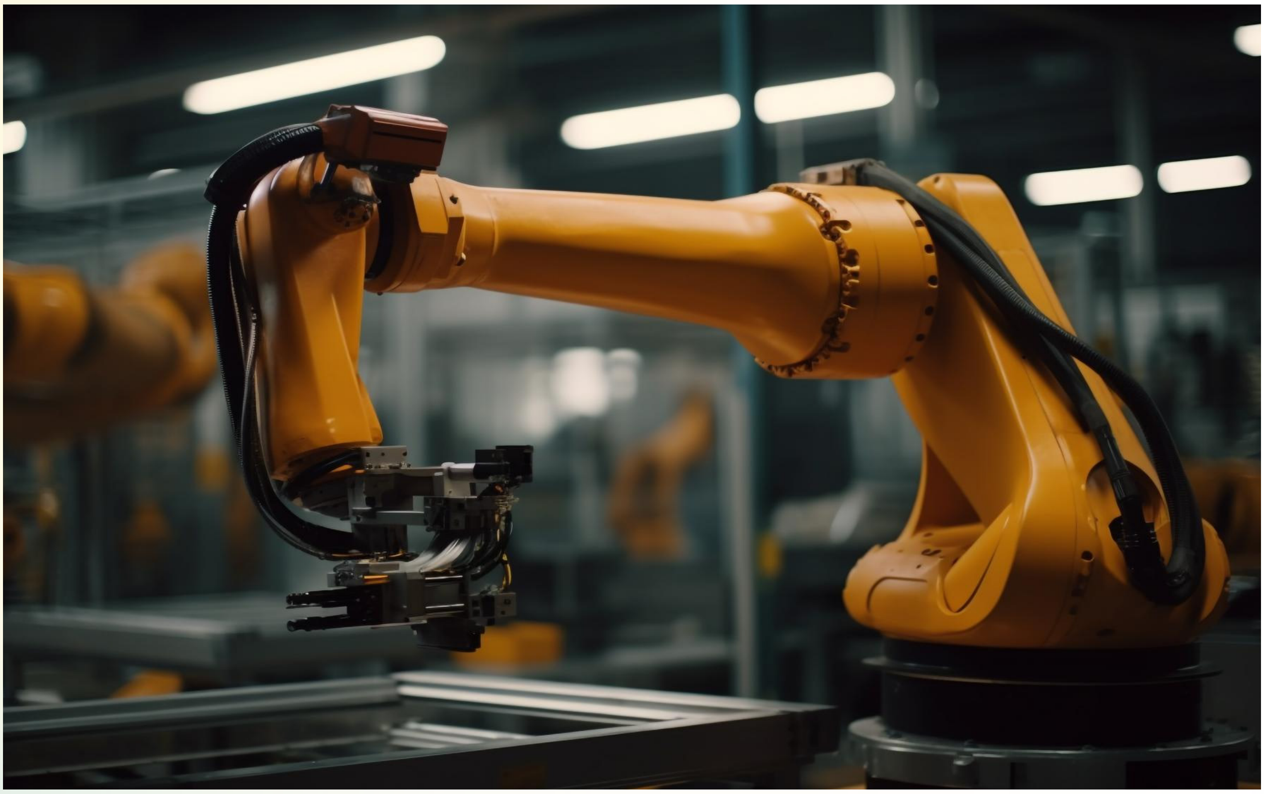
Abstract

The concept of Industry 5.0 involves humans collaborating with robots to improve efficiency and throughput for manufacturing organizations. This brings in the relevance of collaborative robots (cobots) that are user-friendly, affordable, and easily programable for applications like assembly lines, end-of-line testing, and quality inspections. Statista predicts that the market size of cobots worldwide is growing at ~11.8% CAGR between 2022 and 2030, and key drivers that support these are a reduction in prices of cobots, labor shortages, higher productivity usage, and finally, improvising human efforts on more cognitive work than on mundane tasks. One of the sectors highly disrupted by technologies is the automotive industry, where batteries are replacing traditional power packs like internal combustion engines. To cope with these technologies, original equipment manufacturers, and tier 1 electric vehicle battery suppliers are transforming their internal engine assembly lines to battery lines, and this process change is where cobots come in as an enabler and a perfect fit. The battery packs are lighter in weight, which makes them ideal for cobots. The cameras on the arms synced with computer vision provide real-time quality inspection, full-proof assembly with high repeatability, real-time visibility of productivity for each station, low assembly contamination, and zero accidents. These are a few drivers that stronghold the usage of cobots. This white paper focuses on enabling industry leaders to create a successful business case for cobots by deep diving into selection methodology using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)[1], economic feasibility, key considerations, and current industry use cases.



