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A Buffer Analysis in a Transfer Production Line

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Abstract. The objective of this paper is to demonstrate a determination of buffer to increase line efficiency in a transfer line where several workstations are linked together by a conveyer. One of the common problems of a transfer line is minor stoppages i.e. part short, machine adjustment, and so on are the typical problems which result in low uptime efficiency and are detrimental to productivity. Thus, buffer stock is designed to mitigate the problem; however, knowledge in determining optimal number of buffers is not prevalent. The buffer analysis using constant downtime distribution is employed in this paper.

1 Introduction

A transfer production line namely flow production line is one of the manufacturing configurations where two or more workstations consecutively link together and a series of parts smoothly flows through the workstations. It is suitable for mass production with a high volume. A task must be able to divide in small tasks and assigned to each workstation in a balance manner. The task in each workstation must be finished within the designed cycle time and normally the working part is designed to move simultaneously. Therefore, once any workstation interrupts or halts, all of the workstations must also be stopped. As one can imagine, during a production there will be various minor stoppages due to part short, tool or machine adjustment, quality inspection, equipment malfunction and so on. These minor stoppages drastically reduce the productivity. Thus, a buffer between the workstations is designed to mitigate the abovementioned problem with an aim to allow the upstream and downstream workstations to continue their tasks until the buffer is running out or the recovery of the ceased workstation is completed. A number of literatures are investigated. Buzacott formulated equations for a determination of the optimal sizes of intermediate buffers in a continuous flow transfer line with three machines and two buffers [1]. Prombanpong *et al.* presented a buffer design in an automated transfer line for automobile part manufacturer using geometric downtime distribution to calculate the appropriate buffer size [2]. Hillier et al. investigated a production line performance during machine breakdown and then studied an effect of buffer size to the line performance [3]. Wijngaard compared line efficiency between constant down time distribution and geometric down time distribution of a two-stage transfer line with finite buffer [4]. Enginarlar *et al*. demonstrated a calculation of minimum buffer sizes to maintain the production rate [5]. It can be seen that a number of research has been conducted dealing with effect of buffer to production line efficiency during machine break down. The objective of this paper also attempts to demonstrate a calculation of appropriate buffer size using constant downtime distribution assumption to generate a solution for various buffer sizes. Then, the slope of the graph between obtained efficiency and buffer size is determined and the steepest slope will be used as a criterion which will be described next.

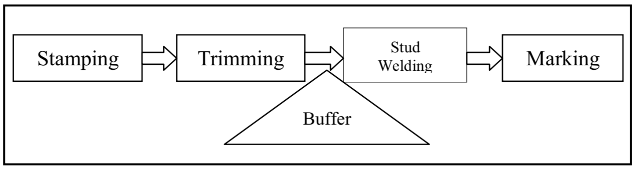

Figure 1. Separation of the line by a buffer.

Table 1. Frequency and average down time.

Machine Adjustment	Frequency (stop /cycle)	Average down time (min)
Stamping machine and Trimming machine (F_1)	0.000280	27.97
Automatic welding machine and marking machine (F_2)	0.000140	31.59

2 Problem scenario

The interested transfer line is consisted of four work stations stamping, trimming, stud-welding, and marking which is linked by a conveyor as shown in Fig. 1. The machine adjustment task can be divided into two groups, group 1 (stamping and trimming) and group 2 (stud-welding and marking) based on the machine adjustment plan. Therefore, a buffer stock between these two groups is proposed to reduce an effect of downtime losses due to machine adjustment. Therefore, the whole transfer line is divided into two stages as stage 1 and stage 2. Thus, the research question is that how large the buffer should be so that it will effectively optimize the overall line efficiency [6, 7]. Therefore, a collection of data such as frequency of line stop per cycle and average down time per line stop was conducted and can be tabulated in Table 1.

