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A New Cobot Deployment Strategy in Manual Assembly Stations: Countering the Impact of Absenteeism

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Abstract: This paper discusses a new strategy for deploying cobots in assembly lines having manual stations. The paper first presents the contribution of absenteeism to the temporary appearance of bottle-neck stations and the resulted lost throughput. It then delineates some barriers and obstacles of cobots' deployment in these stations. Finally, it discusses the advantages of employing a cobot-specialist for a defined segment of the assembly line. The suggested role of the cobot-specialist is to quickly find ways in which a cobot will alleviate the work of a temporary workers filling positions of absentees. Such replacement workers are in their early stages of their learning curve, and are considerably slow, with high chances of becoming a bottleneck. A bottleneck station dictates the pace of the whole line and reducing its cycle-time, increases the throughput of the whole line. Thus, the suggested approach prevents throughput losses due to absenteeism. Having a line-segment specialist that is familiar with the various stations in his/her segment ensures both having some pre-prepared schemes of cobot deployment for each station, and the ability of rapid installation of the cobot. Moreover, replacement workers typically are too busy to deal with the cobot's installation or operation. The approach is validated using ARENA simulation scenarios for various line segments.

Keywords: Cobot, Collaborative robot, Absenteeism, Assembly line, Bottle-neck, Human-Machine Interaction.

1. INTRODUCTION

Cobots are collaborative robots that share the same workspace with the human operators (Tamas, & Murar, 2018). Cobots are suited for work in assembly-lines (Cohen et al. 2017, Bortolini et al. 2017). Some examples of real cases of cobots integration in an assembly lines appear in: Fast-Berglund et al. (2016), Gil-Vilda et al. (2017), and El Makrini et al. (2018). However, there is no standard approach to justify the use of a cobot in assembly lines and no standard method exists for a cobot integration into an assembly station. The main objective of this paper is to analyse cobot-deployment in assembly lines and suggest how cobots should be deployed in reducing the loss of throughput caused by absenteeism and turnover (A&T). When absent experienced workers are replaced by inexperienced ones a major slowdown occurs, causing new bottlenecks and throughput loss in industrial lines. The performance of the inexperienced substitute worker follows a learning curve, characterized by long initial cycle times (Cohen, 2012). Consequently, a replacement worker is a potential bottleneck for the whole line during the worker's early-learning period. Since a single replacement can cause (as a bottleneck) a significant reduction in the line's throughput, this issue concern's assembly lines managers, and is more problematic for long lines with many workstations (Cohen 2012, Bukchin & Cohen, 2013). In such lines workers substitution due to absenteeism happen daily. Worker absenteeism during a shift may occur due to illness errands, vacations, special occasions, etc. Turnover may occur as a result of family move, career move, personal or health constraints, retirement or a layoff decision. So in long lines, many of the stations, the turnover and absenteeism are a daily occurrence (Frick et al. 2018).

Both absenteeism and turnover require a substitution of an experienced person by an inexperienced one. In case of absenteeism, an inexperienced worker replaces the absentee for a time slot (e.g., a shift). In the case of turnover, the inexperienced worker is assigned for an unlimited amount of time. In the two cases, the performance of the new worker follows the learning curve. For absenteeism the learning curve typically lasts until the end of the shift, and for turnover it lasts until reaching the steady state (Bukchin & Cohen, 2013).

This paper analyses the potential of pre-programmed cobots to collaborate with replacement workers to reduce their load and accelerate their learning process. This would enable reducing the throughput loss resulting from A&T.

We start by analysing the effect of A&T on the line throughout assuming no cobots are used. Next, we discuss considerations for cobot's deployment and develop a framework for deploying cobots to counter the effects of A&T on the throughput.

Deployment of substitute workers are the major cause for longer station cycle times which slow the whole line.

However, deploying cobots in these stations with substitute workers, can reduce the cycle-time and keep it close or even below the takt-time. The effect of deploying a cobot in such a station with a substitute worker is depicted in figure 1.

