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Continuous quality inspection in hard disc drive manufacturing: A case study

Yupa Lorkanchanakul*1) and Peerapong Triyacharoen2)

1)Major Field of Industrial Production Technology, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand
2)Department of Materials Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand

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Abstract

This paper presents a continuous sampling plan, CSP-100, that was developed from continuous sampling plans, CSP-1, CSP-4 and CSP-C. The objective of this paper is to use the current continuous sampling plans to develop a new CSP-100 plan proving a reduction in the delivery inspection time compared to a single lot sampling plan (SSP) while maintaining the same or greater quality conformance. This CSP-100 was studied in hard disc drive manufacturing. The parameters used in the CSP-100 plan are as follows; 1) the number of consecutive conforming units, 2) the sampling frequency of a partial number in 100% of inspected units, and, 3) the acceptance number. CSP-100 computes four performance measures, average fraction inspected (AFI), average outgoing quality (AOQ), lot acceptance rate (LAR) and defective parts per million (DPPM). The advantage of this CSP-100 plan is that it not only reduces the inspection time, but also provides higher productivity compared with SSP. The verified results of using a CSP-100 plan included a reduced inspection time of 6,722,702 minutes or 15% compared to SSP. CSP-100 also eliminates work stations, transport to inspection areas and inspectors. A function out of box audit (FOBA) was introduced to monitor CSP-100 performance. FOBA audit results confirmed that CSP-100 maintains the same quality level as SSP. The results of implementing CSP-100 showed a reduction in the inspection costs of 3,693,730.04 baht or 60.40% compared to SSP, as well as the additional cost savings since purchase of a new tester was not required. This resulted in a savings of ~44 million baht. The CSP-100 plan also eliminated the issue of delayed delivery that is part of the SSP process. Moreover, it is a better choice for continuous quality inspection in hard disc drive manufacturing.

Keywords: Single sampling plan, Continuous sampling plan, Average outgoing quality, Average fraction inspected, Acceptance number c

1. Introduction

The Final Quality Audit (FQA) is the delivery inspection process of Hard Disc Drive products. The FQA process uses the single lot sampling plan (SSP) which is designed to achieve outgoing product quality. SSP is used to inspect lots or units submitted for evaluation against certain hypotheses. In a standard sampling plan a hypotheses of the sample makes up the criteria by which the process is judged. The criteria is used to accept or reject a lot or unit on the basis of the specified hypothesis.

The acceptance sampling criteria of SSP by attributes design by proportion defective p = 0.005, AQL 0.02%, LTPD = 0.40% and AOQL = 500 DPPM. If a process has been tested adequately, then the lot or unit is accepted. If the quality control is not sufficient, sampling will prevent unacceptable products from shipping to the customer. The acceptance or rejection a lot is synonymous with accepting or rejecting the null hypothesis in the hypothesis test. The grouping into lots is not always advantageous [1]. In addition, SSP requires a dedicated area to keep the product stored while waiting for the inspection result.

The three types of Hard Disc Drive products are Data Center (DC), Desktop (DT) and Mobile (MB). All product lines undergo the same SSP process for FQA except for a difference in test time. The FQA test time criteria is: DC > DT > MB because of DC drives have higher capacity than DT and MB drives. The higher production volume of DC drives requires more FQA testers to perform SSP. The limitation of FQA test capacity will cause delivery delays. This is due to entire lots being held until their respective SSP test is completed. Figure 1 presents FQA test time, production volume and FQA test capacity for DC, DT and MB.

In summary the SSP is not applicable for high production volume of high capacity Hard Disc Drive products because this product requires a protracted inspection time. This leads to a tester shortages as well as delays in product delivery based upon the existing inspection capacity. However, purchasing a new tester is too expensive. The one possible way is to change the inspection process from SSP to the new CSP-100 process. The concept of continuous sampling plans where the product flow is continuous and the formation of inspection lots is impractical. The continuous sampling plan designs with single sampling plan by attributes as the

