IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Impact of JIT on Quality Control Cost: A Sensitivity Analysis

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Abstract

Many authors have been developed the models to study the influence of JIT on inventory. On other hand, strategic impact of JIT on quality control cost has not been clear-cut. The purpose of this paper is to study the impact of JIT on quality control by developing a model. The developed model is illustrated though a sensitivity analysis and a numeric example so that more attention could be provided on the most critical input parameters of model. The framework developed in this paper provides a step forward towards better planning for quality under JIT context..

Keywords: Just-in-Time (JIT), Quality control, Production control, Inventory control.

Introduction

JIT is a philosophy that calls for reducing work-in-process (WIP) inventory to aid process improvement and reduce process variability. JIT production system is designed in such a way that parts and components arrive at factories just as they are needed for assembly, reducing and sometimes eliminating the need for warehousing expensive parts [1]. Since JIT requires plants to keep trim inventories, even a small glitch in the supply chain can bring production to a standstill. JIT cannot function with high rate of defective items; its success rate requires detailed attention to quality both in purchasing and production. For JIT to be most effective, the manufacturing process must be stable. This stability can be achieved through SPC (statistical process control). SPC quickly detect the occurrence of assignable causes so that process can be investigated and corrective actions can be taken before many more nonconforming units are manufactured [2]. The control charts are widely used for this purpose. In today's JIT operations, control charts are used in more dynamic manner and monitor as a foolproof system. Consistent with JIT quality management principles, the authority is given to workers to shut down the production line, U-cell, or entire plant if process quality drops below a preset level. On other hand, the production continues during searches of defects under traditional production system. This fundamental difference motivates to estimate and compare the overall quality control cost under both cases. A model has been developed for this purpose, which includes (a) expected cost of operating while in control; (b) expected cost of operating while out of control; (c) expected cost of false alarm; (d) expected cost of repair and (e) expected cost of sampling and signaling.

This paper is organized as follows. In the next section, necessary notations and assumptions are developed. The model is developed in section 3. In section 4, an example is provided for illustration purposes. Finally, section 5 contains a summary of the paper and some concluding remarks.

System Operation, Assumptions and Notation

Assume a JIT manufacturing system producing single item. The workers are fully authorized to halt the production line, if production system produces defective product i:e system is out of control. A production cycle is started with a new system, which is assumed to be in-control state and producing items of acceptable quality. However, after a period of time in production, the process may shift to an out of control state. The figure 1 provides an illustration of the timeline of events that occur when monitoring a process with a control charts. The process starts in-control and subject to random shifts in the process mean. Once shift occurs, the process remains there until corrected. Some time between j^{th} and $(j+1)^{th}$ sample, the process shifts to the out-of-control state. The control chart incorrectly indicates that process is in control until $(j+i)^{th}$ sample is collected. There will be time lag to collect and interpret the result at the $(j+i)^{th}$ sample. A search is initiated to determine the assignable cause as an out-of-control condition is signaled. At this point, there is another time lag to remove the assignable cause and return the process to its original operating condition. The length of time the process remains in-control is assumed to be exponentially distributed. If process is not shut down during false alarm, then the average time until occurrence of assignable cause is 1/λ.

