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A Design for Quality Management Information System in Short Delivery Time Processes

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1. Introduction

Recently, by the advance of IT (information technology), the IT control charts have been paid attention and been used in quality management information system, for not only putting quality into products at the production stage but also improving communication between management and manufacturing [1], [2]. Because the high quality, low cost and short delivery time are demand from customer, delivery to the multi-item small-sized production, the reduction of delivery time is emphasized. For those needs, developing the methods and designs of control chart suitable for today's work situations (For example, short delivery time process.) become a new problem for manager, which is also one research theme of control chart practical applications study group of JSQC [3].

The classical definitions of the control chart's PDCA (Plan, Do, Check and Act) procedures are known. Recently, the evaluation of the economy of this control chart's PDCA procedures is connected with "daily management".

By investigating literature cases in the activities of control chart practical applications study group, it is recognized that the act procedure is the most important in the procedures of PDCA of control chart [4]. Because the systematic investigations of control chart's PDCA design was not done in the works before, Sun, Tsubaki and Matsui defined and considered the PDCA designs based on the $\bar{x}$ control chart [5] and P control chart [6], respectively. In addition, the PDCA design of the $\bar{x}$ control chart with tardiness penalty is investigated [7]. However, the ACT time was not considered in above researches.

In this research, first a design of the $\bar{x}$ control chart is presented and its mathematical formulations are shown. Then, the presented design based on the judgment rules of JIS Z 9021 [8], [9] is studied, finally, by numerically consideration using the data from real situation, the relations of key parameters and delivery time and the total expectation cost are discussed.

2. The design

When the control chart is used in short delivery time processes, the penalties for delay of the delivery time should be imposed. In this research, the PDCA design is set up based on the

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case which starts from deciding the control lines of the $\bar{x}$ control chart, in which the penalties for delay of the delivery time (T) have been considered.
The evaluation function of this research is the expected total cost per unit time as follows:

$$C_{t(CAPD)} = \frac{E[cost\ per\ cycle]}{E[cycle\,(PDCA)]} = \frac{E[cost\ per\ cycle]}{E[\min(T_p + I_1 + O_1 + a, T)]} \\ = C_p + C_d + C_c + C_a. \tag{1}$$

The definition of the procedures of the PDCA design and the cost elements of equation (1) are explained in Table 1.
The time variables used in the design of this research are defined by Figure 1.

Procedure	Difinition	Element of cost (per unit time)
PLAN	Constructs control lines of control chart.	*Cp=Cp(p)+Cp(pe)* *Cp(p)* cost of PLAN *Cp(pe)* cost of the penalty for delaying the PLAN
DO	Samples and plots on control chart for monitoring the process.	*Cd=Cd(d)+Cd(pe)* *Cd(d)* cost of DO *Cd(pe)* cost of the penalty for delaying the DO
CHECK	Examines whether the points plotted on control chart are beyond the upper and lower control limits.	*Cc=Cc(c)+Cc(e)+Cc(pe)* *Cc(c)* cost of CHECK *Cp(p)* cost of type I error *Cp(pe)* cost of the penalty for delaying the CHECK
ACT	Investigate the assignable cause and correct it.	*Ca=Ca(a)+Ca(pe)* *Ca(a)* cost of ACT *Ca(pe)* cost of the penalty for delaying the ACT

Table 1. The definition and the cost elements of the design

Figure 1 shows some of the time variables used in the design of this research. At the start of the PDCA design, PLAN for deciding the control lines is made in *Tp* time. Therefore, it is thought that the PDCA model starts from the in-control state,
because the process is managed by these control lines. Let the process start at the point of *Q*, and let *S* be the point in time at which the quality characteristic shifts to an out-of-control state as shown in Figure 1. An assignable cause is detected at the point of *C*, and then corrected at the point of *D*. Here, the random variables I_1 and O_1 represent the interval from *Q* to *S* and the interval from *S* to *C*.
The assumptions of the design in this research are as follows:
1. The delivery time is short, and the process is repetitive.
2. The quality shift occurs in the middle of an interval between samples [10]

In this research, both the random variables I_1 and O_1 are assumed to be independently and exponentially distributed with mean λ_1^{-1}, μ_1^{-1}, then (1) is