*Corresponding author. Tel.: +6689 767 3522
Email address: yupal2@yahoo.co.th
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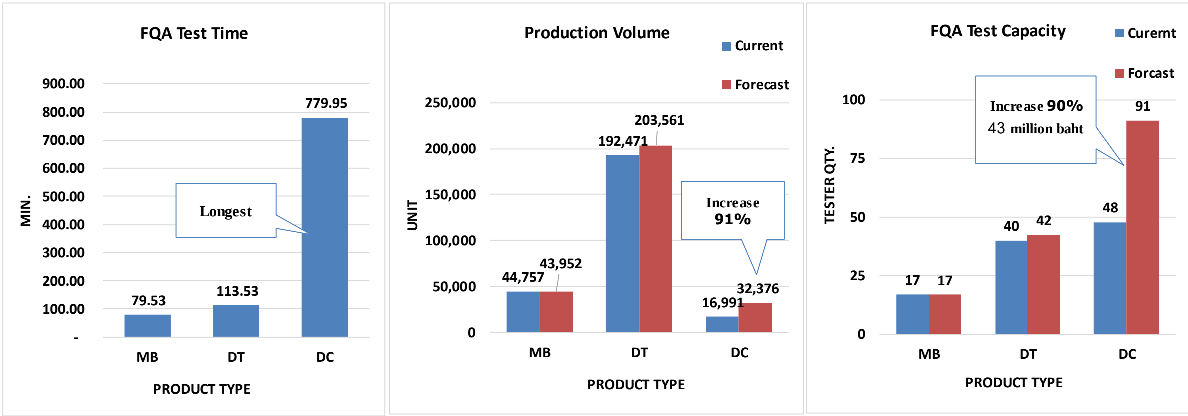

Figure 1 FQA test time, production volume and FQA test capacity for DC, DT and MB.

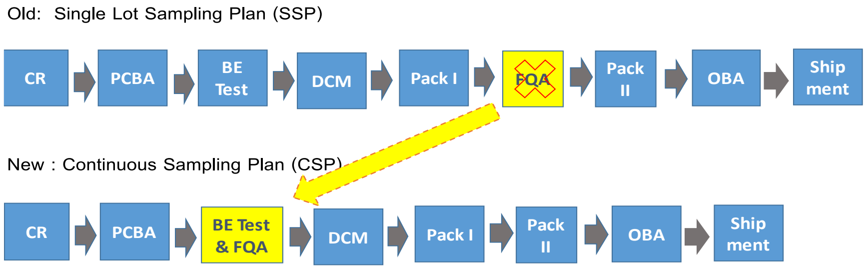

Figure 2 Process of SSP and CSP-100

reference plan which incorporates the best features can be desired for application [2].

The new process proposed in the CSP-100 plan is to combine the quality inspection along with the production test process. This uses the concept of the continuous sampling. The CSP-100 plan utilizes the Final Quality Audit (FQA) in the backend test process (BE Test). This makes better use of the testers by performing the quality inspection to continue test in same production testers. The added benefit is that the products do not require unloading from the tester for the FQA test. A Process flow diagram of both the previous single lot sampling plan (SSP) and the new continuous sampling plan (CSP-100) are shown in Figure 2.

The objective of this paper is to reduce the process and inspection time in Hard Disc Drive production line by using Continuous Quality Inspection.

2. Continuous sampling plans

The reference plans used to design for CSP-100 are mentioned as follows

2.1. CSP-1

CSP-1 plan was introduced by Dodge in 1943 as the original CSP plan. CSP-1 consists of alternate sequences consisting of 100% inspection and random inspection used in continuous production systems. CSP-1 starts with 100% inspection of i units. When i consecutive conforming units are confirmed, then 100% inspection will discontinue and sampling of a fraction f units will proceed. When a defective unit is found in the sampling f units, it will be stopped and will revert back to 100% inspection of i units. CSP-1 is selected to apply for CSP-100 plan as the Average Outgoing Quality Limit (AOQL) affects parameters i and f units [3].

In 2004 Haji, A. and Haji, R. have also investigated the optimal policy for a sampling plan for use in continuous production manufacturing environments in terms of the clearance number to derive the minimum cost policy for the sampling plan. The result shows the optimal clearance number is independent from the fraction of the units that are being inspected during random inspection periods [4]. CSP-100 will consider i and f units from SSP plan as a reference to minimize the inspection cost.

2.2 CSP-4

CSP-4 has been developed from CSP-1 by Derman, Jones and Lieberman in 1959. When they found the first defective unit in fraction inspection k units, the product k – 1 units in the same lot are segregated out from production line [1, 3]. CSP-100 used the concept of CSP-4 in segregating k units from remaining r units when the number of non-conforming units is greater than c number. This makes a prompt decision and act on the non-conforming lot.

2.3 CSP-C

CSP-C plan was introduced by Govindaraju and Kandasamy in 2000. CSP-C plan defined the acceptance number c units for non-conforming units found in the fraction inspection f units. The main point is to meet quality requirements while utilizing a reduction in the average fraction inspected [5-6]. When a total number of (c + 1) units of non-conforming sample have been found in the fraction inspection, the sampling inspection will be discontinued and revert back to 100% inspection. CSP-C plan uses performance measurements such as AOQ and AFI. A comparison of this CSP-C plan with the CSP-1 plan reveals that the CSP-C sampling plan with c > 0 has a smaller average fraction inspection (AFI) than the AFI of a matching CSP-1 plan having the same AOQL and f [6].

