Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 54-1 (2021) 613–616

Absenteeism and Turnover as Motivation Factors for Segmenting Assembly Lines

Francesco Pilati*†, Maurizio Faccio, Yuval Cohen*****

** Department of Industrial Engineering, University of Trento, via Sommarive 9, 38123 Trento, Italy*

***Department of Management and Engineering, University of Padova, Stradella San Nicola, 3, 36100 Vicenza, Italy*

**** Industrial Engineering, The Open University of Israel, Raanana 43537, Israel*

† Corresponding author e-mail: francesco.pilati@unitn.it

Abstract: Many assembly lines for complex products are divided into segments (zones and sections), each with its own manager. While zones are usually large and derived from the nature of the process, the segmentation into smaller sections is less obvious. This paper explores the relationship between the effects of absenteeism and turnover (requiring a slowdown because of the substitute workers' learning period) and the segments length. The paper analyses and discusses the effect of dissecting the assembly line into sections in curbing the slowdowns due to absenteeism and turnover in large assembly lines. Quantitative model is developed to represent this factor, and bounds are found for the sections length. An important implication of dividing several hundred stations into small sections is that each section can be efficiently designed and balanced independently, making the optimization complexity irrelevant.

Keywords: Assembly line, Absenteeism, Turnover, Throughput, Learning.

1. INTRODUCTION

Operating a long line without any segments (or zones) causes critical problems in events of machine failures, absenteeism, and deteriorating product quality (Baudin, 2002; Yılmaz, 2020; Blumenfeld and Inman, 2009; Farid and Neumann, 2020). Therefore, long assembly lines are typically divided into zones and segments (Inman and Blumenfeld, 2010; Dagkakis et al., 2019). However, only scant research has been done on this subject, and almost no work exists on the considerations, justifications, and motivations for segmenting the line.

This paper sets forth the case for line segmentation (and partitioning) as means for effectively dealing with: (1) line stoppages (unscheduled and scheduled maintenance, and any other event that stops the processing at any station), (2) absenteeism and turnover, and (3) managerial span of control. An example of partition into zones could be found in the automotive assembly lines (Moon et al ., 2006; Giampieri et al., 2020), assembly lines for complex appliances, and in the aircraft industry. The division into sections of 8 to 12 stations frequently appears in the literature as the allocation of work into teams (Bukchin and Masin, 2004; Inman and Blumenfeld, 2010; Kumar et al., 2019).

This paper considers the segmentation of long, paced assembly lines into small sections. The number of stations in a section can range from several stations to approximately two dozen, depending on the specific assembly system. Assembly lines may also be divided into large departments or zones. This paper focuses on dividing each zone (or department) into line sections of smaller length.

2. MOTIVATION

Absenteeism and turnover require employing substitute workers to temporarily replace the regular staff. An absentee rate of several percent is typical of assembly lines (Villalobos et al., 2011; Lin and Naim, 2020). Long lines (with more than several dozen stations) will have absentees, who are replaced by substitute workers, on every shift. The substitute workers must learn the job, and their initial pace is slow. During the learning phase, their cycle-times are typically longer than the line's takt-time (Montano et al., 2007; Cavagnini et al., 2020). During that period they are candidates for being a bottleneck and setting the pace for their line's section (or for the whole line, if there are no sections). Therefore, the following discussion focuses on the learning curve of the substitute worker. If we let t_x be the execution time of the x^{th}

10.1016/j.ifacol.2021.08.172

cycle, then the learning model (Yelle, 1979; Lohmann et al., 2019) can be expressed as

$$t_x = t_1 \cdot x^{-b} \quad (1)$$

Where t_1 is the first cycle-time, and b is the learning constant. A cumulative description of the duration of x cycles the learning curve is given by integration of equation (2) as follows:

$$T(x) = \frac{t_1}{1-b} x^{1-b} \quad (2)$$

Learning curves are characterized by the fact that the cycle time is reduced by a constant percentage (ϕ) every time the quantity produced is doubled (ϕ is called the learning slope).