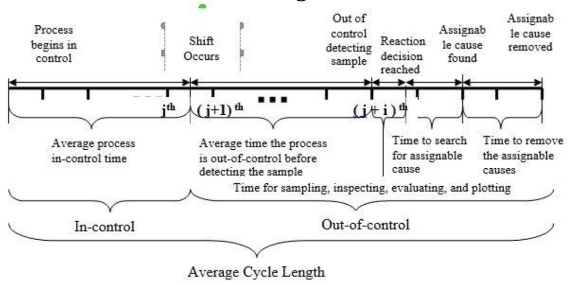

Fig.1: Average Cycle Length

The following notation is used to develop the model:
a = fixed sampling cost;
b = cost per unit sampled;
n = sample size taken from the process at each sampling interval;
h = interval between the sampling;
C_f = cost to instigate false alarm;
C_o = hourly quality lost cost while producing in control;
C_1= hourly quality lost cost while producing out of control;
C_r = cost to locate a repair an assignable cause;
N_s = expected number of samples while process is in control;
1/λ = Average time until an occurrence of an assignable cause, if the process is not shutdown during false alarm;
ARL_0 = Average run length while process is in control;
ARL_1 = average run length while process has shifted to an out of control;
T_f = expected time to determine a false alarm;
T_a = expected time to locate the assignable cause;
T_r = expected time to repair the process;
T_s = expected time to sample and chart one item;
E (T) = expected total cycle time;
E (C) = expected cost per cycle;
E = expected cost per hour;
f_1, f_2= production indicator functions.

Model Components and Cycle Length

The cycle length is defined as the total time from which the process starts in-control, shifts to an out of control condition, has the out of control condition detected, and result in assignable cause identification and rectification. A complete cycle length consists of five time intervals as shown in fig.1. These five time intervals are (a) the interval the process is in-control; (b) the interval the process is out of control before taking the (j+ i)th sample; (c) the interval to sample, inspect, evaluate and plot the results; (d) the interval to search for the assignable cause; and (e) the interval to remove for the assignable cause.

The expected total cycle length is sum of (1) in-control cycle time; and (2) out-of-control cycle time.

(1) In-control cycle time is expressed as follows:

(a) Average process in-control time is 1/λ. (Since average time for occurrence of the assignable cause is exponentially distributed with mean 1/λ, this is average process in-control time.) (1)

(b) The expected time spent on searching for false alarms is

$$= \frac{(1-f_1)\times N_s \times T_f}{ARL_0} \quad \text{where } N_s = \frac{e^{-\lambda h}}{1-e^{-\lambda h}} \tag{2}$$

and

$$f_1 \begin{cases} 0 & \text{(JIT Production System)} \\ 1 & \text{(Otherwise, if production continue during search)} \end{cases}$$

So, the expected in-control time is (1) + (2)

$$= \frac{1}{\lambda} \div \frac{(1-f_1)\times\left[\dfrac{e^{-\lambda h}}{1-e^{-\lambda h}}\right]\times T_f}{ARL_0} \tag{3}$$

(2) The expected out-of-control time is described as

(a) The expected time that a process shifts out of control between jth and (j+1)th sample is

$$= \frac{\int_{jh}^{(j+1)h} e^{-\lambda h}(t-jh)dt}{\int_{jh}^{(j+1)h} e^{-\lambda h}dt}$$

$$= \frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} \tag{4}$$

(b) The time between an occurrence of an assignable cause and next sample is

$$= h - \frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} \tag{5}$$

(c) The expected time to sample, evaluate and plot time for each sample is given by

$$= n \times T_s \tag{6}$$

(d) The expected time until an out-of-control signal is triggered is given by

$$= (ARL_1 - 1)\times h \tag{7}$$

(e) The expected time to discover the assignable cause is

$$= T_a \tag{8}$$

(f) The expected time to repair the process is

$$= T_r \tag{9}$$

So, the expected out-of-control cycle time is (5) + (6) + (7) + (8) + (9)

$$= h - \frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} + (n\times T_s) + ((ARL_1 - 1)\times h) + T_a + T_r$$

$$= h - \frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} + (n\times T_s) + (ARL_1 \times h) - h + T_a + T_r$$

$$= (n\times T_s) + (ARL_1 \times h) + + T_a + T_r - \frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} \tag{10}$$

Thus, the expected total cycle time is given by (3) + (10)

$$E(T)=\frac{1}{\lambda}\div\frac{(1-f_1)\times\left[\frac{e^{-\lambda h}}{1-e^{-\lambda h}}\right]\times T_f}{ARL_0}+(n\times T_s)+(ARL_1\times h)+T_a+T_r-\frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)} \quad (11)$$

Cost formation

The expected quality control cost per cycle for this model is sum of (a) expected quality loss cost while process is in control; (b) expected quality loss cost while process is out of control; (c) expected cost of sampling; (d) expected cost of false alarm; and (e) expected cost of locating and repairing.

