Engineering Letters, 14:1, EL_14_1_13 (Advance online publication: 12 February 2007)

The Development of a Generic Technique for Flow Line Monitoring

C. S. TANG[1] *, C. Y. CHAN[2], *Member, IAENG*, and K. L. Yung[3]

ABSTRACT

Realize the operating conditions of a manufacturing plant are essential for providing corresponding actions responsively. This is because all processes are interrelated and a small fluctuation can affect overall performance in such a dynamic system. Presently, substantial integrations in both the hardware and the software are required to monitor the fabrication processes. More importantly, the decision model to interpreting the information from the associated monitoring devices is usually a great challenge due to its complexity and great variety for different cases. To overcome this integration bottleneck, we propose an alternative method. The concept is to treat the plant as a whole and with the help of identical counting facilities; both the quantitative and qualitative issues at the plant can be reflected. Simulations have been employed to verify the results and it showed that with the assistance of the proposed technique, problematic locations could be identified when the plant was operating.

Keywords: decision model, manufacturing monitoring, computer integrated manufacturing

I. INTRODUCTION

A manufacturing system can be characterized by three basic flows; flows of materials, information, and costs [1]. The fundamental purpose concerns converting the raw materials into desirable products and this is done by going through a series of fabrication processes and usually the operation conditions are dynamics with respect to time. Realize the process conditions are essential for providing analogous actions. However, this may not be so easy because of the complication arising from the intimate operations and one can also refer to the JIT philosophy for further elaboration on this sort of scenarios [2]. More importantly, this has an effect on the costs flow that can be viewed as the nutrition for maintaining activities in an entire industrial enterprise in good healthy. Presently, relative complicated knowledge and mathematical models are often required to interpret the information obtained from associated monitoring devices. Typically, the success of a Computer Integrated Manufacturing (CIM) programme is relied on how deep in knowledge related to the process technologies and product functionalities, not to mention that the integration of both the hardware and the software from various sources will also give rise to substantial challenges as well [3]. In comparison with the classical CIM approach, the ANDON-TPS is relatively effortless; it can be a very simple light indication system with three different colors such as the traffic light system to signify various process conditions [4]. However, most of the ANDON systems are manually operated and human justifications are involved. Consequently, this brings about some consistence concerns. An alternative monitoring approach has been explored in this paper. The concept is to treat the manufacturing system as a whole and with the help of identical counting facilities; both the quantitative and qualitative issues at the system can be reflected promptly.

Author:
C.S. Tang[1]*, C.Y. Chan[2], and K.L. Yung[3]
Address: Department of Industrial & Systems Engineering
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

Fax: (852) 2363 5267
[1]Tel.: (852) 2766 4596, Email: jackson.tang@polyu.edu.hk
[2]Tel.: (852) 2766 4980, Email: mfcychan@inet.polyu.edu.hk
[3]Tel.: (852) 2766 6592, Email: mfklyung@inet.polyu.edu.hk
* Corresponding author

II. SYSTEM MONITORING MODELING

In general, having the macro view of a production plant is not necessary to understand the operation of each process deeply and this is usually wanted by the management as there will be no need for any more technical jargons to be drawn in. Thus, we can focus on the smoothness of the entire operation instead. In fact, the essential knowledge of a flow line is two folds and a monitoring system which is capable of presenting the quality and the output quantity conditions mutually to an observer such that he/she can understand the performance at a glance is the key step to success. Figure 1 shows the elementary framework to implement such a concept. Since there are a variety of production types, the simple flow line that produces one type of product at a time will be used to demonstrate the concept.

Figure 2 presents the basic infrastructure of a simple flow line that contains "*r*" states (or processes, stations, etc.) each of which is labeled as S_1, S_2, …, S_r and corresponding to each of these states there are the processing times such as T_1, T_2, …, T_r respectively. To collect information with regard to the qualitative and quantitative aspects, it will be necessary to install hardware devices along the flow line. However, one should always aim at keeping the system configuration as simple as possible and hence a generic approach can be adopted potentially. In contract, employing various dedicated monitoring devices will dramatically increase the complexity of a system and more poorly, it will diverse the focus on the formulation of a generic monitoring model. Therefore, we would like to propose a straightforward hardware setup with a basic counting function only. Subsequently, there are identical counting devices installed along a flow line and each of these counting devices can be inserted at any transition (symbolized by "→" in Figure 2) between two fabrication states. At every check point, the data recorded is simply the cumulative number of entities flow through. With reference to the Little's Law [5] and by watching at the WIP, the performance of the flow line can be figure out with little effort. The coming sections describe how the concept works and how it detects the qualitative and quantitative matters happen to a flow line.

