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Strategic View on Cobot Deployment in Assembly 4.0 Systems

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Abstract: Collaborative robots (cobots) are intended to physically interact with humans in a shared workspace. While cobots research proliferated in the recent decade, only scant attention was given to the strategic consideration of deploying them. The obvious strategic consideration is related to economic cost-benefits trade-off. However, the economic decision is tightly tied to the technology improvement rate, as cobots lifetime expectancy strongly depend on the technological developments. In this regard, the difference between different types of cobots may be dramatic. Another strategic issue is the sociological effects including the reaction of the operators and unions to cobot deployment. This paper reviews the related literature and proposes a model to analyze the underlying factors and facilitate the decision making process of: where and when to deploy which cobots.

Keywords: Cobots, Industry 4.0, collaborative robot, robot collaboration, assembly 4.0, robot-human interaction.

1. INTRODUCTION

Collaborative robots (cobots) are intended to work alongside human-workers in a shared workspace (Malik & Bilberg, 2018). The idea of cobots is not new, and for a while their development has been slow and their integration in industry has been limited. In 2016, their US market share reached $100 million with annual growth rate of 50% (Djuric et al. 2016). Many papers assume the standard presence of cobots in Industry 4.0 settings (Bortolini et al. 2017). However, the decision on acquisition and deployment of cobots is a complex strategic decision (Fast-Berglund et al. 2016). It involves the timing of purchase and the cobots' lifetime expectancy, it involves the selection of work-stations for deploying the cobot, it also involves choosing between the various cobot types, and it even involves the social implications of deploying cobots (Romero et al. 2016).

Gil-Vilda et al. (2017) present a real case study of deploying cobots. Their framework is based on Roozenbergs's engineering design cycle (including simulation) for the deployment of cobots in existing assembly cells for enhanced productivity. However, cell's throughput is their only measure of effectiveness, and the economic dimension is missing. As shown in Table 1, the current literature touches many aspects of cobots. However, it leaves large gaps in the managerial and strategic decision making that this study seeks to fill. The benefit of Industry 4.0 is the reduction of internal operating costs through digital end-to-end integration. However, whether these costs weigh against the benefits left to be researched (de Man & Strandhagen, 2017). This challenge remains also for cobot technology, and this paper strives to close part of this gap.

Table 1. Examples of cobot deployment aspects dealt by the literature

Cobot deployment aspect	References
Business model	Johansson et al. 2016; de Man & Strandhagen, 2017; Fast-Berglund 2016
Deployment framework	Djuric et al. 2016 ;Bortolini et al. 2017
Collaboration	Vysocky & Novak 2016; Tamas & Murar 2018
Task assignment: cobot vs human	Malik & Bilberg, 2018;Rosati et al. 2013
Cobot type selection	Chatterjee et al. 2010; Ic et al. 2013; Yurdakul and Dengiz 2013 Parameshwaran et al. 2015; Ghorabaee 2016; Koch et al. 2017
Safety	Guiochet et al. 2017
Cobot Deployment case-study	Gil-Vilda et al. 2017 Devi 2011
Socio economic perspective	Virgillito 2017; Dekker et al. 2017; Makridakis 2017; McClure 2018
Human-centric perspective: I 4.0	Romero et al. 2016 Vysocky & Novak 2016 Smith & Anderson 2014 Malik & Bilberg, 2018

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The rest of the paper is structured as follows: section 2 discusses the necessity of cobots in the assembly line, section 3 describes the considerations of lifetime deployment of cobots and its related financial considerations; section 4 focuses on the cobot selection considerations; section 5 describes the psychological and sociological aspects of deploying cobots. Finally, section 6 concludes the paper.

2. THE NECESSITY OF COBOTS IN ASSEMBLY LINES

In assembly lines, the flow of material is usually linear, and the bottleneck station dictates the production rate (throughput) for the entire line. A single station that holts its production can stop the entire line. Furthermore, a failure in one workstation can affect previously completed tasks in other workstations (Shoval et al. 2017). It is, therefore, that preventing such occurrences may justify large expenses. However, at first sight it is not at all clear that deploying cobots is related to this issue. A deeper analysis is required to establish the connection.