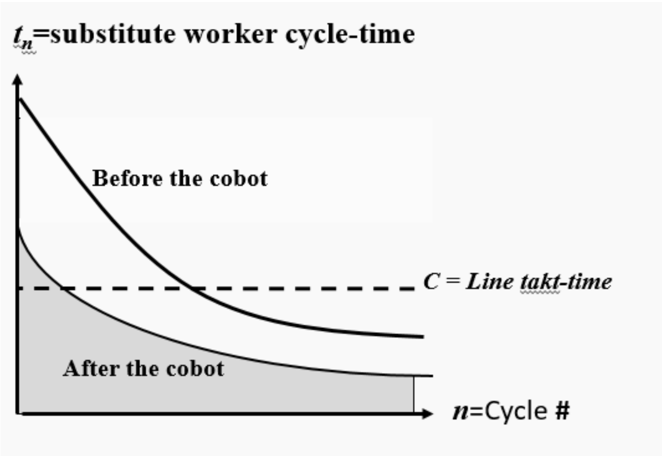

Fig. 1. Example of substitution worker's learning curve before and after cobot deployment.

In figure 1 the first part of the learning curve above the takt-time reflects the part where the replacement worker is likely to become a bottle-neck to the whole line. The area between the learning curves and the takt-time is the lost time due to the learning curve. As shown in figure 1, this area is greatly reduced by the cobot.

The analysis in the coming sections clearly shows that cobots can significantly reduce the learning period and minimize the time to reach under the line's takt-time. The rest of the paper is organized as follows. Section 2 reviews the literature; section 3 gives a numerical example for cobot's justification, while solution framework is presented in section 4. Section 5 concludes the paper.

2. LITERATURE

The slowdowns, caused by inexperienced replacement workers in assembly-lines, reduce throughput significantly (Bukchin & Cohen, 2016). Cobots can accelerate manual work by performing part of the work, and assisting by holding parts or tools in convenient locations and convenient orientations (Cohen et al. 2019). Therefore, this paper examines ways to using cobots to help inexperienced replacement workers in assembly-lines for reducing throughput loss. Cobots designed for the assembly line worker - can reduce the manual workload and improve station's performance (Surdilovic et al. 2010; Bortolini et al. 2017).

There are three ways in which a cobot can accelerate the work in its station: (1) performing part of the station manual tasks, independently, simultaneously or sequentially of the human worker (El Zaatari et al. 2019) (2) bringing parts or tools saving worker movements, and (3) holding part or tool providing better orientation for worker dexterity. The cobot can be programmed to perform any combinations of these assistance acceleration.

Some advantages of cobots over robots are: lower installation costs and space savings due to the lack of safety cages; simpler programming which reduces commissioning time and costs and allows rapid adaption to new tasks; and lower capital costs, with a shorter payback period (Bogue, 2016).

Cobots can also reduce assembly ergonomic complications due to physical and cognitive loading, while improving safety, quality and productivity (Akella et al. 1999, Battaïa et al. 2018). However, the work characteristics in different assembly stations differ greatly, and cobot evaluation is needed to find stations with high improvement potential (Fast-Berglund et al. 2016). A real case study of integrating a cobot in a U-shaped production line is described by Gil-Vilda et al. (2017). A comprehensive overview of cobots and their integration in production processes is given by (El Zaatari et al. 2019). Real-world report on using cobots in an automotive assembly-line is given by El Makrini et al. (2018).

3. JUSTIFYING SYSTEMWIDE COBOT DEPLOYMENT: A COMPUTATIONAL EXAMPLE

The following are the computations applied to an example with a situation similar to the one in figure 1. The following facts are given for the example: (1) a workday is an 8-hour shift (2) takt-time is1 minute, (3) station learning coefficient: b=0.322 (4) without the cobot the first cycle of the substitute worker lasts 4 times the takt-time. (5) with the cobot assistance the first cycle-time of the substitute worker reduces to twice the takt-time.

3.1 Number of Cycles & Learning Period Above Takt-Time

We now examine the replacement of a worker during an 8 hour shift, and use the general learning equation to find the number of cycles that the learning curve is a bottleneck (the curve is above the takt-time C). The learning equation is:

$$t_n = \left(t_1\right) n^{-b} \tag{1}$$

Where n is the number of cycles, t_n is the n^{th} cycle-time, t_1 is the first cycle time, and b the learning slope. So number of cycles it takes to reach the takt-time (C) is:

$$C = \left(t_1\right) n^{-b} \tag{2}$$

Without the cobot the t_1=4C, substituting for t_1:

$$C = \left(4C\right) n^{-b} \;\Rightarrow\; \frac{1}{4} = n^{-0.322} \tag{3}$$

So the number of cycles it takes the learning curve to reach the takt-time without a cobot is: **74**; and with a cobot (using similar computations for t_1=2C) it takes **9** cycles only.