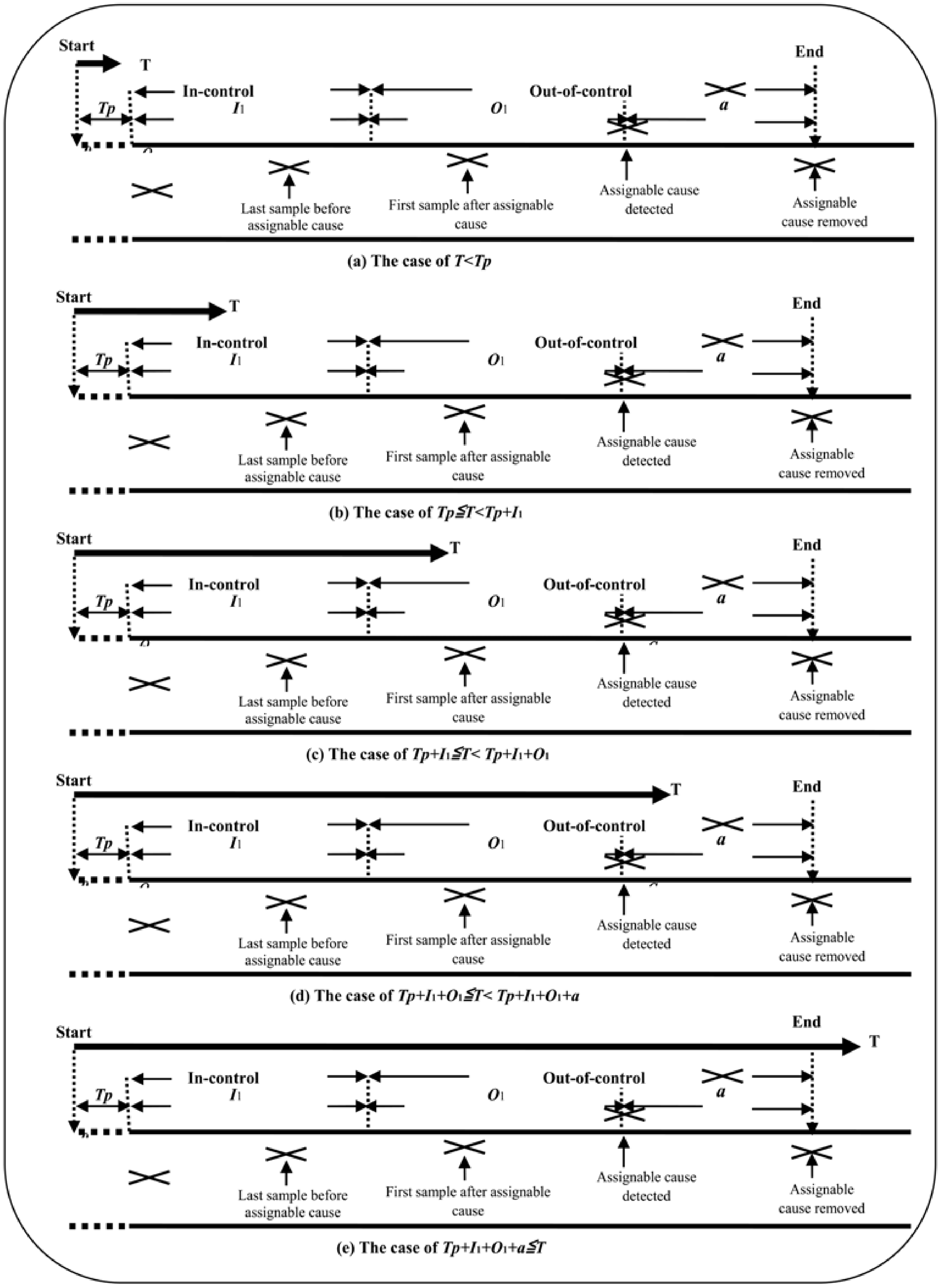

Fig. 1. Some of time variables used in the design

$$Ct = \{((c_0 + c_1 n)/v)[T\phi_1 + T_p(1-\phi_1)] + c_{\beta p}\phi_1 + [(c_0 + c_1 n)/v]$$
$$[\frac{1}{\lambda_1 - \mu_1}\{\frac{\mu_1}{\lambda_1}(e^{-\lambda_1(T-T_p-a)} - 1) - \frac{\lambda_1}{\mu_1}(e^{-\mu_1(T-T_p-a)} - 1)\} + T_p + a -$$
$$(T\varphi_1 + T_p(1-\phi_1))] + c_{\beta d}\phi_2 + (c_2/v)[\frac{1}{\lambda_1 - \mu_1}\{\frac{\mu_1}{\lambda_1}(e^{-\lambda_1(T-T_p-a)} - 1) -$$
$$\frac{\lambda_1}{\mu_1}(e^{-\mu_1(T-T_p-a)} - 1)\} + T_p + a - (T\phi_1 + T_p(1-\phi_1))] +$$
$$(c_3/v_1)\alpha\frac{1}{\lambda_1}(1 - e^{-\lambda_1(T-T_p)}) + c_{\beta c}[\frac{1}{\mu_1} + \frac{1}{\lambda_1 - \mu_1}(e^{-\lambda_1(T-T_p)} - \tag{2}$$
$$\frac{\lambda_1}{\mu_1}e^{-\mu_1(T-T_p)})] + c_4[a + \frac{1}{\lambda_1 - \mu_1}(\frac{\lambda_1}{\mu_1}e^{-\mu_1(T-T_p)}(1 - e^{\mu_1 a}) -$$
$$\frac{\mu_1}{\lambda_1}e^{-\lambda_1(T-T_p)}(1 - e^{\lambda_1 a}))] + c_{\beta a}[\frac{\lambda_1\mu_1}{\lambda_1 - \mu_1}(-\frac{1}{\mu_1}e^{-\mu_1(T-T_p)}(1 - e^{\mu_1 a}) +$$
$$\frac{1}{\lambda_1}e^{-\lambda_1(T-T_p)}(1 - e^{\lambda_1 a}))]\} / [\frac{1}{\lambda_1 - \mu_1}\{\frac{\mu_1}{\lambda_1}(e^{-\lambda_1(T-T_p-a)} - 1) -$$
$$\frac{\lambda_1}{\mu_1}(e^{-\mu_1(T-T_p-a)} - 1)\} + T_p + a]$$

Where

$$\mu_1^{-1} = v(1/P_a - 1) + v/2 = v(1/P_a - 1/2). \tag{3}$$

3. Numerical experiments

A. Explanation of parameters from a real situation

The parameters used in this research are from A company, which is based on a real situation. Where $c0$=50，$c1$=40，$c2$=100, $c3$=2000, $c4$=8000, $c_{\beta a} = c_{\beta p} = c_{\beta d}$ =1000000, $c_{\beta c}$ =1000000, v=1day, f'=20, ϕ_1 =0.01, ϕ_2 =0.001, $1/\lambda_1$=10days, δ=1, k=3.0, a=0.083 day. The notation used is as follows:

n the sample size per each sampling
v the sampling interval
T delivery time
Tp the interval of PLAN
c_0 fixed sampling cost
c_1 variable sampling cost
c_2 cost of per unit time for checking the point plotted
c_3 cost of a false alarm
c_4 cost of restoring an in-control state