2.1 Analysis by type of station

To begin the analysis, we can observe that assembly-line work-station has mainly three possible types (Rosati et al. 2013):

(1) Fully automated process performed by a fully automated station.

(2) Semi-automated process performed by both a human worker and automated machinery (such as robots). In Industry 4.0 context this is mainly where cobots are deployed (Malik & Bilberg, 2018).

(3) Fully manual process performed fully by a human worker.

Automated workstations are usually very costly (in comparison to manual stations) due to high cost of equipment and setup, and require high skilled personnel for its maintenance. Their advantages are related to minimal variations in performance over time and performance quality. As long as there is no equipment failure, fully automated workstations do not become bottlenecks. They are typically built so that their function is precise and repetitive, and its process duration is preplanned to keep the material flow in order. Assembly lines all over the world went through a process of automating large number of stations. However, automation of the assembly lines is a long term process, and human operators are expected to remain in significant number of stations in most assembly lines through the Industry 4.0 era (Romero et al. 2016; Cohen et al. 2017).

Fully manual workstations, on the other hand, have several occasions where they may become a bottle neck:

(1) Replacement of an absent trained worker with a new one that has to learn the job from scratch.

(2) Human production error that resulted in rework on the work piece.

(3) Fatigue: rate deterioration.

(4) Loss of concentration and rate deterioration

(5) Fixing quality defects of prior stations

It is clear that in some of these occasions, a manual station may become a bottle-neck. However, cobot integration into that manual station relieves the worker from some part of the work and increases the station productivity and speed, eventually preventing the station from becoming a temporary bottleneck.

2.2 Where should cobots be deployed

As discussed, cobots should be assigned to manual stations that may become a temporary bottleneck for any reason. This is exactly where cobots are economically justified. Since a cobot collaborates with a human worker in a shared workspace – the deployment of cobot is by definition done in a partly manual workstation (the shared space). So, the work station to be compared is composed of a human and a cobot. If a cobot helps in keeping its station throughput rate high enough so that its processing time is below the line's cycle times – its savings are proportional to the throughput saved. Thus, if the savings are greater than the robot's implementation cost, its deployment is financially justified.

2.3 Computational Example

The following example is simplistic and is given just to provide a sense of the magnitude required for justifying the cobot purchase and deployment.

For the example, assume that a cobots expected life-time is 5 years, so the cobot's cost is justified only from a specific threshold percentage of the five-year throughput. To continue the example, consider an automotive-line that has 250 work-day per year that produces 1,000 cars a day (or 250,000 cars per year), and sells each car for $ 5,000. The automotive-line has a five-year annual throughput worth $ 6,250,000,000. Thus, a cobot that costs $ 35,000 and has 5 years operational costs of $ 35,000, is justified as long as it saves more than $ 70,000. This is more than 1.4% of one day throughput in five years (or 0.014 of 1,250 work-days). So, as long as a fully manual station has a chance (absenteeism, turnover, failure or delay) of becoming a bottle neck for more than 7 minutes in a five years of operation – the addition of a cobot with five year cost of $ 70,000 (including operation) should be justified.

As will be discussed in the next sections, the above example is simplistic and ignores important strategic considerations.

3. LIFETIME DEPLOYMENT CONSIDERATIONS

Currently, the prices of cobots are related to their sophistication level. However, prices of new technologies permanently decline over time as experience improves the efficiency, and new competing technologies are developed (Jaber, 2016). Experience shows that the price of a new product behaves in a similar manner to wright's classic learning curve model (Egelman et al. 2016; Dosi et al. 2017). It is also expected that in the next decade or so, several events, spaced in time, will mark the addition of new technologies (with their learning curves) into the world of cobot deployment. This process is depicted in Fig. 1.