Industry landscape transformation

In addition to Industry 4.0, Industry 5.0 can make a meaningful contribution in terms of workforce development. Industry 5.0 makes it possible for high-quality workers and cooperation robots of all kinds to work side by side with each other, increasing production value as a result. As part of this evolving generation of machines, they use sensors, actuators, and AI-powered controllers that allow them to work side by side with humans in a safe and unobtrusive fashion. The cobots are flexible, easy to configure, safe, and simple to use. This whitepaper aims to make it easier for managers to understand the role that a cobot plays in a changing automotive sector and how CXOs can meet this objective in these difficult times of disruption. It's about robots helping humans work better and faster by leveraging advanced technologies like the Internet of Things (IoT) and big data. It adds a personal human touch to the Industry 4.0 pillars of automation and efficiency. In manufacturing environments, robots have historically performed dangerous, monotonous, or physically demanding work, such as welding and painting in car factories and loading and unloading heavy materials in warehouses. As machines in the workplace get smarter and more connected, Industry 5.0 has to merge those cognitive computing capabilities with human intelligence and resourcefulness in collaborative operations.

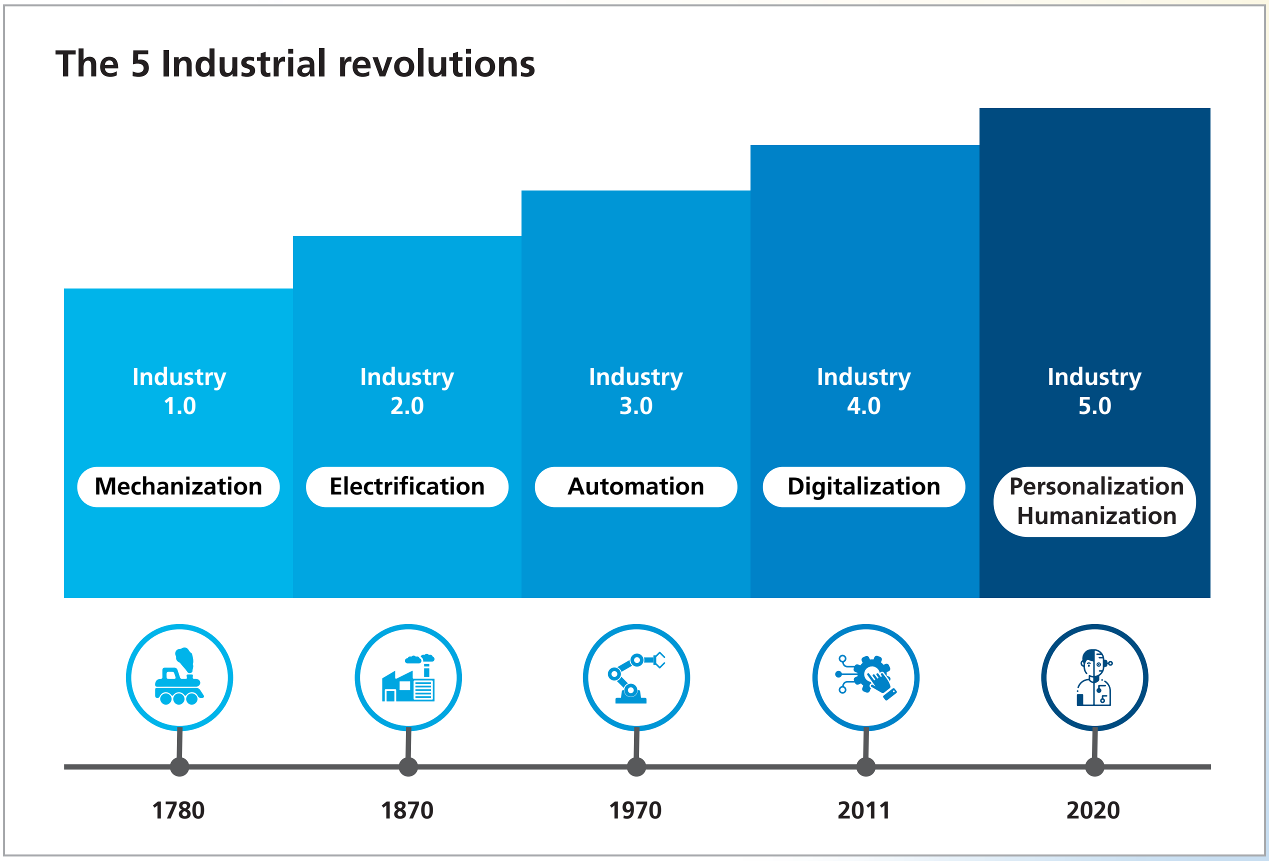


Figure 1: Industrial revolution 5.0-New Era

Key drivers

Cobots are a new form of workplace automation. They aim to improve productivity by freeing workers from dirty, dull, or dangerous work. Cobots also aim to enhance quality by eliminating contamination, errors, and variations. They also allow companies to reduce operating costs by replacing increasingly expensive workers with even cheaper machines. The following figure 2 shows the main drivers that are improving the adoption of cobots for manufacturing.

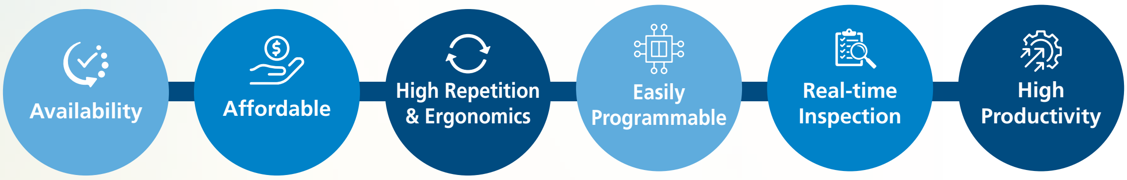


Figure 2: Key drivers for cobots

Availability: Cobots are becoming more readily available owing to the increased presence in the market of established and trustworthy suppliers, as well as aftermarket services support. Businesses now have access to a diverse range of cobot models from various manufacturers, and they can choose the model that best fits their specific needs.