3 Methodology

In the automated production line, if there is no break down or line stop, the line will ideally operate at 100% uptime efficiency. Line efficiency can be referred to the proportion of uptime on the line and can be used as performance measurement. The line efficiency can be calculated from equations as the following [8]. Equation (1) is to calculate the line efficiency when it has no buffer stock.

$$E_0 = \frac{T_c}{T_c + (F_1 + F_2)T_d} \tag{1}$$

where E_0 is line efficiency without buffer stock, T_c is cycle time (sec), F_1 and F_2 is frequency of downtime stop at stage 1 and stage 2 respectively (stop/cycle), T_d is average downtime per line stop (sec/stop).

It can be explained that the second term of the denominator is an additional time to the normal cycle time whenever there is any line stop, as a consequence, the efficiency will be less than 100 percent.

The efficiency at stage 2 can be calculated by:

$$E2 = \frac{T_c}{T_c + (F_2)T_d} \tag{2}$$

Thus, when buffer stock is implemented, the line efficiency will be improved. In addition, it is assumed that the frequency of breakdown of each stage is equal. Thus

$$E_b = E_0 + D_1^{'} h(b) E2 \tag{3}$$

Equation (3) shows the efficiency improvement gained from buffer b additional to the efficiency with no buffer stock E_0. The second term on the right hand side indicates additional efficiency improvement. $D_1^{'}$ is the proportion of expected downtime of stage 1 to the total production time and can be formulated in equation (4). The term h(b) is the rate of improvement obtained from buffer b and can be formulated as in equation (5) and (6).

$$D_1^{'} = \frac{F_1 T_d}{T_c + (F_1 + F_2)T_d} \tag{4}$$

In the calculation for h(b), it is assumed that downtime is constant because the mentioned downtime is machine adjustment and it is less variation. According to the formula given by Buzacot, there are two cases depending upon the value of F_1/F_2 [8]. If F_1/F_2 is equal to 1, case I will be applied; otherwise, case II will be used. The formula of both cases are as follows:

Case I

$$h(b) = \frac{\mathrm{B}}{\mathrm{B}+1} + \left(\mathrm{L} \frac{\mathrm{T_c}}{\mathrm{T_d}} \right) \frac{1}{(\mathrm{B}+1)(\mathrm{B}+2)} \tag{5}$$

Case II

$$h(b) = r\left(\frac{1 - r^B}{1 - r^{B+1}} \right) + \left(L \frac{T_c}{T_d} \right) \frac{(r^{B+1})(1-r)^2}{(1 - r^{B+1})(1 - r^{B+2})};$$

$$r = \frac{F_1}{F_2}, \; b = B\frac{T_d}{T_c} + L, \; B \le b\frac{T_c}{T_d} \tag{6}$$

where r is the proportion of frequency per line stop of stage 1 and stage 2. B is largest integer and L is left over stock.

Equation (5) and (6) indicate an ability of buffer b in the improvement during down time occurrence. The term h(b) is multiplied with E2, as a result, the rate of improvement obtained from buffer is mainly due to the value of h(b).

The equation (1) to (6) can be used to calculate efficiency for any b buffer. For this case study, the relevant information is as following, cycle time (T_c) = 0.17 min., the frequency of line stop in stage 1 and 2 F_1= 0.000280, F_2=0.000140. (stop per cycle), the downtime (T_d) = 27.79 min. Thus, the line efficiency E_0 and E_2 can be calculated from equation (1) and (2) by substitute T_c, F_1, F_2, and T_d in the equation respectively.

$$E_0 = \frac{0.17}{0.17 + (0.00028 + 0.00014)27.79}$$

$$= 0.9357$$

Thus, the line efficiency without buffer is 93.57%. Next, the efficiency of stage 2 namely E2 can be calculated as:

$$E2 = \frac{0.17}{0.17 + (0.000140)\,27.79}$$

$$= 0.9776$$

Next, h(b) will be calculated by substitute T_c, T_d, F_1, and F_2 in (4) obtain :

$$D_1^{'} = \frac{0.00028(27.79)}{0.17 + (0.00028 + 0.00014)27.79}$$

$$= 0.042$$

In order to determine appropriate buffer size, efficiency of different buffer sizes must be investigated. Thus, buffer sizes ranged from 50 up to 250 pieces are designed to calculate line efficiency for comparison.