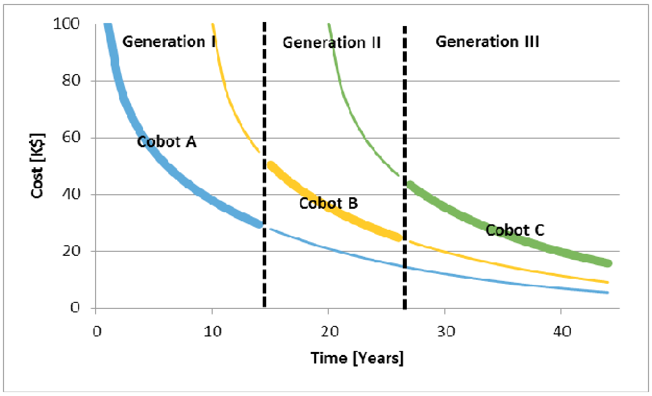

Fig. 1. Example of schematic price graph for 3 generations of cobots, and their deployment timing (in bold).

While considering the cost benefit tradeoff related to cobot deployment, there are two major points in time that have to be considered: these are the start and the end of the cobot deployment. These points are related to the wear and maintenance cost of the current cobot which increases with the cobot's age, and the decreasing price of new cobots (as depicted in Fig. 1). The additional benefits come from new capabilities of the new cobot (utilizing next generation technologies). The overall cost structure is depicted in Fig. 2.

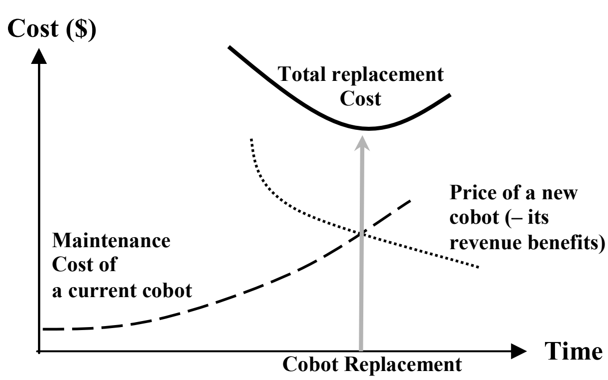

Fig. 2. Schematic graph depicting the cost structure leading to a cobot's replacement by a new one.

4. COBOT SELECTION CONSIDERATIONS

4.1 prior research on cobot/robot selection

Multiple studies were made to achieve the objective of scoring and evaluating the selection parameters of cobots through various scientific analysis e.g. mathematical, statistical, simulations etc. (Ic Yurdakul and Dengiz, 2013). Early research on selecting a robot is summarized in Chatterjee et al. (2010) which classified attributes or properties of an industrial robots as follows:

1.1. **Objective properties**: e.g. payload, working envelope, accuracy, repeatability, cost etc. Their values are numerically defined.

1.2 **Subjective properties**: e.g. programming flexibility, operational flexibility, vendor's service quality etc. Their value is qualitative in nature.

2.1 **Beneficial properties**: e.g. load carrying capacity, maximal reach etc. (whose higher values are desirable)

2.2 **Non-beneficial properties**: e.g. cost, repeatability etc. (whose lower values are desirable)

Ic et al. (2013) presented a literature review of 19 studies for robot evaluation that enlists various sets of parameters used for the evaluation method. Parameshwaran et al. (2015) treated 15 objective criteria and 7 subjective criteria. The following objective parameters were found to appear in most studies:

- Price
- Degrees of freedom (number of axes)
- Payload
- Repeatability
- Positioning accuracy
- Working volume
- Velocity or tip speed

The popular subjective criteria in most studies are:

- Stability
- Man–machine interface
- Compliance
- Programming flexibility/ simulation quality
- Quality of robot supplier and its service

Ghorabaee (2016) developed a multi-criteria decision making (MCDM) method for robot selection with fuzzy sets which continues a line of research based on fuzzy sets (e.g. Parameshwaran et al. 2015).

4.2 Current cobots and their main characteristics

There are several commercially available cobots with varying capabilities and strengths. It is critical to select a cobot that best suits to the needs of the assembly system (Malik & Bilberg, 2018).