Affordability: The affordability of cobots has been a notable factor contributing to their increased adoption, especially among small and medium-sized enterprises (SMEs). A few of the factors that facilitate affordability are market competition, economies of scale, modular designs, complementary training programs, and the use of open-source hardware and software platforms.

High repetition and ergonomics: Cobots may be able to take over tedious physical tasks such as loading and unloading, packaging small components with precision, or operating in a restricted workspace that makes operators more tired at regular intervals.

Easily programmable: Cobots have been designed for quick installation and integration, reducing the interruptions caused by implementation. The ability to rapidly deploy to build a proof of concept and implement automation without disrupting their daily operations is essential for businesses.

Real time inspection: A Cobot arm equipped with a camera can be a real game changer, as it provides real-time inspection when the task is executed. Integrated computer vision tech will help save a lot of money by eliminating secondary quality checks and ensuring consistent quality across the clock.

High productivity: Cobot's collaboration with human workers creates an ecosystem balance for tasks that require precision, strength, or repetitive actions. This collaboration enhances overall productivity by leveraging the strength of both human and robotic workers. Fully automated production lines can operate 24x7x365 days, which helps the operation's scalability based on market demand.

Battery plant of the future

The epoch of electric vehicle is about to arrive, and batteries are on the verge of becoming a major source of energy for mobility and sustainability. Cell manufacturers are adding large amounts of production capacity to capture market shares and economies of scale. But this effort is constraint by conventional manufacturing. The paper indicates that the most efficient means of making battery producers cost-effective in a market with optimal capacity is to improve their operating performance and the safety of the workforce. The concept of factory of the future for battery manufacturing encompasses around adoption of Industry 5.0 technology like cobot across battery manufacturing process and thereby achieve new heights of manufacturing excellence.