$c_{\beta p}$ cost of per unit time for penalties delay of PLAN
$c_{\beta d}$ cost of per unit time for penalties delay of DO
$c_{\beta c}$ cost of per unit time for penalties delay of CHECK (penalties for sending the mistake information)

$c_{\beta a}$ cost of per unit time for penalties delay of ACT
f' number of samples taken during T-Tp
δ size of the quality shift in the mean
a the ACT time
k control limits width
In this research, the outside dimension of molding plate is a key quality characteristic. The difference between the outside dimension and set value is plotted on the $\bar{x}$ control chart.

B. Investigations based on the judgment rules of JIS Z 9021

In the production process, the power (*Pa*) is different depending on the kind of the judgment rule. In this section, the presented design is considered based on the rule 1 (3σ rule) and rule 2 (9 ARL rule) of JIS Z 9021. Because sample size *n* is not only an influence element to test but also an important parameter of cost, at first, the two judgment rules are studied by the change of *n*.
From Figure 2, it can be noted that the *Pa* by the two rules increases with the increase of sample size *n*, and the speed of increase of 9 ARL rule is faster.
Next, the design based on the two judgment rules is studied by the change of *n*. From Figure 3, it can be note that when *n* is small, the expected total cost *Ct* of 9 ARL rule is cheaper.
From Figure 3, it also can be note that the expected total cost *Ct* of 3σ rule is the cheapest when n is five. This result is corresponding to the sampling size actually used in A company. Therefore, it could be said that the presented design is applicability.

C. Investigations of the relations between the power and delivery time and the total expectation cost

From Figure 4, it can be understand that the expected total cost per unit time *(Ct)* decreases with the increase of the power (*Pa*). This is because that the cost of defective goods decreases by the increase of the power (*Pa*).