In 2004 Balamurali, S., Subramani K. have also studied the modified CSP-C continuous sampling plan for consumer protection. This single level continuous sampling plan in the sampling inspection phase is characterized by a maximum allowable number of non-conforming unit c, and a constant sampling rate f. Using a Markov chain model, expressions for the performance measures of the modified CSP-C plan are derived. The main advantage of this modified plan is that it is possible to lower the average outgoing quality limit (AOQL) [7].

In 2012 Muthulakshmi have also studied Stopping Rules to Limit Inspection Effort in CSP-C Continuous Sampling Plan. This paper presents the stopping rules to limit the inspection effort during one screening sequence and the derivation or performance measures like OC, AOQ and AFI functions based on simplified Markov Chain approach for CSP-C continuous sampling plan [8]. The simplified Markov Chain approach is used to derive various measures of performance such as the Average Outgoing Quality (AOQ), the Average Fraction Inspected (AFI), and the probability of acceptance (P_a) for the CSP-100 Plan.

2.4 Other continuous sampling plans using to design CSP-100

In 2014 Subbarayan, A. has considered a tightened continuous sampling plan exhibiting a markovian character using a probability sampling method. This studied desires the expected number of units passed in r units as lot sizes N and uses single sampling plan (SSP) to attribute in each lot to decide c acceptance number. This will decide whether to accept or reject the r lot with size N [9]. CSP-100 applies this concept with a new proposed plan for when the number of non-conforming units exceeds the c number. Then, it will discontinue inspecting the remaining k units in r units and move them to rescreen and re-inspect with all of the units that have already passed the process with SSP.

2.5 The performance measures

The performance measures that we define in CSP-100 are generalizations of the performance measures AFI (Average Fraction Inspected) and AOQ (Average Outgoing Quality) used in the conventional CSPs [2]. The CSP-100 also uses Lot Acceptance Rate (LAR) and Defective Parts Per Million (DPPM) to measure its performance. CSP-100 defines 3 parameters i (the number of consecutive non-conforming units during a 100% inspection), f (the specified units of inspection used for small number less than i units in order to promptly determine a non-conforming lot) and c (the acceptance number of non-conforming units). The given values of the parameters (i, f, c) and incoming fraction of defective units on the line (p) are used to compute the CSP-100 performance. The validity of the performance measure formulas have been tested by extensive simulations [10].

The simplified Markov Chain is used to derive the performance measures of CSP-100. The phases of CSP- 100 plan are SC and PA where SC = 100% inspection on Screening phase and PA = 100% inspection on Partial phase. The direction of flow from screening phase proceeds only to partial phase with a probability of one, and flow from partial phase proceeds only to screening phase with a probability of one. This is the transitional probability matrix is.

To

From		SC	PA
	SC	0	1
	PA	1	0

The state probabilities are P”SC = P”PA and P’’PA = P”SC. Solving for the state probabilities in term of any one phase (P”PA), we obtain P”SC = P”PA and P”PA = P”PA. The expected lengths of time in terms of the number of units for screening and partial phases are $(1-q^i)/pq^i$ and (c+1)/fp respectively [8]. The formulation can be completed by forming in Table 1. This form will use in computing the CSP-100 performance.

The design of Function Out of Box Audit (FOBA) is designed for monitoring the CSP-100 performance. FOBA uses the SSP for the inspection process. This is temporary process to measure the consistency of CSP-100 performance in production line compared to a SSP.

Table 1 Working table

Phase	Coefficient	Expected Length	Simplification	AFI	
				Density	Numeric
SC	1	$(1-q^i)/pq^i$	$f(1-q^i)$	$f(1-q^i)$	$f(1-q^i)$
PA	1	(c+1)/fp	(c+1)/fp	$(c+1)/q^i$	$f(c+1)/q^i$

3. Research methodology

3.1. Product samples

The samples of Hard Disc Drive product are selected from the quality conforming product with high production volume. This paper uses a simulation based on the experiment result of CSP-100. The experiment will be performed with samples utilizing 200 lots providing the real data, which will be analyzed to compare the SSP and CSP-100 performances matrices.

3.2. CSP-100 process flow

The CSP-100 inspection is designed to detect only one quality characteristic, so that focus will be centered on one kind of defect. The CSP-100 uses 3 parameters for inspection of the units being produced on the production line, namely 3 positive integers i, c, and a fraction f, defines as follows:

i The number of consecutive conforming units that must be produced during a 100% inspection of units produced on the line in SC phase.

f The sampling frequency for a fractional inspection of units produced on the line (f = 1/r) which n is number of inspected units in partial inspect period and r is the partial number to inspection in PA phase.

c The number of non-conforming units to accept r lot in partial inspection.

The units sampled during a fractional f inspection of the manufacturing line must be an unbiased sample of units produced on the line. In all inspection schemes any defective unit that is detected will be replaced immediately by a conforming unit [10].