"Enterprises must adopt IR5.0 to enhance the operating performance and Safety of workforce"

The following figure 3 showcases the application of cobot in a conventional battery manufacturing setup. Figure 3 covers the typical manufacturing process for Li-ion batteries in tier 1 suppliers and original equipment manufacturers of 2-wheeler, 3-wheeler, and solar battery packs. Further, table 1 explains the advantages of implementing cobots.

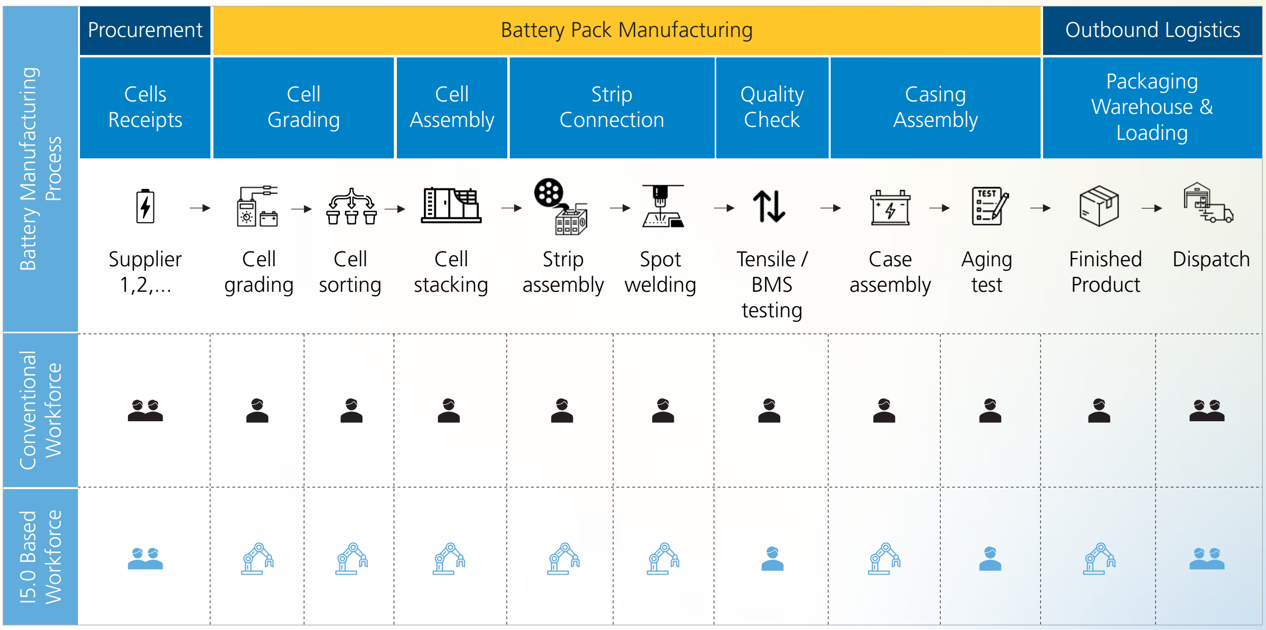


Figure 3: Battery manufacturing process and Industry 5.0 Workforce

Manufacturing process	Application of cobot	Advantages
Grading of the incoming cell	Quality assurance	• 100% verification of incoming cell • Reduced cycle time
Cell sorting	Pick and place	• Sorting is achieved on the basis of IR and voltage values • Worker safety • Reduced cycle time
Battery preparation	Assembly and quality assurance	Stacking and verification of battery
Welding	Fabrication	• Worker safety • Small batteries can be welded • Reduced cycle time
Product casing	Assembly	Reduced cycle time
Packaging	Packaging and palletizing	Reduced cycle time

Table 1: Advantages of deploying cobot on manufacturing

Commercial cobot selection

In practice, when there are multiple attributes for the selection of a cobot, the decision-making becomes highly tedious. Hence, to make this process simpler and to ensure faster adoption, associates should use the following framework for shortlisting their choices of cobots. The broadly classified selection criteria that needs to be considered as per the following sequence are showcased in figure 4.:

Figure 4: Considerations for cobot selection

In this paper, table 2 showcases indicative cobots details that are considered for illustrative purpose. All cobots have more than six degrees of freedom to suit the wide range of assembly and battery packaging requirements.