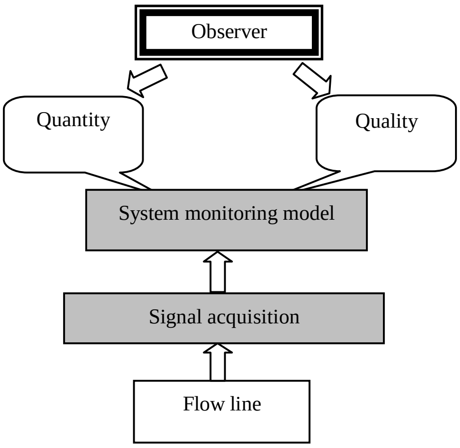

Figure 1. The conceptual framework

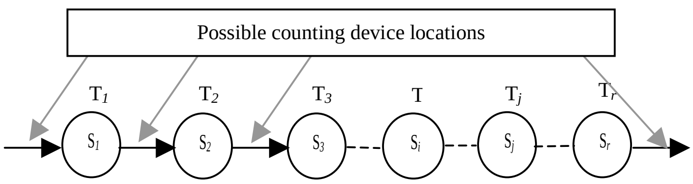

Figure 2. Process flow diagram of a simple flow line

III. Qualitative Performance Monitoring

It is assumed that the flow line is in a steady state and the transition times are absorbed by the adjacent operations. Since there are possible manufacturing unconformities, the actual production rate is decreasing along the flow line but this change is usually small otherwise, the flow is in serious problems. Moreover, the yield rates generally vary from station to station and we consider that they are independent on each another. This means that the changes in defect rate at one station will not influence the defect rate at a following station but this does not imply the production rate is also unaffected. The quality can be observed by watching at the yield rates along the flow line. The main concern is to determine the WIP in the segment between the two counters interested in and this is equal to product rate multiplying by throughput time in between. Hence, the yield rates at any time window between any two counters A and B in sequent can be calculated by:

$$\text{Yield} = 1 - [(\text{cum. val. counter B} + WIP_{A\text{-}B}) / (\text{cum. val. counter A})]$$

Ideally, the yield rates in all transitions could be the same but the later stages will usually be lesser in cumulative values as deflective items have been rejected along the flow line. Therefore, watching the yield rates tells the qualitative performance of a flow line.

In practice, the qualitative performance of a flow line can trigger some predetermined responsive policies to adjust the flow line rather than just showing the passing or failure rates. For example, it is a good idea to have some progressive trend to draw the attention of an operator and Figure 3 shows a schematic that can be used for this purpose. In this figure (any two counters can do), the yield between two points is being plotted against time. Suggested actions are listed in the right-hand column in corresponding to different yield rates and, of course, the response of this plot can be as quick as the data acquisition hardware can do.

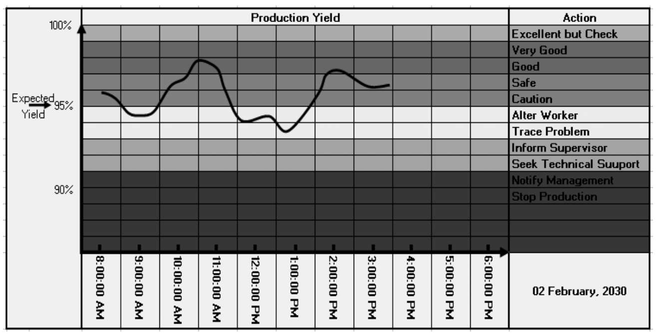

Figure 3. Schematic of quality monitoring display

IV. QUANTITATIVE PERFORMANCE MONITORING

Watching the quality alone will not guarantee the flow line can produce sufficient products to meet the demand. There may be conditions under which operations are idling while the quality is still good. Therefore, meeting the demand is another key factor to be addressed. Once the actual production falls behind at any transition, there is a high possibility that the problem will eventually hit the final output and so the demanded output cannot be met. Unlike the quality issue, where if one stage does not perform well in making good quality products, this may not affect the later yield rates directly and more, it may even run faster than usual as the rejection of a defective unit may save some processing times at the stage. However, in terms of the quantity concern, the fabrication states are not independent anymore. The output at a certain stage is influenced by its performance together with performance of previous stages. To observe the changes in quantity, we propose to use a relative mode and the expected output quantity at the final stage at the time being can be used as the datum. Ideally, a value of "1"is expected at the final stage while the previous stages will be slight larger and they are increasing upstream gradually.