The inspection procedure for the CSP-100 is as follows:

Step 1. SC phase starts with 100% inspection of the units consecutively in the manufacturing line and continue 100% inspection until i conforming units in succession are completed. When i units in succession are found clear of defects, discontinue 100% inspection in SC phase.

Step 2. After discontinuing 100% inspection in SC phase, 100% inspection in partial or PA phase for r units will continue until n units are inspected. The selection of the inspection scheme for the next step depends on the results of the preceding step. The selection rules are as follows:

2.1 If the n number of units inspected consecutively in a 100% inspection of the units is equal to r and defective units were detected $d \leq c$, the next r units will continue inspection by the process defined in step 2.

2.2 If the n number of units inspected consecutively in a 100% inspection of the units is equal to r and defective units were detected $d > c$, the next r units will discontinue inspection. The SC phase will start inspection by the process defined in step 1.

2.3 If the n number of units inspected consecutively in a 100% inspection of the units is less than r and defective units were detected $d \leq c$, the next r units will continue inspection by the process defined in step 2.

2.4 If the number of units inspected consecutively in a 100% inspection of the units is less than r and defective units were detected $d > c$, the next r units will discontinue inspection. The SC phase will start inspection by the process defined in step 1. The k units ($k = r - n$) will skip in the inspection.

Step 3. When the number of non-conforming sampled units reaches (c+1) units, 100% inspection of those remaining k units in r units will stop and a segregation of the units in the same lot will take place to set them aside to rescreen them before running the single lot sampling plan.

Step 4. Replace all non-conforming units with conforming units.

Step 5. If a sample unit is found defective $d > c$, revert immediately to a 100% inspection of succeeding units i and return to step 1.

In summary, a 100% inspection on the line must continue until the specified number i of consecutive conforming units are found to complete the screening phase. The 100% inspection on the line will be continued by an f inspection as partial phase. In partial phase, if a defective unit d is found more than c number then the plan reverts to a 100% inspection to start the screening phase again. This as in the procedure for inspection of the CSP-C plan. The different procedure for inspection of CSP-100 from CSP-C is that if a 100% inspection finds non-conforming units $d > c$ in n units inspected then the process skips inspection for the k units. The k units (the skipped units to inspect as remaining in r lot when found $d > c$) will be segregated out to rescreen under the SSP process. This is required quickly action to control the quality of product.

The process flow of the continuous quality inspection in Hard Disc Drive production line or CSP-100 is designed as shown in Figure 3.

3.3 CSP-100 parameters

CSP-100 table displays the parameter of i (the number of consecutive conforming units which pass 100% inspection), f (sampling frequency for the partial of 100% inspected units) and c (the acceptance number) with $p = 0.005$. These parameters are used in calculating the AOQ and AFI. All parameters of CSP-100 are shown in Table 2.

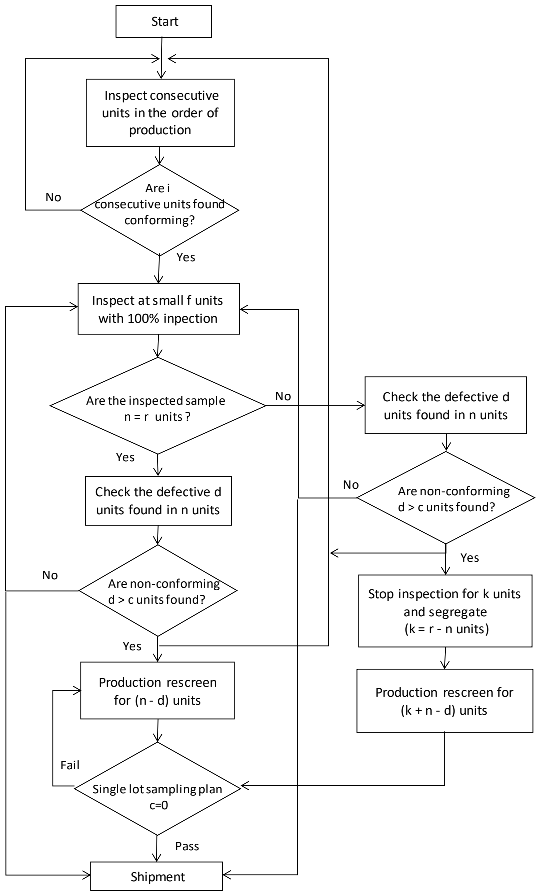

Figure 3 CSP-100 Process Flow

Table 2 CSP-100 table to control parameters i, r, f, c number at $p = 0.005$

i	r	f	c	Pa	AFI	AOQ
3000	300	0.0033	1	0.0002	1.000	0.88
3000	600	0.0017	2	0.0005	0.999	2.65
3000	900	0.0011	3	0.0011	0.999	5.29
3000	1200	0.0008	4	0.0018	0.998	8.82
3000	1500	0.0007	5	0.0026	0.997	13.21
3000	1800	0.0006	6	0.0037	0.996	18.48
3000	2100	0.0005	6	0.0043	0.996	21.55
3000	2400	0.0004	6	0.0049	0.995	24.61
3000	2700	0.0004	6	0.0055	0.994	27.68
3000	3000	0.0003	6	0.0061	0.994	30.73