As of January 2019, some examples of available 7 axis cobots are: the UR3, UR5, and UR10 of Universal Robotics (the number following "UR" designates maximal payload in kilogram), Yumi (two arms) of ABB, LBR iiwa (single arm) of Kuka, and of OB7 of Production Robotics. Examples of popular 6 axis cobots are: CR-35iA of FANUC, Jaco2 and Mico2 (single arm robots) of Kinova, OUR-1 of AUBO, and Racer3, Racer5 of Comau (designating 3 and 5 kg payload, respectively). Only few cobots exist with less than 6 axes per arm, for example: DuAro (dual arm) of Kawasaki. All of the above is a very partial list of contemporary cobots – but it represents the current cobot capabilities: they all are safe to work with (they stop when touching anything that may feel like unexpected solid body). Most cobots have one or two arms and 6 to 7 axes. Typical parameter ranges of current cobots are:

- Payloads between 0.5 to 15 kilograms
- Max reach: 0.5-1.5 meters
- Repeatability 0.01-0.08 millimeter (mm)

The main differences between current cobots and future ones in Industry 4.0 setting are related to additional capabilities as discussed in the next sub-section

4.3 Industry 4.0 cobots - additional criteria

In addition to the properties/criteria described above, Industry 4.0 brings capabilities to cobots in the following areas:

- Mobility
- Intelligence
- Connectivity
- Cobot movement coordination

In terms of *mobility*, the following types of cobots are expected to operate in I-4.0 shop floors.

1. Stationary cobot: rooted in one place at a work-station.
2. Movable (wheeled) cobot: moved by the operator every time a different basis for the cobot location is desired.
3. CAGV based cobot: a cobot that moves according to its assigned tasks in predetermined routes.
4. Fully autonomous mobile cobot: self-managed cobot.

In terms of *Intelligence*, any combination of the following types of intelligence are expected to operate in I-4.0 shop floors. Typically in ascending order.

1. Task related intelligence (handling any information related to the task, e.g., measurement and quality control).
2. Self-aware intelligence (awareness of the cobot status, processes and trends).
3. Context aware intelligence (awareness of the processes in the surroundings, status of neighbouring objects, their processes and trends).
4. Human aware intelligence (awareness to the worker/s and their energetic and emotional status).

In terms of *connectivity*, cobots are expected to operate the following levels in I-4.0 shop floors. Typically in ascending order.

1. Communication related to measurements and quality issues (both for incoming WIP, and outgoing products).
2. Communication processing and maintenance requests, and to negotiating the cobot work schedule.
3. Communication related to cobot status and scheduling maintenance based on self-evaluation.
4. Communications with a human worker.

In terms of *cobot movement coordination*, cobots are expected to operate the following levels in I-4.0 shop floors. Typically in ascending order.

1. Precise verified placement.
2. Trajectory visual analysis and fault identification.
3. Camera feedback-accompanied movement with real-time movement amendments.
4. Coordinating work with a human worker.

5. PSYCHOLOGICAL & SOCIOLOGICAL CONSIDERATIONS

A prevalent misconception of Industry 4.0 is that it is about human workers replaced by machines (Smith & Anderson 2014; Royakkers, & van Est 2015; de Graaf 2016; Makridakis 2017). This misconception still exists, and is partly related to technophobes (McClure 2018), or appears in social studies that either are based on the past, or that are based on classic robots rather than cobots (e.g., Virgillito 2017; Dekker et al. 2017). In fact, most of Industry 4.0 capabilities are directed at improving the human worker productivity rather than replacing the human (Gorecky et al. 2014; de Graaf 2016; Romero et al. 2016; Cohen et al.2017). The main difference between a robot and a cobot is that a robot has a work envelop to which no one should enter (especially no human), so robots are separated from humans. A cobot, on the other hand, works alongside a human operator in a shared space. In addition to being extra safe to work with, cobots have friendly interface, and are built to be easily taught to execute new tasks (Gorecky et al. 2014). All of the above are about to make workers feel comfortable working next to cobots.