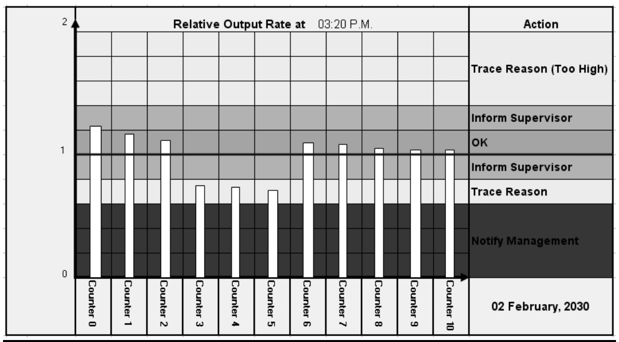

Figure 4. Schematic of quantity monitoring

Figure 4 shows an interface example, which can be employed to monitor the flow line operations; some values are larger than "1" that means they work faster than the expectation and this may not be a good sign in some circumstances. In this figure, we can also see that the counting devices located at transitions 3 to 5 indicated that below 80% of the expected output rates have been obtained and suggests one should start to trace the reason for such shortfalls as these will also propagate the other stages. Actually, the problematic point is at counting devices 4 and state 5 is receiving the consequence while state 3 is being slowdown due to the blocking effect. Therefore, when interpreting this chart one should focus on the sudden drop rather than on those with solely low values as some of which may only reflect the consequence. In addition, if the point with a relative low output rate starts moving to the right it implies that the problem has been resolved and the operations of the flow line is resuming back to normal.

V. SIMULATION SETUP

To test the proposed methodology, the simulation software called ProModel has been used to create the simulation model. A virtual flow line has been created with the setup given in Figure 5. There are six transitions with five machines: Turning Center, Machine Center, Lathe, CNC and Lathe to process the product. The processing time coupled with each operation is given under the corresponding machine. In order to make this flow line balance, capacities of 5, 15, 10, 5, and 15 units are going to be used respectively for these five machines. The six counting devices are labeled as n_0 to n_5 are inserted in between operations from the material incoming to product exit point.

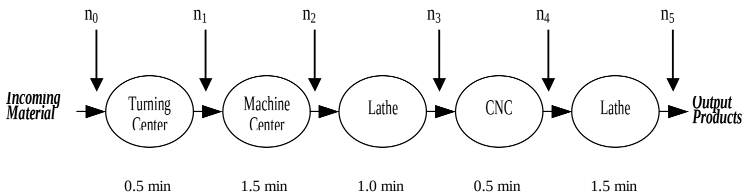

Figure 5. The flow line simulation configuration

If the factory operates at eight hours per shift, the throughput per shift can be calculated by checking the bottleneck station; in this case, since the line in perfectly balance and therefore, any station can be selected. By choosing the first station, the calculation is:

Throughput/shift = (1/Process Time) x Time/shift x Capacity
= (1 / 0.5 min) x 480 min/shift x 5 units
= 4800 units/shift.

Table 1, summarizes all details about this flow line. According to the early calculations, the throughput of this line is 4800 units per 8 hour shift and the throughput rate is 600 units per hour without taking into consideration of rejections due to defective units. Since it is hard to have a product line working in a perfect condition, an Allowance Factor (F_a) should be introduced to tolerate some random causes which may bring about slowdowns in overall operation. Now, by taking into the account of the Allowance Factor, the expected final output (also be treated as the Reference value) within a known lap time gap is equal to:

Reference = Throughput Rate x Allowance Factor x Lap Time

Then, the calculation of the relative output at a time is:

Relative output = Cum. val. at counter / Reference

Obviously, this value should be close to “1” normally and a value less than “1” means underperformance. Additionally, there are a few assumptions have been made: the flow line is in balance with no extra capacity at any station and is single path with no branches along the flow line. More, there is no buffer between any two stations and one product type is being manufactured all the time.