3.4 CSP-100 experiment

The process flow of the continuous quality inspection in Hard Disc Drive production line or CSP-100 is designed as shown in Figure 3. The experiment starts from the Hard Disc Drive product in production line. While the 1st group was inspected by single lot sampling plan (SSP) with lot size N = 3,200 units, sample size n = 600 units, $p = 0.005$, AOQL = 500 DPPM with acceptance number c = 0. The 2nd group was inspected by CSP-100 with 100% inspection i = 3,000 units. After i conforming units the process will start 100% inspection with r units which can be 300, 600, 900, 1,200, 1,500, 1,800, 2,100, 2,400, 2,700 or 3,000. The number of n units to be inspected is determined based on where in population the defective unit was found. CSP-100 uses proportion defective p = 0.005 and acceptance number c which can be 1, 2, 3, 4, 5 or 6. The c units depend on where the defective unit is found in r units. These specified numbers are shown in Table 2. When the number of non-conforming sampled units d reach (c+1) units, 100% inspection for those remaining k units in r units will stop and a segregation of the units in same lot will take place to set them aside to rescreen them before running SSP with the same sampling of the 1st group.

CSP-100 performance was monitored with 10% of CSP-100 units undergoing Function Out of Box Audit (FOBA) with lot size N = 25,000 units and sample size n = 2,315 units. The n number is varied with actual N number. FOBA uses p = 0.005, AQL% = 0.02%, LTPD 0.40%, AOQL = 500 DPPM with acceptance number c = 2 that refers to SSP. FOBA is a temporary process in monitoring the CSP-100 performance to assure that the 100% inspection by CSP-100 will result in good performance.

3.5 CSP-100 performance

CSP-100 performance is measured with LAR, DPPM, AOQ and AFI using the following formulas in calculating the results.

Lot Acceptance Rate, LAR:

$$\text{LAR} = \frac{\text{Passed Inspection Lot}}{\text{Total Inspection Lot}} \times 100 \quad (1)$$

Defective Parts per Million, DPPM:

$$\text{DPPM} = \frac{\text{Defective unit}}{\text{Total Inspection Unit}} \times 1{,}000{,}000 \quad (2)$$

Average Outgoing Quality, AOQ:

$$\text{AOQ} = \frac{pq^i(c+1)(1-f)}{f+(c+1-f)q^i} \quad (3)$$

Average Fraction Inspected, AFI:

$$\text{AFI} = \frac{f(1+cq^i)}{f+(c+1-f)q^i} \quad (4)$$

Average Probability of acceptance, P_a:

$$\text{Pa} = \frac{(c+1)q^i}{f+q^i(c+1-f)} \quad (5)$$

Average number of units inspected in a 100% screening phase, u:

$$\mathcal{U} = \frac{1-q^i}{pq^i} \quad (6)$$

The average number of units passed under the partial inspection before (c + 1) non-conforming units are found, v:

$$\mathcal{V} = \frac{(c+1)}{fp} \quad (7)$$

Where p is the probability that a unit is non-confirming and q = 1- p.

The measurement values of all quality performance matrices for SSP and CSP-100 are used to calculate histogram and outlier box plots using the statistical tool in the JMP10 software program to analyze data and compare their performances.

3.6 Tests of the validity of performance measures for CSP-100

In order to test the validity of the performance measures for CSP-100, the results are calculated from formulas with the values from the performance measures and the results from simulations being compared. The 10 different levels for the incoming fractions p of defective units produced on the line 0.001, 0.002, 0.003, 0.004, 0.005, 0.006, 0.007, 0.008, 0.009, 0.01. For each p value we selected values of i = 3,000, values of r = 300, 600, 900, 1,200, 1,500, 1,800, 2,100, 2,400, 2,700, 3,000 and values of c = 0, 1, 2, 3, 4, 5, 6. The simulation number is 500 cases each.

The each set of values i, f and c are input into a simulation to compute and the values of AOQ and AFI. These values are then compared with the values of AOQ and AFI computed from the formulas given in equations (3) and equation (4) respectively.

The criteria to accept a formula as a valid formula is the percentage difference between the AFI value from the formula and the AFI value from the simulations are less than or equal to 2.

4. Research results

4.1 Experiment result of SSP

The quality performances matrices of Hard Disc Drive product in the experiment from SSP are LAR 93.33%, DPPM 111.12 DPPM, AOQ 171.84 DPPM and AFI 0.966. This is used to compare with CSP-100 performance in an experiment.