Name	Price (in USD)	Payload (in kg)	Approx. Reach (in mm)	DOF
Cobot 1	36,000	6	900	6
Cobot 2	46,000	4	550	6
Cobot 3	70,000	7	800	7
Cobot 4	35,000	1	600	6
Cobot 5	40,000	5	1000	7
Cobot 6	37,000	4	1300	7
Cobot 7	28,000	3	500	6

Table 2: Assembly application Cobots with >= 6 DOF, >=1Kg Payload & >=500 mm reach

To shortlist the top three cobot choices from the above list further, we will adopt the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) technique. It is a multi-criterion-based decision-making methodology that chooses the best alternative by calculating the shortest Euclidean distance from the ideal solution and the farthest distance from the negative ideal solution. TOPSIS gives a way to rank the available choices based on the weightage and impact of the factors considered.

Following are the steps involved in TOPSIS:

1. **Define criteria:** Identify the criteria that will be used to evaluate the alternatives. These criterias should be relevant to the decision problem and contribute to the overall objective.
2. **Normalize the decision matrix:** Normalize the decision matrix to ensure that the different criteria are on a similar scale. This step is crucial as it prevents criteria with larger numerical values from dominating the decision.
3. **Determine weights for criteria:** Assign weights to each criterion based on their relative importance in the decision-making process. The weights represent the significance of each criterion in achieving the overall objective.
4. **Construct the normalized decision matrix:** Multiply each element in the normalized decision-making by the corresponding weights to obtain the weighted normalized decision matrix. The weightage should be established by the end-user based on the application.

5. **Determine ideal and negative-ideal solution:** Identify the ideal solution (maximum values for each criterion) and the negative-ideal solution (minimum values for each criterion). These solutions represent the best and worst possible outcomes for each criterion.
6. **Calculate the separation measures:** Calculate the separation measures for each alternative from the ideal and negative-ideal solutions. The separation measures include the Euclidean distance or other distance metrics. The Euclidean distance for an alternative from the ideal solution is calculated as the square root of the sum of the squared difference between the normalized values of the alternative and the ideal solution.
7. **Calculate the relative closeness to the ideal solution:** Determine the relative closeness of each alternative to the ideal solution by dividing the anti-ideal separation measure by the sum of the ideal and negative-ideal separation measures.
8. **Rank alternatives:** Rank the alternatives based on their relative closeness values. The alternative with the highlighted closeness value is considered the best choice.

In the current scenario, the authors have contemplated the following subjective criteria and weightage shown in figure 5.

Extended Capability **(Weightage – 0.35)**

- 3 -> Easy: Built-in capability like force-torque sensors, grippers, and cameras.
- 2 -> Medium: Purchasable Library of tools availble that fit easily
- 1 -> Hard: Stand-alone robotic arm

Set-up Capability **(Weightage – 0.35)**

- 3 -> Easy: Whole application can be automated
- 2 -> Medium: Partial Pre-programmable applications
- 1 -> Hard: Traditional programming

Support Capability **(Weightage – 0.15)**

- 3 -> Easy: High capability to operate remotely
- 2 -> Medium: Partial capability to operate remotely
- 1 -> Hard: Very less capability to operate remotely

Cobot Cost **(Weightage – 0.15)**

- 3 -> High : >= 50,000 USD
- 2 -> Moderate: > 30,000 and < 50,000 USD
- 1 -> Low : < 30,000 USD

Figure 5: TOPSIS criteria and weightage

Cobot selection using the TOPSIS Technique

Based on the TOPSIS model, the following is the ranking order based on the relative closeness to the ideal solution:

TOPSIS Analysis for Cobot Selection

Technique for order preference by similarity to ideal solution (TOPSIS)