While regular robotics did replace humans, cobots are helpers of the operators and are not intended at all to replace them. Most factory managers realize that the human operator is the most flexible resource, and that replacing workers may cause loss of flexibility. The human operators will need to be retrained and upskilled to replace their manual production tasks with more supervisory and monitoring roles (Fletcher & Webb 2017). In addition, the presence of cobots in the shop floor is expected to add more technicians that are expert on cobot maintenance (Stock & Seliger 2016). So eventually, the amount of workforce in the shop floor is not going to change dramatically during I-4.0 era. Moreover, the fear of humans replaced by automation should subside considerably, as understanding that human and cobots form teams, and that cobot help sustain the human presence in assembly lines, rather than eradicate the human presence.

6. CONCLUSIONS

This paper describes the main considerations related to a deployment decision of a cobot in an assembly line. It reviews the related literature, and discusses the motivation for using cobots in assembly lines, the effect of acquisition timing and its economic trade-off, the selection of a cobot from a list of available cobots, and their expected sociological and psychological effect. One conclusion that could be attained is that as long as there are human workers in workstations along the assembly line, the consideration of cobots will remain relevant. In future years, as Industry 4.0 settles in, the cobot acquisition will be related to strategic decisions in four different dimensions: (1) Mobility, (2) Intelligence, (3) Connectivity, and (4) Cobot movement coordination. It is should be clear from section 5 that cobots will not reduce the overall number of human employees (as they are operated and maintained by humans), and they can pave the way for easier acceptance of automation by the public. Finally, future research may investigate how to improve cobot deployment and take full advantage of the simultaneous developments in AI, communications and mobility (in particular, coordination).

REFERENCES

Bortolini, M., Ferrari, E., Gamberi, M., Pilati, F., & Faccio, M. (2017). Assembly system design in the Industry 4.0 era: a general framework. *IFAC-PapersOnLine*, 50(1), 5700-5705.

Chatterjee, P.; Athawale, V.M. & Chakraborty, S. (2010). Selection of industrial robots using compromise ranking and outranking methods, *Robotics and Computer-Integrated Manufacturing*, 26(5), 483–489

Cohen, Y., Faccio, M., Galizia, F. G., Mora, C., & Pilati, F. (2017). Assembly system configuration through Industry 4.0 principles: the expected change in the actual paradigms. *IFAC-PapersOnLine*, 50(1), 14958-14963.

de Graaf, M. M. (2016). An ethical evaluation of human–robot relationships. *International journal of social robotics*, 8(4), 589-598.

Dekker, F., Salomons, A., & Waal, J. V. D. (2017). Fear of robots at work: the role of economic self-interest. *Socio-Economic Review*, 15(3), 539-562.

de Man, J. C., & Strandhagen, J. O. (2017). An Industry 4.0 research agenda for sustainable business models. *Procedia CIRP*, 63, 721-726.

Devi, K. (2011). Extension of VIKOR method in intuitionistic fuzzy environment for robot selection. *Expert Systems with Applications*, 38(11), 14163-14168.

Djuric, A. M., Urbanic, R. J., & Rickli, J. L. (2016). A framework for collaborative robot (CoBot) integration in advanced manufacturing systems. SAE *International Journal of Materials and Manufacturing*, 9(2), 457-464.

Dosi, G., Grazzi, M., & Mathew, N. (2017). The cost-quantity relations and the diverse patterns of "learning by doing": Evidence from India. *Research Policy*, 46(10), 1873-1886.

Egelman, C. D., Epple, D., Argote, L., & Fuchs, E. R. (2016). Learning by doing in multiproduct manufacturing: Variety, customizations, and overlapping product generations. *Management Science*, 63(2), 405-423.

Fast-Berglund, Å., Palmkvist, F., Nyqvist, P., Ekered, S., & Åkerman, M. (2016). Evaluating Cobots for Final Assembly. *Procedia CIRP*, 44, 175-180.

Fletcher, S. R., & Webb, P. (2017). Industrial Robot Ethics: The Challenges of Closer Human Collaboration in Future Manufacturing Systems. In *A World with Robots* 159-169. Springer, Cham.