Let assume b =50 pieces, calculate r and B as:

$$r = \frac{0.000280}{0.000140}$$

$$= 2$$

$$B \le 50\frac{0.17}{27.79}$$

$$\le 0.306$$

Thus, the largest integer B which less than 0.306 is 0. Then, L can be computed as:

$$L = 50 - 0\left(\frac{27.79}{0.17}\right) = 50$$

Since F_1/F_2 or r is equal to 2, the equation (6) in case II will be used and, therefore, substitute r, B and L in equation (6), obtain:

$$h(50) = 2\left(\frac{1-2^0}{1-2^{0+1}}\right) + \left(50\frac{0.17}{27.79}\right)\frac{(2^{0+1})(1-2)^2}{(1-2^{0+1})(1-2^{0+2})}$$

$$= 0.203$$

Substitute $E_0 = 0.936$, h(b) = 0.203, $D_1^{'} = 0.042$, and $E_2 = 0.977$ in the equation (3) obtain;

$$E_{50} = 0.936 + (0.042x0.203x0.977)$$

$$= 0.9443$$

Thus, the line efficiency when placing 50 pieces of buffer in the line will be 94.43 percent.

Likewise, h(b) value of b at 100, 150, 200 and 250 can be calculated as follows:

$$h(100) = 2\left(\frac{1-2^0}{1-2^{0+1}}\right) + \left(100\frac{0.17}{27.79}\right)\frac{(2^{0+1})(1-2)^2}{(1-2^{0+1})(1-2^{0+2})}$$

$$= 0.407$$

$$E_{100} = 0.936 + (0.042x0.407x0.977)$$

$$= 0.9527$$

$$h(150) = 2\left(\frac{1-2^0}{1-2^{0+1}}\right) + \left(150\frac{0.17}{27.79}\right)\frac{(2^{0+1})(1-2)^2}{(1-2^{0+1})(1-2^{0+2})}$$

$$= 0.611$$

$$E_{150} = 0.936 + (0.042x0.611x0.977)$$

$$= 0.9611$$

$$h(200) = 2\left(\frac{1-2^1}{1-2^{1+1}}\right) + \left(36.53\frac{0.17}{27.79}\right)\frac{(2^{1+1})(1-2)^2}{(1-2^{1+1})(1-2^{1+2})}$$

$$= 0.702$$

$$E_{200} = 0.936 + (0.042x0.528x0.977)$$

$$= 0.9648$$

$$h(250) = 2\left(\frac{1-2^1}{1-2^{1+1}}\right) + \left(86.53\frac{0.17}{27.79}\right)\frac{(2^{1+1})(1-2)^2}{(1-2^{1+1})(1-2^{1+2})}$$

$$= 0.767$$

$$E_{250} = 0.936 + (0.042x0.767x0.977)$$

$$= 0.9675$$

Similarly, the efficiency due to a buffer of 50, 100, 150, and 200 can be computed and they are tabulated in Table 2.

Table 2. Summary of efficiency of each buffer size.

Buffer Size (pc)	$H_{(b)}$	Efficiency (%)
0	-	93.57
50	0.203	94.43
100	0.407	95.27
150	0.611	96.11
200	0.702	96.48
250	0.767	96.75

From Table 2, the line efficiency at zero buffer stock is 93.57 percent. When the 50 pieces buffer size is placed, the line efficiency can reach upto 94,43 percent and so on. Thus, it is obvious that the more buffer, the higher line efficiency. In order to determine the appropriate buffer size, a graph of buffer size against line efficiency is plotted as shown in Figure 2.