Name	Price (in USD)	Pay Load (in kg)	Approx. Reach (in mm)	DOF	Extended Capability (Weightage 0.35)	Setup Capability (Weightage 0.35)	Support Capability (Weightage 0.15)	Cobot Cost (Weightage 0.15)	Relative closeness to ideal Solution	Overall Ranking
Cobot 1	36,000	6	900	6	2	3	3	2	0.669	**3**
Cobot 2	46,000	4	550	6	2	1	3	2	0.383	5
Cobot 3	70,000	7	800	7	1	2	3	3	0.325	6
Cobot 4	35,000	1	600	6	1	2	1	2	0.299	7
Cobot 5	40,000	5	1000	7	3	3	3	2	0.864	**1**
Cobot 6	37,000	4	1300	7	3	2	1	2	0.646	4
Cobot 7	28,000	3	~500	6	2	3	3	1	0.701	**2**

Table 3: TOPSIS ranking framework for selecting the cobot closest to the ideal solution

Economic feasibility

In this section, the top three cobots are considered for economic feasibility study based on the ranking derived from TOPSIS analysis: Cobot 5, Cobot 7 and Cobot 1

Assumptions:

- The cobots can operate 24 hours/day. For Human Resources, 3 shifts/day have been considered
- The maintenance cost of the robot is neglected
- Cost of Capital = 10%, Dollar to INR conversion considered is 1 USD = INR 75
- Annual wage increment = 6%
- Project implementation and completion are considered to be one year
- The life of a cobot (investment) is considered for ten years
- Import duty & GST for robots = 26.85% (7.5% base custom duty and 18% GST)
- Additional accessories include custom grippers, cameras, and fixtures

Description	Cobot 5	Cobot 7	Cobot 1
Investment			
Cost of Robot incl. custome duty (7.5%)	₹ 32,25,000	₹ 22,57,500	₹ 29,02,500
Addition accessories	₹ 3,00,000	₹ 3,00,000	₹ 3,00,000
Total Capex cost of robot including 18% GST	₹ 41,59,500	₹ 30,17,850	₹ 37,78,950
Benefits			
Annual wage for operator (3 operators)	₹ 10,80,000	₹ 10,80,000	₹ 10,80,000
Benefits cost incurred by company (27.5% of wage)	₹ 2,97,000	₹ 2,97,000	₹ 2,97,000
Total saving from elimination of operator	₹ 13,77,000	₹ 13,77,000	₹ 13,77,000
Return Analysis			
Present value of total cash inflow for 10 years	₹ 1,06,56,282	₹ 1,06,56,282	₹ 1,06,56,282
Present value of total cash outflow for 10 years	(₹ 41,59,500)	(₹ 30,17,850)	(₹ 37,78,950)
NPV for the project (INR)	₹ 64,96,782	₹ 76,38,432	₹ 68,77,332
IRR for the project (%)	36%	50%	40%
Payback period for the project (in years)	2.9	2.1	2.6