No.	Machine name	Process Station symbol	Processing time	Processing time symbol (min)	Capacity (unit)	Counting device symbol
0	Incoming material	-	-	-	-	
						n_0
1	Turning center	S_1	$T_{1,2}$	0.5	5	
						n_1
2	Machine center	S_2	$T_{2,3}$	1.5	15	
						n_2
3	Lathe	S_3	$T_{3,4}$	1.0	10	
						n_3
4	CNC	S_4	$T_{4,5}$	0.5	5	
						n_4
5	Lathe	S_5	$T_{5,6}$	1.5	15	
						n_5
6	Output products	-	-	-	-	
Throughput/shift =		4800 unit/shift (600 unit/hour)				
Allowance factor (F_a) =		0.95				
Working hours per shift (T_s) =		8 hours				
Expected output in a shift (Q) =		4800 x 0.95 = 4560 units				

Table 1. The flow line simulation setup information

Three testing cases have been formulated to study the coincident changes in the profile plot with reference to results obtained from counting devices to examine the conditions with different impacts. The product rate is 10 units/min (Product Rate = Capacity / Processing Time) and the individual throughput time is the summation of the processing times in between.

The first one is used to test the simulation model by providing a perfect condition and this can also be used for the comparison purpose. Thus, the yield rates are at 100% (i.e., Allowance Factor = 1.0).

The next one is about the quality problem while quantity output is still in normal, and this has been done by bringing in a yield lost condition. I.e., a tool wear problem has been introduced in the third station (Lathe) and its efficiency drops from 100% to 95% and the case gets worse at the 91 min to 150 min where the yield is further down to 90% and then is 80% up to 180 min after which the old tool has been replaced at the 181 min and the efficiency goes back to 100%.

The last one is the quality is normal but the output quantity is fall behind the desired level. In fact, this is to reflect that the output of the flow line has suffered but does not mean the quality will have problem. Once again, an event has been introduced at the same station as before. The operation begins to slowdown from 1 min per 10 units to 3 min per 10 units, after the production has run for 3.5 hrs, and this situation has lasted for 30 min. The simulation results will be presented in the next section.

VI. Results & Discussion

Three sets of simulation result have been generated. The normal condition setting is used to simulate a normal flow line. With the exception the first case, a 95% yields are expected and therefore, an Allowance Factor of 0.95 has been used. As a result, the Expected Output Capacity (Q) in a shift is:

$$Q = 4800 \text{ units} \times 0.95 = 4560 \text{ units.}$$

Operation Time (hrs)	Counter Reading					
	n_0 (pcs)	n_1 (pcs)	n_2 (pcs)	n_3 (pcs)	n_4 (pcs)	n_5 (pcs)
	---	---	---	---	---	---
1	599	594	579	569	564	549
2	1199	1194	1179	1169	1164	1149
3	1799	1794	1779	1769	1764	1749
4	2399	2394	2379	2369	2364	2349
5	2999	2994	2979	2969	2964	2949
6	3599	3594	3579	3569	3564	3549
7	4199	4194	4179	4169	4164	4149
8	4799	4794	4779	4769	4764	4749

Table 2. The normal condition simulation result

Table 2 gives the simulation result of the first case. If we examine the overall accumulative result from the eighth operation hour, the reading at n_0 is 4799 units and the reading at n_5 is 4749 units. With the application of the formula developed in Section III, the yield rate can be determined. For example, from n_0 to n_5:

WIP = 10 units/min x 5 min = 50
Yield = (4749 units + 50 units) / 4799 unit = 100%

As one may expect the yields between any two counter output will be the same (100%). In terms of the quantity output, the calculated reference output at the eighth hour is:

Reference = 10 units/min x 1.0 x 8 hrs x 60 min/hr
= 4800 units

Relative output = 4749 units /4800 units
= 0.99

It seems that the relative output is slightly less than the expectation and the reason is due to the warm up time of the flow line; the first product takes time (5 min) to reach the last counter (n_5) in the simulation. In fact, a more accurate value for the reference can be determined by taking into the account of the warm up time but the influence here is very small the over throughput time is only 5 minutes.