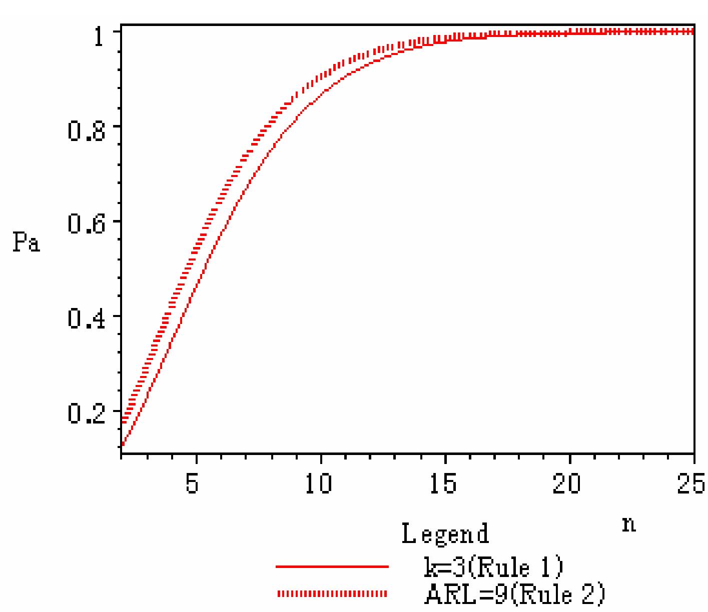

Fig. 2. Power by the two rules

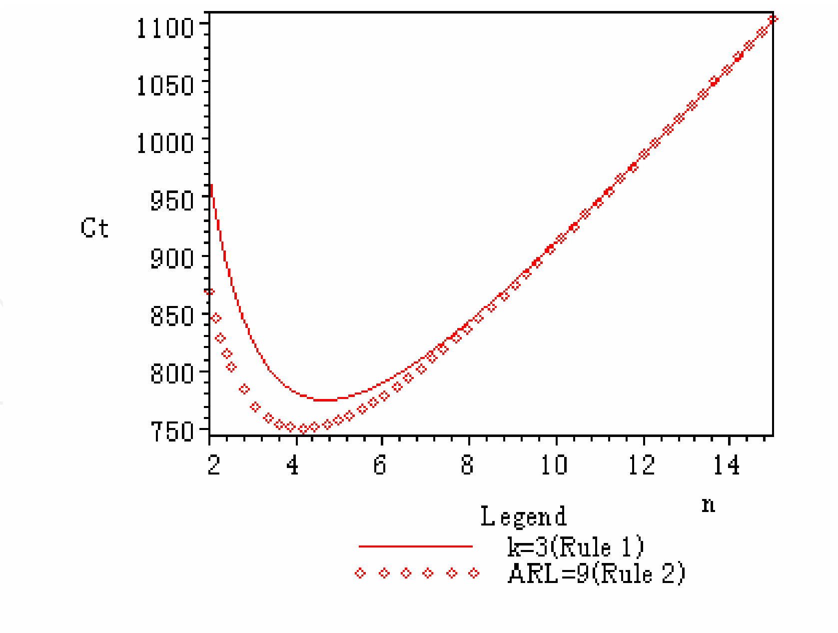

Fig. 3. Investigating the design by the two rules

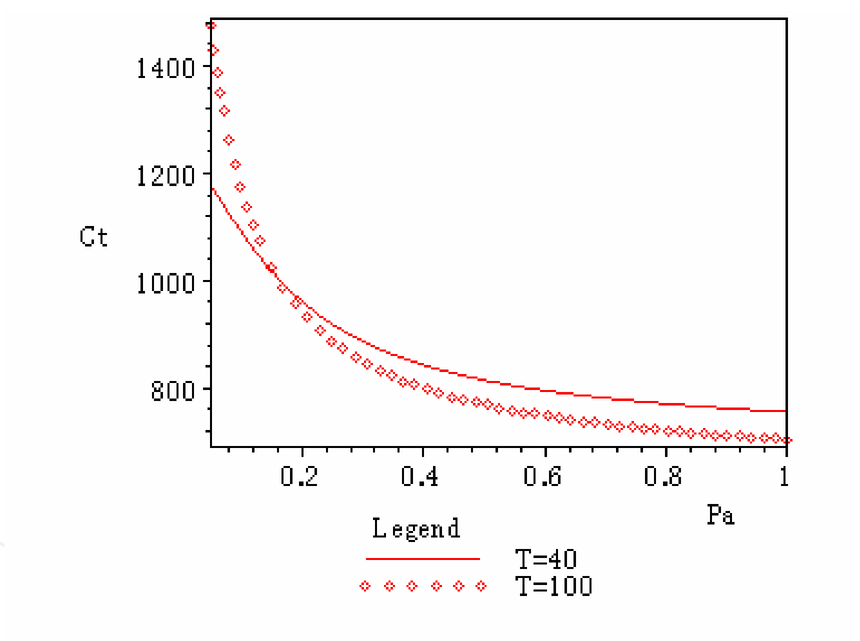

Fig. 4. The relation between *Pa*, *T* and *Ct*

From Figure 4, it also can be understand that a longer delivery time should be set when the higher power for higher quality is demanded; while a shorter delivery time should be set when the low power for not higher quality is demanded.
In addition, to understand a more detailed setting, Table 2 is shown, which is based on the case of A company. The axis of ordinate and abscissas are *Pa* and *T*.
From Tables 2, it can be understood that this tables are divided into two areas: in the colourlessness area, a longer delivery time should be set for the higher power (higher quality) being demanded; in the Blue area, a shorter delivery time should be set for the low power (not higher quality) being demanded.

Pa	*T*								
	40	*50*	*60*	*70*	*80*	*90*	*100*	*110*	*120*
0.05	1176.9	1302.2	1377.4	1422.1	1448.7	1464.6	1474.0	1479.5	1482.7
0.10	1090.8	1135.5	1155.3	1163.8	1167.3	1168.6	1169.05	1169.06	1168.9
0.15	1017.8	1023.5	1024.6	1024.8	1024.6	1024.4	1024.15	1023.88	1023.6
0.20	961.3	949.7	944.8	942.8	941.9	941.4	941.03	940.71	940.4
0.30	890.0	863.6	855.2	852.0	850.6	849.9	849.47	849.11	848.8
0.35	860.0	836.8	827.7	824.2	822.8	822.0	821.58	821.21	820.9
0.40	840.0	816.2	806.6	802.9	801.4	800.6	800.12	799.74	799.4
0.46	824.1	796.0	786.0	782.1	780.5	779.7	779.25	778.87	778.5
0.50	810.0	786.4	776.1	772.2	770.5	769.7	769.25	768.87	768.5
0.55	800.0	775.2	764.8	760.8	759.1	758.3	757.79	757.40	757.1
0.60	799.0	765.9	755.2	751.1	749.5	748.6	748.13	747.74	747.4