$$b = -\log 2(\phi) \quad (3)$$

Dar-El (2000) and Glock et al. (2019) have empirically showed that the relationship between any task's standard time (*STD*) and its first cycle time (t_1) is:

$$t_1 = (57\text{-}60\ \phi)STD \quad (4)$$

For example, with ϕ=80%, the first cycle time is 9 times its standard time. Since the absentees vary on every shift, different jobs need replacement each time. Therefore, the substitutes cannot obtain consistent experience, and start their learning curve at the beginning of each shift. The learning curve of the slowest substitute worker is the bottle-neck station and dictates the section's throughput during a shift. The intermediate buffers between sections enable the line to overcome such slow shifts. Therefore, a section's throughput during a standard shift of eight hours (480 min.) is:

$$480 = \frac{t_1}{1-b} x^{1-b} \quad \Rightarrow \quad \frac{480(1-b)}{t_1} = x^{1-b}$$

$$\Rightarrow \left(\frac{480(1-b)}{t_1}\right)^{\frac{1}{1-b}} = \left(x^{1-b}\right)^{\frac{1}{1-b}} = x$$

or

$$\left(\frac{480(1-b)}{t_1}\right)^{\frac{1}{1-b}} = x \quad . \quad (5)$$

3. THE MODEL

Utilizing equations (3) and (4), the section's throughput for the shift is:

$$\left(\frac{480(1-b)}{(57-60\phi)STD}\right)^{\frac{1}{1-b}} = x \quad \Rightarrow \quad \left(\frac{480(1-b)}{(57-60(2^{-b})STD}\right)^{\frac{1}{1-b}} = x \quad (6)$$

The following example illustrates the use of equation (6). For example, assume a typical value for b=0.322 (ϕ=0.8) which yields:

$$\left(\frac{36.1}{STD}\right)^{1.475} = x$$

For a minute of standard time per station, the standard throughput is 480 and this is the number of items produced by the section during a standard shift. Using (6), it is evident that the section's bottle-neck reduces the throughput to: x=36.1^1.475= 198.7~199. Thus, the section's throughput is reduced from its standard by 480-199=281 items. In pull systems such a phenomenon causes the same throughput drop in all the upstream stations and line segments. This of course reduces the WIP that may accumulate in push systems (where 480 units are expected to be produced in all upstream stations and line segments). In push system if the line is composed of one section only, this (281 items) indeed is the throughput loss. However, if the line is composed of segments with large intermediate buffer spaces, WIP is accumulated in front of the section during the shift and must be produced using overtime. Phasing the production of the segments enables to generate WIP between line segments on purpose. This WIP may help preserve line's throughput in such cases of absenteeism, but returning to normality would require overtime or temporarily doubling the workforce of that section to increase the throughput. Assuming overtime rate of \$ *O* per full shift, the additional costs would be:

(*NS*)(281/480)(*O*).

If the buffer's WIP level (*Buf*) is smaller than 281 (*Buf*<281), the lines throughput loss would be: 281-*Buf*, and the overtime/acceleration would have to compensate for the depletion by producing extra y units. The additional costs would be:

(*NS*)(*Buf*/480)(*O*).

The above example could be generalized as follows:

Define:

- *H* – The standard throughput of a shift: *H*=480/*C* (for example, if *C*=1 *then H*=480)
- *L* – A shift's throughput loss of a line section due to absentee replacement*: L=H-x*
- (for example, *L*=480-199=281.)
- r – Revenue per product (different than the total revenue - *R*).
-

Thus, the cost of absentee substitution is:

$$\begin{matrix} Absentee\_cost \\ per\_shift \end{matrix} = \begin{cases} r(L-Buf)+(NS)\left(\frac{Buf}{H}\right)(O) & if \;\; Buf < L \\ (NS)\left(\frac{L}{H}\right)(O) & if \;\; Buf \geq L \end{cases} \quad (7)$$