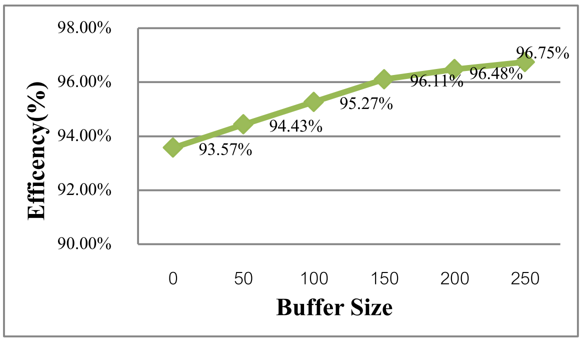

Figure 2. Productivity of the production line

A slope can be used to determine appropriate buffer size and summarized in Table 3. It is obvious that a buffer upto 50 piece-buffer size provides the steepest slope; therefore, the 50 piece-buffer size is the most appropriate size since the slope after this point becomes flat. Consequently, it is not worth to increase more buffer while the increment rate of efficiency is lower.

Table 3. Slope of each buffer

Buffer Size (pc)	Slope
0-50	0.0176
50-100	0.0164
100-150	0.0168
150-200	0.0074
200-250	0.0052

4 Conclusion

As mentioned earlier, different buffer sizes are considered to calculate the line efficient at various buffer capacities. The result of line efficiency at buffer size of 50 to 250 is summarized in Table 2 and plotted in Figure 2. It can be seen from the graph that at 50 piece-buffer size is the most lucrative point in this case study.

5 Discussion

This paper demonstrates the numerical approach to determine an appropriate number of buffer stocks to mitigate the adverse effect of down time in an automated transfer line. When machine adjustment occurs during the production, an efficiency will be decreased if no buffer is provided. The machine adjustment oss can be considered as constant downtime since this adjustment is a routine task and normally becomes a standard time. Therefore, a constant downtime equation is used.

Typically in any factory, a buffer is used to placed between work stations without calculating an appropriate number of buffer. Thus, a maximum efficiency may not be obtained if buffer size is not enough. On the contrary, too large buffer sizs does not proportionally increase the line efficiency.

References

1. J. A. Buzacott, “Automatic Transfer Lines with Buffer Stocks,” International Journal of Production Research, Vol. 5, No.3, pp. 183-200. (1967).
2. S. Prombanpong, J. Kaewyu, N. Thanadulthaveedech, and M. Matwangsang. “ A Buffer Design for Mitigation Downtime Effect in an Automated Transfer Line”, International Journal of Innovation, Management and Technology, vol.4, pp. 155-158. (2013).
3. F. S. Hillier and K. C So, “The effect of machine breakdown and internal storage on the performance of production line systems”, International Journal of Production Research, vol. 29, pp. 2043-2055, (1991).
4. J. Wijngaard,” The effect of inter-stage buffer storage on the output of two unreliable production units in series, with different production rates,” AIIE Transaction,vol. 11, no.1,(1979).
5. E. Enginarlar, J. L, Semyon, M. Meerkov, and R. Q., Zhang, “ Buffer capacity for accommodating machine downtime in serial production lines, International Journal of Production Research, vol. 40, no. 3, pp 601-624, (2002).
6. Y. Dallery, R. David and X. Xie, “An efficient algorithm for analysis of transfer lines with unreliable machines and finite buffers,” IIE, Transactions, vol. 20, no. 3, pp. 280-283,(1988).
7. Kubat, P. and Sumita, U, Buffers and backup machines in automatic transfer lines, International Journal of production Research, vol.23, pp.1259-1270,(1985)
8. M. P. Groover, Automation, Production Systems and Computer-Integrated Manufacturing, 2nd ed. Prentice Hall International Inc. NJ, ch.18, pp. 565-595,(1987).