0.65	791.0	757.9	747.1	742.9	741.2	740.4	739.88	739.49	739.1
0.70	781.4	751.0	740.0	735.8	734.1	733.3	732.76	732.37	732.0
0.75	775.7	744.9	733.9	729.7	727.9	727.1	726.55	726.15	725.8
0.80	770.6	739.6	728.5	724.2	722.4	721.6	721.08	720.68	720.3
0.85	766.2	734.9	723.7	719.4	717.6	716.7	716.23	715.83	715.5
0.90	762.1	730.7	719.4	715.1	713.3	712.4	711.90	711.50	711.1
0.95	758.5	726.9	715.5	711.2	709.4	708.5	708.01	707.61	707.3
1.00	755.3	723.5	712.0	707.7	705.9	705.0	704.50	704.10	703.7

Table 2. The balance of *Pa*, *T* and *Ct*

From Tables 2, it also can be understood that how much total expectation cost should be paid by the different power, when the delivery time is strictly demanded; how much total expectation cost should be paid by different delivery time, when the power of process is strictly demanded. Because Table 2 shows the relation (concrete value) of power, the delivery date and the total expectation cost, it would become a reference for business plan.

D. The balance of k, T and Ct

In this section, we study the relations between the delivery time and ACT time and the total expectation cost, then we investigate the balance of control limits width (*k)* and delivery time *(T)* and the total expectation cost *(Ct)* by numerically analyzing the above design. Where, c_0=1，c_1=0.1，c_2=10, c_3=50, c_4=25, $c_{\beta a} = c_{\beta p} = c_{\beta d}$ =200, $c_{\beta c}$ =2400, n_1=4, v_1=0.0316, Tp=1, ϕ_1 =0.01, ϕ_2 =0.001, λ_1=1.

Table 3 show the balance of the quality (control limits width) and delivery time and the total expectation cost of the above case, which is useful for setting the optimal delivery time and control limits width to the supplier.