Since the cost in equation (7) grows linearly with NS, minimizing the number of stations per section (or maximizing the number of sections) minimizes the cost. For *Buf*<*L* the cost is also a linear function of Buf, as shown in (13).

$$\begin{matrix}Absentee\_cost\\ per\_shift\end{matrix} = (r)(L) + Buf\left(\left(\frac{(NS)(O)}{H}\right) - (r)\right) \quad \text{if } Buf < L \tag{8}$$

We shall extend the previous example to illustrate the implications of equation (8). Assume a revenue per car of r=$ 5,000, H=480, NS=10 and O=$ 80 per shift. This yields

$$\begin{aligned}\begin{matrix}Absentee\_cost\\ per\_shift\end{matrix} &= (5000)(281) + Buf\left(\left(\frac{(10)(80)}{480}\right) - (5000)\right) \quad \text{if } Buf < 281\\ &= 1,405,000 + Buf\left((1.66) - (5000)\right)\\ &= 1,405,000 - Buf\left(4998.34\right)\end{aligned}$$

This result would change very little, if at all, even if NS increases tenfold or a hundredfold. Segmenting the line is a strategic decision that applies to several thousand shifts. Increasing Buf by one saves almost R per shift. Assuming a lifetime of LT=5,000 shifts, the buffer space saves approximately $5,000 ($R$). The number of buffer spaces for increasing Buf is multiplied by the number of sections $\left\lceil \frac{n}{NS} \right\rceil^+$.

So for buffer cost B, and lifetime shifts LT, the overall buffer cost is:

$$(Buf)\left\lceil \frac{n}{NS} \right\rceil^+ (B) + (LT)\left((r)(L) - Buf(r) + Buf\left(\frac{(NS)(O)}{H}\right)\right) \quad \text{if } Buf < L \tag{9}$$

or

$$(LT)(r)(L) + (Buf)\left(\left\lceil \frac{n}{NS} \right\rceil^+ (B) - (LT)\left(r + \frac{(NS)(O)}{H}\right)\right) \quad \text{if } Buf < L \tag{10}$$

Except extreme cases, the number of sections would never exceed 100, and B is usually no more than $ 50,000 so typically $\left\lceil \frac{n}{NS} \right\rceil^+ (B)$ <$5,000,000.

Using the above examples also yields:

$$(LT)\left(r + \frac{(NS)(O)}{H}\right) = 5,000\left(5,000 + \frac{10(80)}{480}\right) = 5,000\left(5,001.66\right)$$
$$= 25,008,300$$

Thus, equation (10) with these values would be decreasing with Buf, and minimizing cost would lead to maximizing Buf, so Buf=L.

In equation (10) the $\left(\frac{(NS)(O)}{H}\right)$ is several orders of magnitude smaller than the other expressions, and could be ignored for decision-making purposes. Thus, it follows that increasing the space for buffers between sections is profitable under two conditions:

1. $Buf < L$ (11)
2. $\left\lceil \frac{n}{NS} \right\rceil^+ (B) < (LT)r \quad \Rightarrow \quad \left\lceil \frac{n}{NS} \right\rceil^+ < \frac{(LT)r}{B}$ (12)

Since $\left\lceil \frac{n}{NS} \right\rceil^+$ is the number of sections, inequality (12) specifies an upper bound on the number of sections. While the upper bound may not be tight, in quite useful in some cases. For example, using LT=1,000; r=$ 1,000; B=$50,000; in equation (12) yields:

$$number\_of\_sections < \frac{(1,000)(1,000)}{50,000} = 20 .$$

Dividing the assembly line to 20 identical segments exactly may not always be possible. But it is the guideline from which deviations should be minimized.