(a) The expected quality loss cost while the process is in control is given by

$$=C_0\times\frac{1}{\lambda} \quad (12)$$

The expected quality loss cost while process is out-of-control is given by

$$=C_1\times\left[(n\times T_s)+(ARL_1\times h)+(f_1\times T_a)+(f_2\times T_r)-\frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)}\right].. \quad (13)$$

f_2 — 0 (JIT Production System); 1 (Otherwise, if production continues during repair)

(b) The expected sampling cost per cycle is given by the following

$$=\frac{(a+b\times n)\times E(T)}{h} \quad (14)$$

(c) The expected cost of evaluating the false alarm is

$$=\frac{N_s\times C_f}{ARL_0}$$

$$=\frac{e^{-\lambda h}}{1-e^{-\lambda h}}\times\frac{C_f}{ARL_0} \qquad \text{where} \quad N_s=\frac{e^{-\lambda h}}{1-e^{-\lambda h}} \quad (15)$$

(d) The expected cost of locating and repairing an assignable cause

$$=C_r \quad (16)$$

So, the expected quality control cost per cycle is (12) + (13) + (14) + (15) + (16)

$$=\left(C_0\times\frac{1}{\lambda}\right)+C_1\times\left[(n\times T_s)+(ARL_1\times h)+(f_1\times T_a)+(f_2\times T_r)-\frac{\left(1-(1+\lambda h)\times e^{-\lambda h}\right)}{\lambda\left(1-e^{-\lambda h}\right)}\right]$$

$$+\left(\frac{(a+b\times n)\times E(T)}{h}\right)+\left(\frac{e^{-\lambda h}}{1-e^{-\lambda h}}\times\frac{C_f}{ARL_0}\right)+C_r \quad (17)$$

Hence,

ISSN: 2277-9655
Impact Factor: 1.852

$$E\ [\text{expected quality control cost per hour}] = \frac{E(C)}{E(T)} \quad (18)$$

Sensitivity Analysis

The proposed model in eqn. (18) requires 17 input parameters that determine total quality control cost per hour under JIT production system. To study the sensitivity of input parameters, a sensitivity analysis is performed by varying four cost parameters, four time parameters, and three critical process parameters. The analysis is limited to these eleven input parameters varied at six levels.

Table 1 provides the maximum and minimum levels of variable parameters while table 2 provides the remaining parameters that are held at affixed levels for all experimental runs. The parameters setting of base-case scenario is established by using midpoints of maximum and minimum levels of factors. The remaining settings of base-case parameters come from table 2.

Suppose the fixed cost of sampling is Rs. 1.50, the variable cost of sampling is Rs. 0.4, and it takes approximately 6 minutes (0.1 hours) to take and analyze the each observation. The process shifts occur following an exponential distribution with an average shift occurring about every 70 hours. The cost of investigating a false alarm is Rs. 240 and repair cost is Rs. 185.

Table1: Variable parameters for sensitivity analysis

	Input Parameter	C_0	C_1	C_f	Cr	$1/\lambda$	ARL_0	ARL_1	T_f	T_a	T_r	T_s
Level	Minimum	50	100	60	60	20	50	02	1.50	01	02	0.025
	Maximum	175	600	420	310	120	300	14	9.00	06	12	0.175
	Base-case	112.5	350	240	185	70	175	08	5.25	3.5	07	0.1

Table 2: Fixed parameters for sensitivity analysis

Input parameters	n	h	a	b	f_1	f_2
Level (JIT Prod. System)	20	2	1.5	0.4	0	0
Level (Trad. prod. system)	20	2	1.5	0.4	1	1