Table 4: Economic feasibility calculations

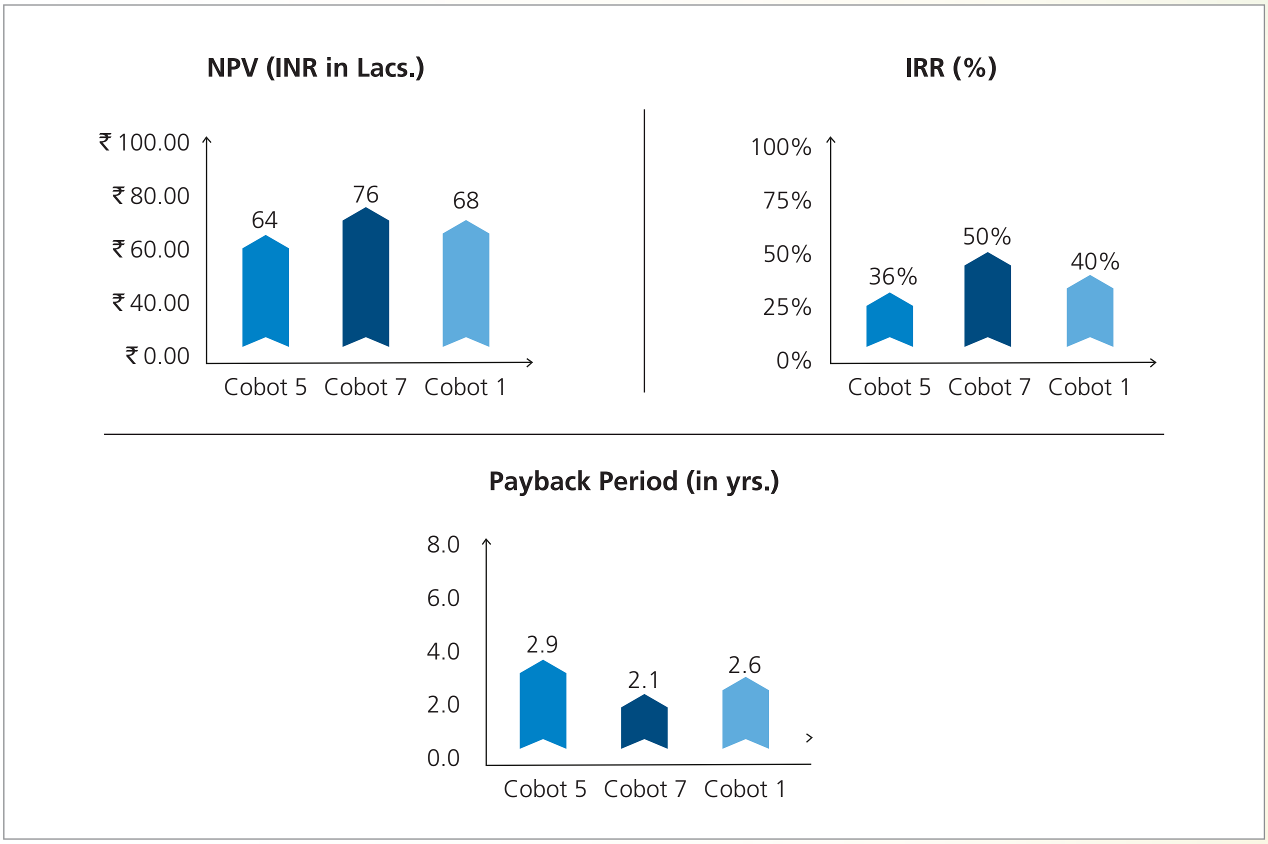


Figure 7: Return on Investment (ROI) calculation output

Use cases

Here are some of the most common industrial applications of cobots in battery manufacturing lines. The collaborative dimension has remarkably increased operation excellence.

	Fabrication and machining process: Many enterprises have been devastated by a surge in the number of cases of coronavirus in Texas, but the metal factory in Texas was run by eight cobots for a continuous period.
	Quality assurance: By putting cobots on production lines to carry out strenuous tasks, a leading two-wheeler manufacturer headquartered in Maharashtra is improving quality and empowering the workforce. There are about 150 cobots on the assembly line.
	Logistics: Third-party logistics company headquartered in Fremont, California, deployed an additional cobot -based fulfillment cell. This resulted in a staggering 500% increase in productivity, with the ROI for each robot being three months.
	Machining: Cobots can handle computerised numerical control machines, which leads to increased growth by 40% and can operate 24/7 in a CNC engineering company. Cobots were used by CNC-based businesses when skilled labor was in short supply during pandemic.

Sandboxing to production

When transitioning from a traditional assembly line to a cobot-enabled battery assembly manufacturing line, meticulous planning is indispensable. The first pivotal step involves identifying the bottleneck process in the manufacturing line, showcased in figure 3. Once the first bottleneck is pinpointed, sandbox the first cobot deployment in the specific task with adequate buffer inventory before and after to avoid any potential disruption to line flow. After the following deployment, monitor the cycle time to stabilize and optimize the process stage. This will also make workers accustomed to the new way of working alongside the cobot and eliminate any unprecedented anxiety. Simultaneously, sigma level validation for the specific tasks would be a crucial metric to affirm the level of process improvement and consistency.