Operation Time (hrs)	Counter Reading					
	n_0 (pcs)	n_1 (pcs)	n_2 (pcs)	n_3 (pcs)	n_4 (pcs)	n_5 (pcs)
	---	---	---	---	---	---
1	599	589	570	552	551	543
2	1199	1184	1161	1106	1108	1112
3	1799	1780	1755	1614	1622	1634
4	2399	2372	2346	2195	2205	2221
5	2999	2964	2935	2779	2794	2826
6	3599	3555	3521	3361	3380	3418
7	4199	4150	4110	3946	3966	4018
8	4799	4748	4702	4531	4554	4612

Table 3. The result with quality problem

Table 3 shows the results with the introduction of a quality problem as the quantity output maintains. The first hour operation was about normal and then, tool failures had occurred.

When we look at the reading at n_3 in the second operation hour, it is 1106 units. The reference value should be 1229 units (1199 + 10 x 3) and the yield is just below 90%. Similar problem occurs in the third and fourth hours. After the fourth hour, the problem has been fixed. Although the quality issues occur on this flow line, it still can meet the demand; n_5 at the eighth hour is 4612 units still greater than 4560 units.

Operation Time (hrs)	Counter Reading					
	n_0 (pcs)	n_1 (pcs)	n_2 (pcs)	n_3 (pcs)	n_4 (pcs)	n_5 (pcs)
	---	---	---	---	---	---
1	599	589	570	552	551	543
2	1199	1120	1158	1141	1146	1148
3	1799	1769	1745	1724	1737	1749
4	2205	2170	2140	2110	2133	2165
5	2806	2767	2735	2703	2727	2751
6	3407	3360	3327	3288	3312	3343
7	4008	3955	3915	3868	3896	3938
8	4609	4552	4507	4456	4487	4538

Table 4. The result with quantity fall behind

Table 4 records the result of the last test case with which the quality issue is normal but the quantity output is fall behind. In this table, we can see that the yield at station 3 at the fourth hour is nearly equal to 0.99 which is in good quality condition. But when wee look at the quantity compare with the reference value (Reference Equation in Section VI.), it is (2251 – 2110), 141 units in difference. If we look back to the third hour by the same station, both yield and quantity outputs are in good condition. When we look at it in further at the eighth hour, the yield is also nearly 0.99 but the quantity is still less then the reference values. Therefore, we can see that there should be slow down in station 3 in between the third and fourth operation hours.

VII. Conclusion

In this paper, a generic model in monitoring a production flow line has been introduced. It requires only one type of simple signals from the flow line. Consequently, the hardware architecture can be very straightforward and so typical integration problems are minimized. By checking the numbers of entities flowing through transition points (between any two processing stations) with respect to the operation time, the overall picture can be observe. This is done by plotting the yields and out quantities along the flow line and little technical skill is required to understand the information. Such an approach can also be interpreted to reflect the state of health of the fabrication system instantaneously.

Acknowledgment

The work described in this research project was substantially supported by a grant from the Department of Industrial & Systems Engineering, The Hong Kong Polytechnic University and the Research Grants Council of the Hong Kong Special Administrative Region (Project No. RGCG)

References

[1] Hitomi, K., “Strategic Integrated Manufacturing Systems: The Concept and Structures”, in *International Journal of Production Economics*, 1991, **25** (1), 5-12.

[2] Masao, N., & Sadao, S. & Roger, S., “Adoption of Just-In-Time Manufacturing Methods at U.S. – and Japanese-Owned Plants: Some Empirical Evidence”, *IEEE Transactions on Engineering Management*, August 1998, **45** (3), 230-240.

[3] Kang. Suk-Ho, & Kim. Yeongho & Lee. Young Chang, “A Time-Controlled Petri Net Model and Deadlock Detouring Algorithm for Real-Time FMC Control”, in *International Journal of Computer Integrated Manufacturing*, 2000, **13** (6), 533-544.

[4] Stevenson,W., *Production/Operations Management*, 7th Edition, Boston: McGraw_Hill/Irwin, 1996.

[5] Tanner, M., *Practical Queuing Analysis*, New York McGraw_Hill, London, 1995.

[6] Gourgand, M., & Lacomme, P., & Traore, K., “Design of a monitoring environment for manufacturing systems management and optimization”, *International Journal of Computer Integrated Manufacturing*, January 2003, **16**(1), 61-80.