Table 3: Sensitivity analysis

	C_0	C_1	ARL_0	ARL_1	C_f	$\square_1$	$\square_2$	E	Variation	Sensitivity
Trad. Prod.	112.50	350.00	175	8	240.00	1	1	145.45	----	
JIT Prod. (Basecase)	**112.50**	**350.00**	**175**	**8**	**240.00**	**0**	**0**	**143.86**	**----**	
	50.00	350.00	175	8	240.00	0	0	99.47	-30.859	
	75.00	350.00	175	8	240.00	0	0	117.23	-18.514	Highly
	100.00	350.00	175	8	240.00	0	0	134.98	-6.1692	Sensitive
	125.00	350.00	175	8	240.00	0	0	152.74	6.17557	
	150.00	350.00	175	8	240.00	0	0	170.50	18.5204	
	175.00	350.00	175	8	240.00	0	0	188.26	30.8652	
	112.50	100.00	175	8	240.00	0	0	103.27	-28.213	
	112.50	200.00	175	8	240.00	0	0	119.51	-16.926	Highly
	112.50	300.00	175	8	240.00	0	0	135.75	-5.6402	Sensitive
	112.50	400.00	175	8	240.00	0	0	151.98	5.64651	
	112.50	500.00	175	8	240.00	0	0	168.22	16.9332	
	112.50	600.00	175	8	240.00	0	0	184.46	28.2199	
	112.50	350.00	50	8	240.00	0	0	141.47	-1.6581	
	112.50	350.00	100	8	240.00	0	0	143.13	-0.5043	Sensitive

ISSN: 2277-9655
Impact Factor: 1.852

112.50	350.00	150	8	240.00	0	0	143.70	-0.1103	
112.50	350.00	200	8	240.00	0	0	143.99	0.08850	
112.50	350.00	250	8	240.00	0	0	144.16	0.20838	
112.50	350.00	300	8	240.00	0	0	144.28	0.28855	
112.50	350.00	175	4	240.00	0	0	125.23	-12.949	Highly
112.50	350.00	175	6	240.00	0	0	134.94	-6.1991	Sensitive
112.50	350.00	175	8	240.00	0	0	143.86	0.00314	
112.50	350.00	175	10	240.00	0	0	152.09	5.72153	
112.50	350.00	175	12	240.00	0	0	159.70	11.0105	
112.50	350.00	175	14	240.00	0	0	166.76	15.9167	
112.50	350.00	175	8	60.00	0	0	143.50	-0.2471	
112.50	350.00	175	8	140.00	0	0	143.66	-0.1359	Insensitive
112.50	350.00	175	8	210.00	0	0	143.80	-0.0385	
112.50	350.00	175	8	280.00	0	0	143.94	0.05877	
112.50	350.00	175	8	350.00	0	0	144.08	0.15613	
112.50	350.00	175	8	420.00	0	0	144.22	0.25348	

Table 3: Sensitivity analysis (contd..)

C_r	1/□	T_f	T_a	T_r	T_s	$\square_1$	$\square_2$	E	Variation	Sensitivity
60.00	70	5.25	3.50	7.00	0.1	0	0	142.60	-0.8786	
110.00	70	5.25	3.50	7.00	0.1	0	0	143.10	-0.5259	Insensitive
160.00	70	5.25	3.50	7.00	0.1	0	0	143.61	-0.1732	
210.00	70	5.25	3.50	7.00	0.1	0	0	144.12	0.17950	
260.00	70	5.25	3.50	7.00	0.1	0	0	144.63	0.53221	
310.00	70	5.25	3.50	7.00	0.1	0	0	145.13	0.88492	
185.00	20	5.25	3.50	7.00	0.1	0	0	173.13	20.3486	
185.00	40	5.25	3.50	7.00	0.1	0	0	156.20	8.57781	Sensitive
185.00	60	5.25	3.50	7.00	0.1	0	0	147.03	2.20546	
185.00	80	5.25	3.50	7.00	0.1	0	0	141.29	-1.7880	
185.00	100	5.25	3.50	7.00	0.1	0	0	137.35	-4.5250	
185.00	120	5.25	3.50	7.00	0.1	0	0	134.48	-6.5179	
185.00	70	1.50	3.50	7.00	0.1	0	0	144.92	0.73417	
185.00	70	3.00	3.50	7.00	0.1	0	0	144.49	0.44044	Insensitive
185.00	70	4.50	3.50	7.00	0.1	0	0	144.07	0.14847	
185.00	70	6.00	3.50	7.00	0.1	0	0	143.66	-0.1417	
185.00	70	7.50	3.50	7.00	0.1	0	0	143.24	-0.4302	
185.00	70	9.00	3.50	7.00	0.1	0	0	142.83	-0.7169	
185.00	70	5.25	1.00	7.00	0.1	0	0	147.49	2.52036	
185.00	70	5.25	2.00	7.00	0.1	0	0	146.01	1.49791	Sensitive
185.00	70	5.25	3.00	7.00	0.1	0	0	144.57	0.49632	
185.00	70	5.25	4.00	7.00	0.1	0	0	143.16	-0.4850	
185.00	70	5.25	5.00	7.00	0.1	0	0	141.78	-1.4467	