As the assembly line stabilizes under first cobot deployment, the foundation is set for the introduction of a second cobot. Follow a similar process as the first cobot deployment till the seventh cobot deployment in the assembly line explained in figure 3. This will ensure a smooth, continuous integration and deployment of all cobots into the assembly line. For processes inherently reliant on human intervention, the maintenance of sufficient inventory serves as a buffer against potential disruptions and safeguards operational continuity. Validate the throughput for the traditional and the new human-cobot configuration assembly line to check the end state and as-is improvement.

Further deployment of cobots to convert the assembly line into a fully automated line will depend on the takt time and market demand. A similar feasibility study, along with the lesson learned, will be a vital factor in making this decision.

The orchestrated progression from manual assembly to human-cobot assembly line is analogous to the continuous integration and continuous deployment approach, delineating long lead for stages of conceptualization, implementation, and refinement. Just as software undergoes rigorous testing and validation before deployment, each cobot integration undergoes meticulous scrutiny, ensuring seamless assimilation into the assembly line ecosystem.

In essence, the journey toward cobot-human configuration in battery manufacturing epitomizes a meticulously orchestrated symphony of innovation and efficiency. By adhering to a structured methodology, the proof of concept materializes into a paradigm shift, heralding a new era of productivity and precision in assembly line operations.

Conclusion

Businesses and industry must remain at the forefront of current technological developments in automation to keep up with a fast, unpredictable environment where competition is becoming increasingly fierce. Businesses will have a realistic assessment of the benefits and limitations for cobots in terms of their efficiency, productivity, or security at work as well as how they can increase them if they take into account the possibility and possible use of these technologies.

The approach that has been proposed above in the field of battery manufacturing opens endless opportunities to integrate people and machines. In figure 8, the summarized framework of investment justifications for cobots is deduced.

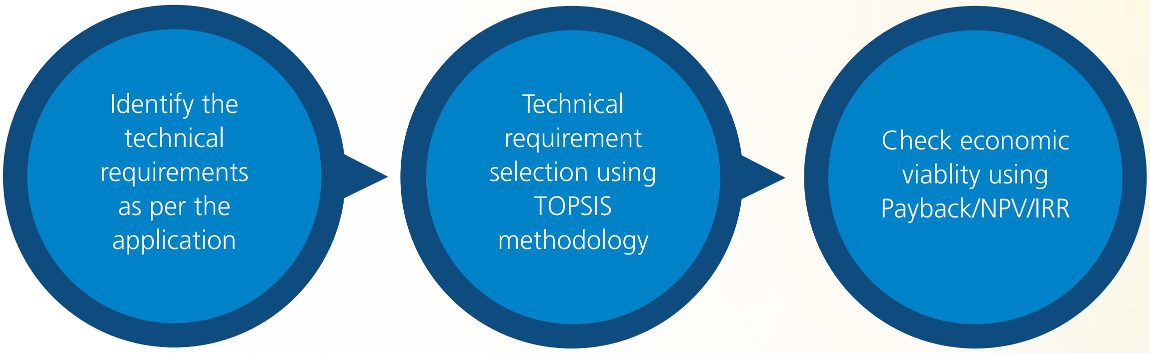


Figure 8: Framework for building cobot business case

As the use case of Industry 5.0 is still in its early stages, business leaders should actively plan how to connect human and machine workers with a view to maximizing the unique benefits that can be achieved as this movement progresses.

References

[1] *Technique for Order Preference by Similarity to Ideal Solution,* Methods for Petroleum Well Optimization, ScienceDirect, 2022: https://www.sciencedirect.com/topics/engineering/technique-for-order-preference-by-similarity-to-ideal-solution#:~:text=TOPSIS%20method%20has%20been%20developed,%2Dideal%20point%20%5B55%5D

About the Authors

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Vipin has 11+ years of experience in automotive, process and information technology. He has vast experience managing product development, solutioning and consulting to embrace NextGen Digital Technologies to drive operational excellence and business growth. He holds a postgraduate degree in automotive engineering and an MBA from IIM Calcutta.

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