To understand the impact of this we use the equation for accumulated time of n cycles:

$$T_n = \left(\frac{t_1}{1-b}\right) n^{(1-b)} \tag{4}$$

Where T_n.is the time to produce n cycles. Substituting the numbers of the example we have for the case without a cobot:

$$T_n = \left(\frac{4}{0.678}\right) 74^{0.687} = 109.18 \tag{5}$$

So without a cobot, the inexperienced worker remains a bottleneck 74 cycles during 109.18 minutes (equation 5).

The bottleneck period for the case of a cobot deployment is:

$$T_n = \left(\frac{2}{0.678}\right) 9^{0.687} = 13 \tag{6}$$

So deploying a cobot reduces this period to 13 minutes for 9 cycles (equation 6).

The throughput loss *without a cobot* is the difference between producing 109 products (during 109 minute), and the actual production of only 74 – a loss of: 35 products.

The throughput loss *with a cobot* is the difference between 13 products (during minutes) and actual production of 9 – a loss of 4 products.

To conclude: the cobots contribution per 8 hour-shift is:

35-4=31 products out of 480 items per shift (480 minutes/shift) or 6.5% mean daily throughput loss leading to direct 6.5% revenue loss.

3.2 Justification of Cobot-System Deployment

First, the time horizon of the cobot purchase decision must be determined. This is typically related to the cobot's lifespan (until it is either replaced or disposed-of). A typical average lifespan may be five years, and this is also the period assumed for the rest of the paper.

In automotive and large assembly lines, the magnitude of this loss for five years may justify installing a cobot in each-and-every station. For a hundred manual stations line, the purchase cost of 100 cobots is about $ 4 million; the installation and integration of the cobots may cost another million $; employing 10 cobot technicians (with the cost of cobots parts) for five years may cost another $ 5 million. So total cost for deploying 100 cobots, would be $10 million for five years or $ 2 million per year. For 250 days per year, and 480 products per day (one minute takt-time) – any product revenue above $ 257 justifies the cobots' deployment and installation in each-and-every station.

4. SINGLE STATION COBOT JUSTIFICATION: A COMPUTATIONAL EXAMPLE

The computations in section 3 were based on some very heavy assumptions: (1) the management is willing to invest in 100 cobots simultaneously, without any prior experience with cobots (2) the cobot always cut the first cycle-time by half. In reality, most managers would be reluctant to invest millions of dollars in cobot' technology, before having some experience with cobots. Additionally, in many cases a cobot can reduce the learning curve but not to the extent of reaching half of the first cycle time. Therefore, a more realistic scenario would be where a manager considers the deployment of a single cobot in a single work-station.

The following example is given to generally illustrate the scale required for justifying the acquisition and deployment of a single cobot in a work station along the assembly-line.

4.1 Probability assessment

Industrial typical annual absenteeism per worker is between 6-12 workdays (Kocakulah et al. 2016) out of 250 annual workdays (mean of 3.6% of workdays). Each of these absence days occurs simultaneously with other absences. The range of a typical daily absenteeism rate: 2%-5% (Cohen, 2012). So for a 100 manual stations line, this leads to 2 to 5 simultaneous daily absence replacements, each having chances of becoming a bottle neck. In a day of 2 absences, each station has a chance of (3.6%)(50%) = 1.8% to become the bottle-neck, whereas in a day of 5 absences, each station has a chance of: (3.6%)(20%) = 0.72% to become the bottle-neck. For computation convenience we shall assume that on the average, each day a station has a chance of about 1% to become a bottle neck. (for 250 annual workdays it is close to 2.5 days/year, and 12.5 per five years).

4.2 Cost assessment

To justify the acquisition means the cobot's cost must be exceeded by its savings or its contribution within 5 years. To continue the example, consider an automotive-line that has 250 work-days per year and that produces 500 cars a day (or 125,000 cars per year), and sells each car for $ 5,000. The automotive-line has daily throughput of $ 2,500,000 and a five-year annual throughput worth $ 12,500,000. Thus, a cobot that costs $ 50,000, and 5 years operational costs of $ 100,000, (including maintenance) is justified as long as it saves more than $ 150,000. This is: 150K/12.5M = 1.2% of one day throughput in five years. So to justify the cobot five year cost of $ 150,000 the cobot has to save only 1.2% of a single day's throughput. Each station with a cobot considers 1,250 work-days, each with 1% for becoming a bottle neck (according to 4.1). So the probability of a station for becoming a bottle-neck is: $1\text{-}0.99^{\wedge 1250} \cong 1$, meaning a certainty. Thus, given that a station is a bottle neck in a given day, it only has to save 1.2% (or more) of the throughput, to justify acquiring a cobot (a reasonable condition).