4. CONCLUSIONS

This paper investigates the way worker replacement (due to absenteeism and turnover) is affecting the size of a section of an assembly line. The quantitative model presents the large magnitude of impact that worker replacements have on section length and profitability. An upper bound on the number of stations per section (NS) was found. The model reveals the importance of buffer costs and revenue (both total revenue and revenue per product) in deciding the section length. Buffer costs are positively correlated with section length, and revenue is negatively correlated with section length. The principle of "divide and conquer" works not only for management and control, but also for optimization complexity. Designing and balancing each section separately and in parallel ensures that the design is limited to NS stations (typically fewer than 30 stations and machines). The limited problem size makes it possible to use exact solutions, such as integer programming (IP), dynamic programming (DP), and branch and bound (BB). Future research directions may also seek ways to increase efficiency by modelling the effect of policies for handling absenteeism, work sharing, cross training, and including the effects of maintenance, quality, and inventory.

REFERENCES

Baudin, M. (2002). Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow, Productivity Press, New York.

Yılmaz, Ö. F. (2020). Examining additive manufacturing in supply chain context through an optimization model. Computers & Industrial Engineering, 142, 106335.

Blumenfeld, D. E. and Inman, R. R. (2009). Impact of absenteeism on assembly line quality and throughput, Production & Operations Management, 18 (3), 333-343.

Farid, M., & Neumann, W. P. (2020). Modelling the effects of employee injury risks on injury, productivity and production quality using system dynamics. International Journal of Production Research, 58(20), 6115-6129.

Inman, R. R. and Blumenfeld D. E. (2010). Assembly line team sizing with absenteeism, International Journal of Production Research, 48 (22), 6537-6558.

Dagkakis, G., Rotondo, A., & Heavey, C. (2019). Embedding optimization with deterministic discrete event simulation for assignment of cross-trained operators: An assembly line case study. Computers & Operations Research, 111, 99-115.

Moon, D. H., Cho, H. I., Kim, H. S., Sunwoo, H. and Jung, J. Y. (2006). A case study of the body shop design in an automotive factory using 3D simulation, International Journal of Production Research, 44 (18-19), 4121-4135.

Giampieri, A., Ling-Chin, J., Ma, Z., Smallbone, A., & Roskilly, A. P. (2020). A review of the current automotive manufacturing practice from an energy perspective. Applied Energy, 261, 114074.

Bukchin, Y. and Masin, M. (2004). Multi-objective design of team oriented assembly systems, European Journal of Operational Research, 156 (2), 326-352.

Kumar, A., Pattanaik, L. N., & Agrawal, R. (2019). Multi-objective Scheduling Model for Reconfigurable Assembly Systems. In Innovations in Soft Computing and Information Technology (pp. 209-217). Springer, Singapore.

Dar-El, E. M. (2000). Human Learning: From Learning Curves to Learning Organizations, Kluwer Academic Publishers, Norwell, MA.

Glock, C. H., Grosse, E. H., Jaber, M. Y., & Smunt, T. L. (2019). Applications of learning curves in production and operations management: A systematic literature review. Computers & Industrial Engineering, 131, 422-441.

Montano, A., Villalobos, J. R., Gutierrez, M. A. and Mar, L. (2007). Performance of serial assembly line designs under unequal operator speeds and learning, International Journal of Production Research, 45 (22), 5355-5381.

Cavagnini, R., Hewitt, M., & Maggioni, F. (2020). Workforce production planning under uncertain learning rates. International Journal of Production Economics, 225, 107590.

Villalobos, J. R., Gutierrez, M. A., Mar, L. R., Sanchez O., and Ahumada, O. (2011). The use of dynamic work sharing production methods to reduce the impact of labor turnover in serial assembly lines, International Journal of Manufacturing Technology and Management, 23 (1-2), 34-53.

Lin, J., Naim, M. M., & Spiegler, V. L. (2020). Delivery time dynamics in an assemble-to-order inventory and order based production control system. International Journal of Production Economics, 223, 107531.

Yelle, L .E. (1979). The learning curve: historical review and comprehensive survey, Decision Science, 10, 302-328.

Lohmann, M., Anzanello, M. J., Fogliatto, F. S., & da Silveira, G. C. (2019). Grouping workers with similar learning profiles in mass customization production lines. Computers & industrial engineering, 131, 542-551.