4.2 Experiment result of CSP-100 plan

The performance of continuous quality inspection in Hard Disc Drive production line or CSP-100 in the experiment was measured with LAR, DPPM, AOQ and AFI. All values used histogram and outlier box plot in program JMP10 and the results are shown in Figure 4; LAR 95.50%, DPPM 410.08 DPPM, AOQ 23.65 DPPM and AFI 0.995. LAR was higher than single lot sampling plan with additional defective units found from the 100% inspection, which was shown to screen more non-conforming units than SSP. AOQ was very low. This indicates a high quality assurance level with 100% inspection. This is highly advantageous in critical products which requires high quality performance.

The CSP-100 performance was measured and the data is shown in Table 2. The f number did not impact with AOQ and AFI from 100% inspection. The c number was higher when fixing f number. This also caused higher AOQ and lower AFI. The 100% inspection provided a good AOQ with a high AFI number. When the c number is higher. This indicated a higher AOQ with more defective units. The higher AOQ was still within acceptable limits. However, it is depended on the AOQL requirement. The n number was lower when inspection within f units stopped. This made AOQ increase and lower the AFI. The defective units found

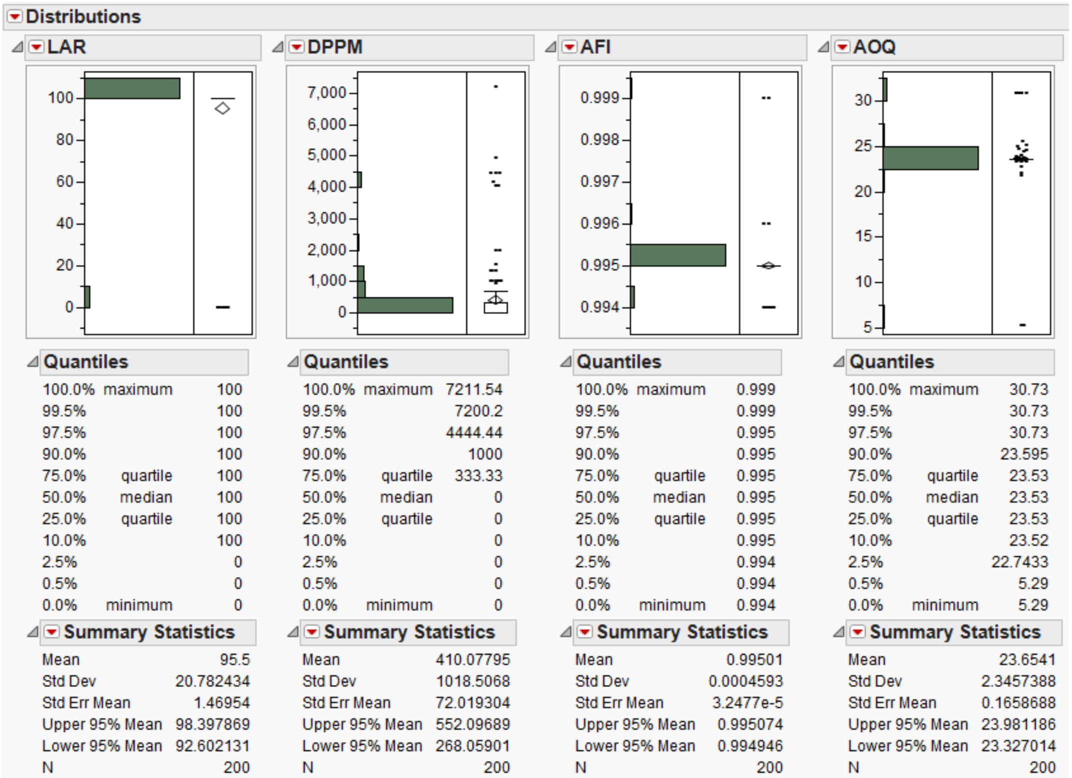

Figure 4 LAR, DPPM, AOQ and AFI result from using CSP-100 sampling plan in 200 lots