T	k													
	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00
2.50	284.941	285.070	286.939	290.475	295.984	304.187	316.349	334.550	362.096	403.805	465.203	548.437	645.798	740.137
2.75	283.866	283.992	285.869	289.420	294.957	303.206	315.447	333.810	361.788	404.863	470.364	563.733	679.704	798.529
3.00	283.039	283.164	285.046	288.609	294.166	302.448	314.745	333.210	361.406	405.115	472.825	572.936	703.662	844.432
3.25	282.376	282.500	284.385	287.957	293.529	301.836	314.174	332.713	361.056	405.130	474.100	578.676	720.880	880.838
3.50	281.825	281.947	283.836	287.414	292.998	301.322	313.691	332.286	360.737	405.055	474.801	582.367	733.437	909.961
3.75	281.351	281.473	283.364	286.947	292.539	300.878	313.270	331.907	360.438	404.934	475.194	584.798	742.705	933.441
4.00	280.933	281.054	282.947	286.534	292.133	300.483	312.893	331.562	360.155	404.784	475.404	586.425	749.612	952.502
4.25	280.554	280.676	282.570	286.161	291.765	300.123	312.548	331.241	359.882	404.612	475.495	587.523	754.794	968.065
4.50	280.206	280.327	282.223	285.816	291.424	299.789	312.225	330.938	359.616	404.424	475.505	588.260	758.701	980.833
4.75	279.879	280.001	281.897	285.492	291.103	299.474	311.918	330.647	359.354	404.224	475.456	588.746	761.652	991.350
5.00	279.568	279.690	281.587	285.184	290.798	299.173	311.624	330.366	359.096	404.014	475.363	589.053	763.881	1000.038
5.50	278.980	279.102	281.000	284.600	290.218	298.599	311.062	329.821	358.585	403.572	475.085	589.309	766.817	1013.199
6.00	278.420	278.542	280.441	284.042	289.664	298.050	310.520	329.292	358.078	403.111	474.728	589.271	768.430	1022.266
6.50	277.875	277.998	279.898	283.500	289.124	297.513	309.989	328.770	357.573	402.636	474.322	589.064	769.250	1028.517
7.00	277.340	277.462	279.363	282.967	288.592	296.985	309.465	328.253	357.068	402.154	473.887	588.757	769.588	1032.807
7.50	276.809	276.932	278.834	282.438	288.065	296.460	308.944	327.738	356.563	401.666	473.434	588.391	769.632	1035.723
8.00	276.281	276.405	278.307	281.913	287.541	295.938	308.425	327.224	356.058	401.175	472.970	587.989	769.497	1037.673

Table 3. The balance of *k*, *T* and *Ct*

From Table 3, it can be understood that this tables are divided into two areas by the changed control limits width: in the colorlessness area, the expected total cost per unit time *(Ct)* increases with the increase of delivery time *(T)*; in the blue area, the expected total cost per unit time *(Ct)* decreases with the increase of delivery time *(T)*.

From Table 3 and Figure 5, it can be noted that the expected total cost per unit time *(Ct)* increases with the increase of control limits width *(k)*. This is because that the cost of defective goods increases by the increase of control limits width.

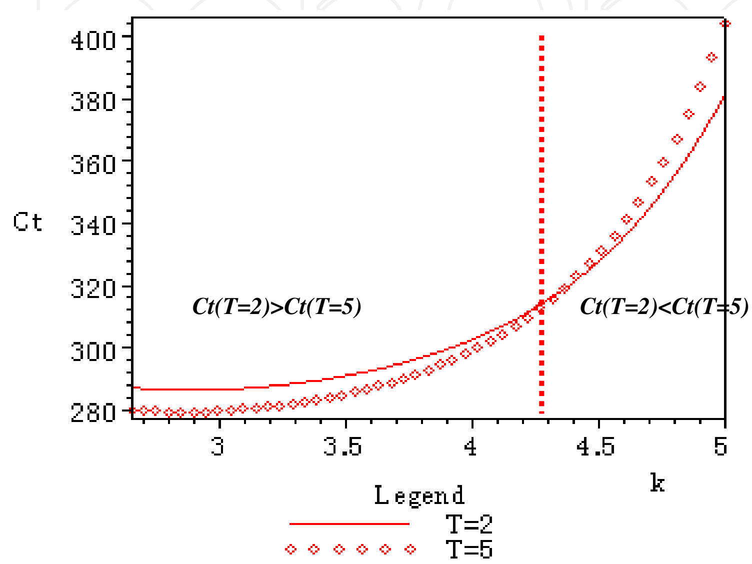

Fig. 5. The relation between *k* and *Ct* (*T*=2, *T*=5).