Gil-Vilda, F., Sune, A., Yagüe-Fabra, J. A., Crespo, C., & Serrano, H. (2017). Integration of a collaborative robot in a U-shaped production line: a real case study. *Procedia Manufacturing*, 13, 109-115.

Ghorabaee, M. K. (2016). Developing an MCDM method for robot selection with interval type-2 fuzzy sets. *Robotics and Computer-Integrated Manufacturing*, 37, 221-232.

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014, July). Human-machine-interaction in the industry 4.0 era. In *Industrial Informatics (INDIN), 2014 12th IEEE International Conference*, 289-294.

Guiochet, J., Machin, M., & Waeselynck, H. (2017). Safety-critical advanced robots: A survey. Robotics and *Autonomous Systems*, 94, 43-52.

Ic, Y.T.; Yurdakul, M. & Dengiz, B. (2013). Development of a decision support system for robot selection, *Robotics and Computer-Integrated Manufacturing*, 29(4), 142–157.

Jaber, M. Y. (2016). *Learning curves: Theory, models, and applications*. CRC Press.

Johansson, A., Christiernin, L. G., & Pejryd, L. (2016). Manufacturing system design for business value, a holistic design approach. *Procedia CIRP*, 50, 659-664.

Koch, P. J., van Amstel, M. K., Dębska, P., Thormann, M. A., Tetzlaff, A. J., Bøgh, S., & Chrysostomou, D. (2017). A Skill-based Robot Co-worker for Industrial Maintenance Tasks. *Procedia Manufacturing*, 11, 83-90.

Malik, A. A., & Bilberg, A. (2018). Framework to implement collaborative robots in manual assembly: A Lean automation approach. *Annals of DAAAM & Proceedings*, 1151-1161.

Makridakis, S. (2017). The forthcoming Artificial Intelligence (AI) revolution: Its impact on society and firms. *Futures*, 90, 46-60.

Maurice, P.; Padois, V.; Measson, Y. & Bidaud, P. (2017). Human-oriented design of collaborative robots, *International Journal of Industrial Ergonomics*, 57, 88–102.

McClure, P. K. (2018). "You're Fired," Says the Robot: The Rise of Automation in the Workplace, Technophobes, and Fears of Unemployment. *Social Science Computer Review*, 36(2), 139-156.

Parameshwaran, R., Kumar, S. P., & Saravanakumar, K. (2015). An integrated fuzzy MCDM based approach for robot selection considering objective and subjective criteria. *Applied Soft Computing*, 26, 31-41.

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., & Gorecky, D. (2016). Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies. In: I*nternational conference on computers and Industrial Engineering (CIE46*) 1-11.

Rosati, G., Faccio, M., Carli, A., & Rossi, A. (2013). Fully flexible assembly systems (F-FAS): a new concept in flexible automation. *Assembly Automation*, 33(1), 8-21.

Royakkers, L., & van Est, R. (2015). A literature review on new robotics: automation from love to war. *International journal of social robotics*, 7(5), 549-570.

Shoval, S., Efatmaneshnik, M., & Ryan, M. J. (2017). Assembly sequence planning for processes with heterogeneous reliabilities. *International Journal of Production Research*, 55(10), 2806-2828.

Stock, T., & Seliger, G. (2016). Opportunities of sustainable manufacturing in industry 4.0. *Procedia Cirp*, 40, 536-541.

Smith, A., & Anderson, J. (2014). AI, Robotics, and the Future of Jobs. *Pew Research Center*, 6.

Tamas, L., & Murar, M. (2018). Smart CPS: vertical integration overview and user story with a cobot. International *Journal of Computer Integrated Manufacturing*, 1-18.

Terziyan, V., Gryshko, S., & Golovianko, M. (2018). Patented intelligence: Cloning human decision models for Industry 4.0. Journal of Manufacturing Systems.

Virgillito, M. E. (2017). Rise of the robots: technology and the threat of a jobless future. *Labor History*, 58(2), 240-242.

Vysocky, A. L. E. S., & Novak, P. E. T. R. (2016). Human-Robot Collaboration in Industry. *MM Science Journal*, 9(2), 903-906.