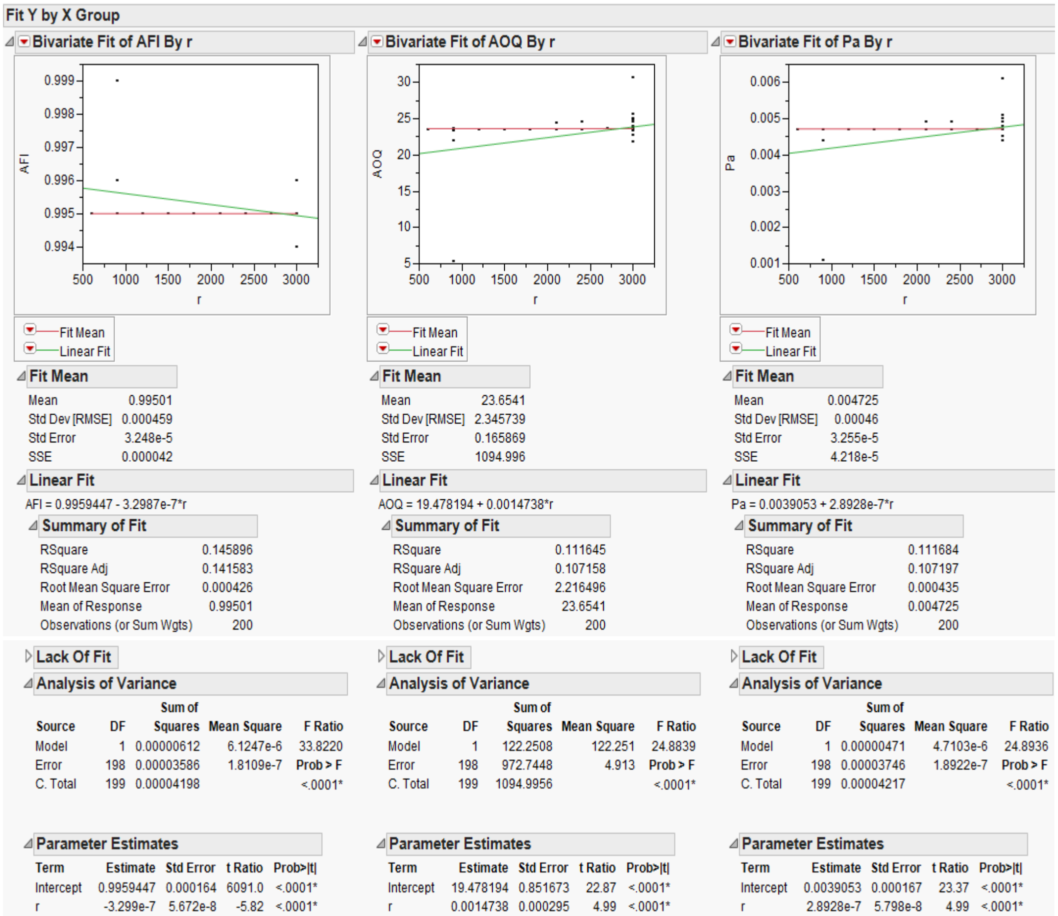

Figure 5 The experiment results of CSP-100 Plan in DPPM, LAR, AOQ and AFI of 200 lots

within c number would not impact AOQ and AFI. The number of non0conforming units directly impacted the LAR value, indicating a lower LAR but higher DPPM.

Experimentation confirmed that the CSP-100 plan is ideal for maintaining quality performance of products due to 100% inspection which given the consistency of AOQ and AFI. The CSP-100 plan will also allow streamlining the production process by eliminating the requirement for transportation, inspectors and an inspection area.

The experiment of CSP-100 was performed on 200 lots of samples and measure the performance is shown in Figure 5. In order to tests for the validity of CSP-100, this paper uses the AFI, AOQ values from the formulas and the AFI, AOQ values from the simulations. The values are then compare. The validity test results are addressed in item 4.5.

4.3 Monitoring result of the CSP-100 performance

LAR, DPPM, AOQ and AFI were used to monitor the CSP-100 performance by performing Function Out of Box Audit (FOBA). The results are 100% LAR with slightly increasing DPPM at a value of 175.22 DPPM, due to inspecting more samples than the normal single lot sampling plan. The AOQ value of 1,973.46 DPPM had increased from the single lot sampling plan. The AFI value of 0.60 decreased from the single lot sampling plan. When it compared with LTPD level at 0.40%, it showed good results.

4.4 The sensitivity of CSP-100 parameters

The particular CSP-100 parameters that affect to the performance measures are the values of c, p and r. The values of P_a, AOQ and AFI of each cases are shown in Table 3 - 5.

4.5 The validity of performance measures for CSP-100

The percentage differences of the AFI, AOQ values from the formulas and the AFI, AOQ values from the simulations are shown in Figure 6 for AOQ and Figure 7 for AFI. The simulations indicated that AOQ formula is valid for p = 0.001 and p>0.005 AOQ values is very good. AFI formula is valid at $p \geq 0.005$. The CSP-100 will use p = 0.005 in implementation.