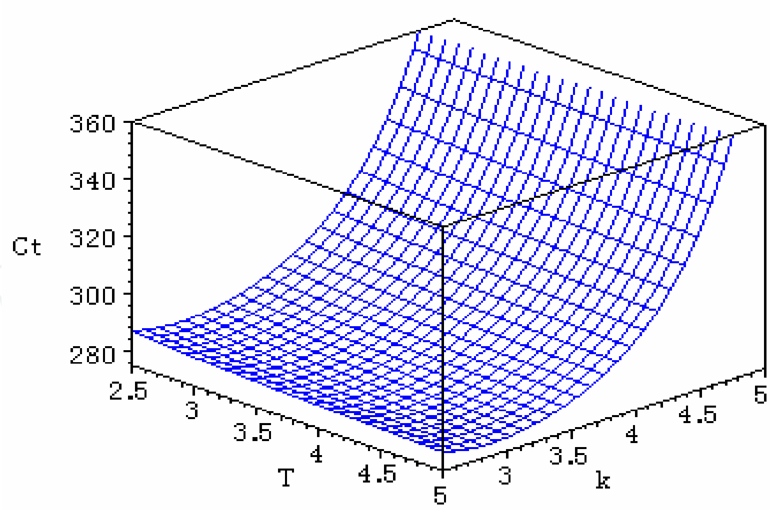

Fig. 6. The relation between *T*, *k* and *Ct*.

From Table 3, it also can be understand that a longer delivery time should be set when the high quality (when *k* is small) is demanded, while a shorter delivery time should be set when the low quality is demanded from an economic aspect.

In addition, to clarify it more, we also show the Figure 6 which is the same as the case of Table 3.

T	a													
	0.15	0.25	0.35	0.45	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
2.50	221.694	230.491	238.745	246.552	253.999	257.612	261.164	264.665	268.122	271.545	274.942	278.323	281.696	285.070
2.75	226.160	234.398	242.090	249.321	256.171	259.474	261.164	265.877	268.993	272.060	275.087	278.080	281.046	283.992
3.00	229.371	237.191	244.462	251.266	257.674	260.750	263.750	266.680	269.549	272.360	275.122	277.839	280.518	283.164
3.25	231.686	239.192	246.148	252.632	258.712	261.619	264.447	267.201	269.887	272.512	275.081	277.598	280.070	282.500
3.50	233.351	240.619	247.338	253.583	259.417	262.198	264.897	267.520	270.072	272.559	274.985	277.355	279.675	281.947
3.75	234.533	241.623	248.164	254.228	259.878	262.565	265.168	267.693	270.145	272.528	274.849	277.110	279.317	281.473
4.00	235.354	242.311	248.718	254.647	260.159	262.775	265.306	267.757	270.134	272.440	274.682	276.862	278.985	281.054
4.25	235.902	242.759	249.067	254.895	260.304	262.867	265.344	267.740	270.061	272.310	274.492	276.611	278.671	280.676
4.50	236.242	243.026	249.260	255.013	260.345	262.869	265.306	267.662	269.940	272.146	274.284	276.357	278.371	280.327
4.75	236.424	243.154	249.334	255.033	260.308	262.803	265.211	267.535	269.782	271.956	274.061	276.101	278.080	280.001
5.00	236.482	243.175	249.317	254.976	260.211	262.685	265.070	267.373	269.597	271.748	273.828	275.843	277.796	279.690
5.50	236.338	242.989	249.087	254.700	259.886	262.335	264.694	266.970	269.166	271.287	273.338	275.322	277.242	279.102
6.00	235.963	242.602	248.685	254.281	259.448	261.886	264.234	266.497	268.681	270.789	272.825	274.794	276.698	278.542
6.50	235.450	242.093	248.179	253.776	258.940	261.376	263.722	265.983	268.163	270.267	272.299	274.262	276.161	277.998
7.00	234.852	241.511	247.610	253.217	258.391	260.831	263.179	265.443	267.625	269.730	271.763	273.727	275.626	277.462
7.50	234.203	240.884	247.003	252.627	257.816	260.262	262.618	264.887	267.074	269.185	271.222	273.190	275.092	276.932
8.00	233.522	240.230	246.372	252.018	257.225	259.681	262.044	264.321	266.516	268.633	270.677	272.651	274.559	276.405