185.00	70	5.25	6.00	7.00	0.1	0	0	140.42	-2.3895	
185.00	70	5.25	3.50	2.00	0.1	0	0	151.30	5.17213	
185.00	70	5.25	3.50	4.00	0.1	0	0	148.23	3.03961	Sensitive
185.00	70	5.25	3.50	6.00	0.1	0	0	145.29	0.99455	
185.00	70	5.25	3.50	8.00	0.1	0	0	142.47	-0.9683	
185.00	70	5.25	3.50	10.00	0.1	0	0	139.75	-2.8538	
185.00	70	5.25	3.50	12.00	0.1	0	0	137.15	-4.6666	
185.00	70	5.25	3.50	7.00	0.025	0	0	146.00	1.48716	
185.00	70	5.25	3.50	7.00	0.050	0	0	145.28	0.98742	Sensitive
185.00	70	5.25	3.50	7.00	0.075	0	0	144.57	0.49277	
185.00	70	5.25	3.50	7.00	0.125	0	0	143.17	-0.4815	
185.00	70	5.25	3.50	7.00	0.150	0	0	142.48	-0.9613	
185.00	70	5.25	3.50	7.00	0.175	0	0	141.79	-1.4363	

The hourly cost of operating in the in-control state is Rs. 112.50 while hourly cost of operating in the out-of-control state is Rs. 350. The value of each parameter was perturbed from the base case. For each 6*11=66 cases run, the expected quality control cost per cycle is determined and compared with base case environment to investigate the effect of the input parameters of model on quality control cost per hour.

The results are presented in table 3. It is easy to see that user should pay particular attention to obtaining good estimates of C_0, C_1 and ARL_1. Some attention should be given to estimates of λ, T_s, and T_r .The model results are very insensitive to C_f, C_r and ARL_0 at least for the example presented above. Other interesting observations include the following:

1. The results from the experiment are revealed that quality control cost per hour is less under JIT production system as compared to tradition production system for same time and cost parameters tabulated in table 1 and table 2.
2. When average process in-control time $1/\lambda$ increases, quality control cost per hour decreases. The increment in quality control cost is more for lower values of $1/\lambda$ as compare to higher values.
3. The model results are highly sensitive to C_0 and C_1. The higher values of these parameters lead to higher quality control cost.
4. The repair time for process (T_r) has a moderate effect on quality control cost while other time parameters such as T_a, T_f, and T_s are relatively less sensitive.
5. Large variation in cost of locating and repairing an assignable cause leads to small changes in quality control cost. Similarly, model results are also insensitive to the cost of investigating the false alarm.
6. The input parameter ARL_1 has significant effect on quality cost per hour while ARL_0 is relatively less sensitive.

Conclusions

This paper has shown the detailed development of a model that estimates the quality control cost per hour under JIT production system. It considers appropriate revenues and costs based upon time and cost parameters involved. Sensitivity analysis gives an indication of sensitivity to each of input parameters, and identifies those parameters that deserve a strong look. It has shown that out of 11 input variables selected; only these three variables C_o, C_1 and ARL_1 are critical to great extent. More importantly, this study recognizes that control charts can be more effective and economical, when they are implemented with principles of JIT quality control.

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