4. COBOT DEPLOYMENT GUIDELINES

The above example assumed that the cobot helps the inexperienced replacement worker during a shift. To do this the following steps must be taken in a station prior to the absence:

1. Examine and classify the station's activities to: (a) activities that could be totally done by a cobot (e.g., pick & place activity), (b) activities that could be assisted by a cobot (e.g., activity that requires a tool – which the cobot could bring and hand to the worker, and take back to its place after the usage). (c) Ergonomic assistance (e.g., placing parts in a certain orientation, or supporting or holding a part).

2. Design the overall operation for the cobot in the station.

3. Program the cobot according to its operational design.

4. Test the cobot on the station to check the validity of planning.

After these steps, the cobot only has to be located and activated when in need.

It must be noted that cobots are relatively slow, and usually working at a pace of humans, so that working simultaneously with the replacement operator is the main way to assist the replacement operator.

A concrete case study will be presented at the conference.

5. CONCLUSIONS

Absenteeism and turnover happen daily in assembly lines leading to deployment of substitute workers that slow the whole line. This paper shows that absenteeism in assembly-lines and their replacement by temporary workers has great financial impact that could be offset by the help of cobots. The paper gives a computational example of system wide financial justification for cobots in each manual station. A second example deals with justifying the cobot's deployment in a single station. Finally, the paper lists general guidelines for cobot's deployment in an assembly-line station. These guidelines are pre-conditions for integrating cobots in various stations. The guidelines require work analysis and pre-programming of cobot operation in each manual station. Future research could explore the case where cobots are either reinstalled according to the daily needs, or even moving cobots between stations. Both cases are means to reduce the number of required cobots for the assembly-line.

REFERENCES

Akella, P., Peshkin, M., Colgate, E. D., Wannasuphoprasit, W., Nagesh, N., Wells, J., ... & Peacock, B. (1999, May). Cobots for the automobile assembly line. In Proceedings 1999 IEEE International Conference on Robotics and Automation (Cat. No. 99CH36288C) (Vol. 1, pp. 728-733). IEEE.

Battaïa, O., Otto, A., Sgarbossa, F., & Pesch, E. (2018). Future trends in management and operation of assembly systems: from customized assembly systems to cyber-physical systems. Omega, 78, 1-4.

Bogue, R. (2016). Europe continues to lead the way in the collaborative robot business. Industrial Robot: An International Journal, 43(1), 6-11.

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.

Bukchin, Y., & Cohen, Y. (2013). Minimising throughput loss in assembly lines due to absenteeism and turnover via work-sharing. International Journal of Production Research, 51(20), 6140-6151.

Cohen, Y. (2012). Absenteeism as a major cause of bottlenecks in assembly lines. International Journal of Production Research, 50(21), 6072-6080.

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.

Cohen, Y., Naseraldin, H., Chaudhuri, A., & Pilati, F. (2019). Assembly systems in Industry 4.0 era: a road map to understand Assembly 4.0. The International Journal of Advanced Manufacturing Technology, 1-18.

Frick, B., Simmons, R., & Stein, F. (2018). The cost of shift work: Absenteeism in a large German automobile plant. German Journal of Human Resource Management, 32(3-4), 236-256.

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.

El Makrini, I., Elprama, S. A., Van den Bergh, J., Vanderborght, B., Knevels, A. J., Jewell, C. I., ... & Berte, J. (2018). Working with walt: How a cobot was developed and inserted on an auto assembly line. IEEE Robotics & Automation Magazine, 25(2), 51-58.

El Zaatari, S., Marei, M., Li, W., & Usman, Z. (2019). Cobot programming for collaborative industrial tasks: An overview. Robotics and Autonomous Systems, 116, 162-180.

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

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.

Kocakulah, M. C., Kelley, A. G., Mitchell, K. M., & Ruggieri, M. P. (2016). Absenteeism problems and costs: causes, effects and cures. International Business & Economics Research Journal (IBER), 15(3), 89-96.

Surdilovic, D., Schreck, G., & Schmidt, U. (2010, June). Development of collaborative robots (cobots) for flexible human-integrated assembly automation. In ISR 2010 (41st International Symposium on Robotics) and ROBOTIK 2010 (6th German Conference on Robotics) (pp. 1-8). VDE.

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