Table 4. The balance of *a*, *T* and *Ct*

E. The relation between T, a and Ct

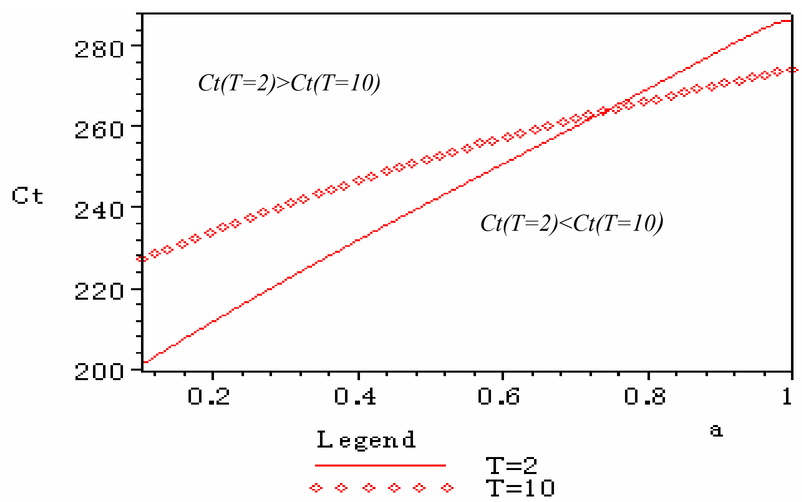

Fig. 7. The relation between *a* and *Ct* (*T*=2, *T*=10)

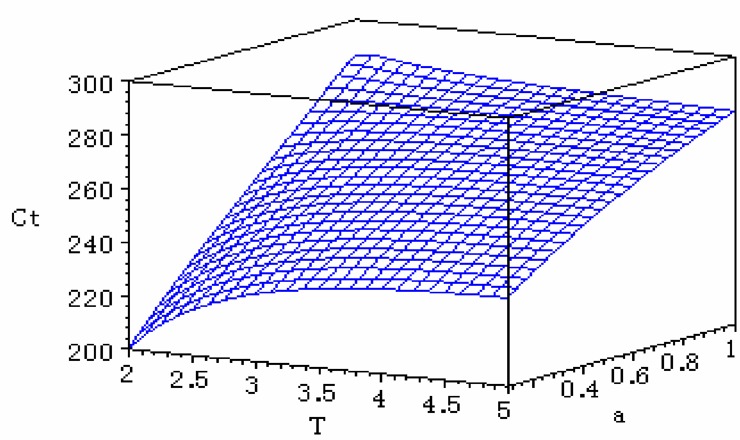

Fig. 8. The relation between *T*, *a* and *Ct*

Figure 7 show the relation between the delivery time and ACT time and the total expectation cost, which is useful for setting the optimal delivery time and ACT time to the supplier.
From Figure 7, it can be understood that this tables are divided into two areas by the changed ACT time: in the colorlessness area, the expected total cost per unit time *(Ct)* increases with the increase of delivery time *(T)*; in the blue area, the expected total cost per unit time *(Ct)* decreases with the increase of delivery time *(T)*.
From Figure 7 and Table 5, it can be noted that the expected total cost per unit time *(Ct)* increases with the increase of Act time *(a)*. This is because that the cost of defective goods increases by the increase of ACT time. Also it can be understand that a longer delivery time should be set when the ACT time is long, while a shorter delivery time should be set when the ACT time is short from an economic aspect.
In addition, to clarify it more, we also show the Figure 8 which is the same as the case of Figure 7.

4. Conclusions

In this research, from an economic viewpoint, a design of the $\bar{x}$ control chart is analyzed for quality management information system used in short delivery time processes.
Because of competition in markets, studying the balance of quality and the delivery time and cost has become a new problem to manager. To resolve this problem, the mathematical formulations which correspond to this design were shown, and then by numerically consideration using the data from real situation, the relations of the power of process and delivery time and the total expectation cost, the balance of quality (control limits width) and delivery time and the total expectation cost, the relations between the delivery time, ACT time and the total expectation cost are discussed, respectively. Moreover, the presented design based on the judgment rules of JIS Z 9021 was studied.
Some comments are drawn as follows, which would become useful references for setting the optimal delivery time, ACT time and the power of process to manager.

1. The expected total cost per unit time decreases with the increase of the power of process.
2. The power by the two rules (3σ rule and 9 ARL rule) increases with the increase of sample size *n*, and the speed of increase of 9 ARL rule is faster.
3. A longer delivery time should be set when the higher power for higher quality is demanded from an economic aspect.
4. A longer delivery time should be set when the ACT time is long, from an economic aspect.

5. References

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