4.6 Comparison of the results of all sampling plans

The comparison among quality performance results of all sampling plans with the matrices are shown in Table 6. SSP BM and SSP in experiment indicated equal results and performance of product samples. CSP-100 LAR value of 95.50%, increased by 2.32% from SSP LAR value of 93.33%. CSP-100 DPPM value of 410.08 DPPM, increased 298.97 DPPM from SSP DPPM value of 111.11 DPPM. CSP-100 plan was able to screen more defective units by 100% inspection. The CSP-100 AOQ at a defective proportion *p* 0.005 was 23.65 DPPM which was reduced by 148.19 DPPM from SSP AOQ 171.84 DPPM value. The CSP-100 AFI value was 0.99 which was higher than the SSP AFI value of 0.97. The monitoring CSP-100 by FOBA also showed good results at LAR 100% and the 175.22 DPPM value was lower when compared with the AOQL value of 500 DPPM. All results indicated good performance of the CSP-100 plan.

Table 3 A higher c number will give a higher P_a, and AOQ along with a lower AFI

i	r	f	c	P	Pa	AFI	AOQ
3000	300	0.0033	1	0.005	0.0002	0.9998	0.88
3000	300	0.0033	2	0.005	0.0003	0.9997	1.32
3000	300	0.0033	3	0.005	0.0004	0.9996	1.76
3000	300	0.0033	4	0.005	0.0004	0.9996	2.20
3000	300	0.0033	5	0.005	0.0005	0.9995	2.64
3000	300	0.0033	6	0.005	0.0006	0.9994	3.08
3000	300	0.0033	7	0.005	0.0007	0.9993	3.52
3000	300	0.0033	8	0.005	0.0008	0.9992	3.96
3000	300	0.0033	9	0.005	0.0009	0.9991	4.40
3000	300	0.0033	10	0.005	0.0010	0.9990	4.84

Table 4 A higher r number will give a higher P_a and AOQ along with a lower AFI

i	r	f	c	P	Pa	AFI	AOQ
3000	300	0.0033	1	0.005	0.0002	0.9998	0.88
3000	600	0.0017	1	0.005	0.0005	0.9995	2.65
3000	900	0.0011	1	0.005	0.0011	0.9989	5.29
3000	1200	0.0008	1	0.005	0.0018	0.9982	8.82
3000	1500	0.0007	1	0.005	0.0026	0.9974	13.21
3000	1800	0.0006	1	0.005	0.0037	0.9963	18.48
3000	2100	0.0005	1	0.005	0.0049	0.9951	24.61
3000	2400	0.0004	1	0.005	0.0063	0.9937	31.60
3000	2700	0.0004	1	0.005	0.0079	0.9921	39.44
3000	3000	0.0003	1	0.005	0.0096	0.9904	48.13

Table 5 A higher p number will give a lower P_a and AOQ along with a higher AFI

i	r	f	c	P	Pa	AFI	AOQ
3000	300	0.0033	1	0.001	0.9691	0.0341	965.89
3000	300	0.0033	1	0.002	0.5971	0.4049	1,190.22
3000	300	0.0033	1	0.003	0.0681	0.9321	203.58
3000	300	0.0033	1	0.004	0.0036	0.9964	14.30
3000	300	0.0033	1	0.005	0.0002	0.9998	0.88
3000	300	0.0033	1	0.006	0.0000	1.0000	0.05
3000	300	0.0033	1	0.007	0.0000	1.0000	0.00
3000	300	0.0033	1	0.008	0.0000	1.0000	0.00
3000	300	0.0033	1	0.009	0.0000	1.0000	0.00
3000	300	0.0033	1	0.010	0.0000	1.0000	0.00

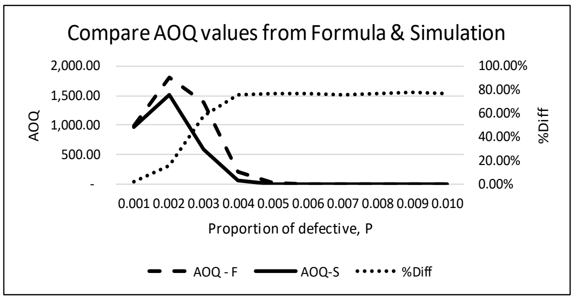

Figure 6 Graph show value of AOQ of CSP-100

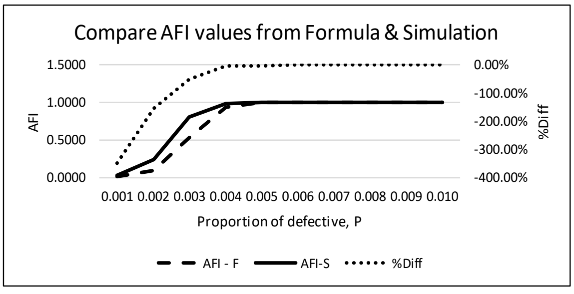

Figure 7 Graph show value of AFI of CSP-100

4.7 The cost saving of CSP-100

The achievements of CSP-100 were measured with process time, area, number of operator and cost of inspection. The process time of SSP and CSP-100 are shown in Figure 8. CSP-100 process time was decreased by 362 minutes or 15% from the SSP process time of 2,381 minutes to 2,019 minutes. Using CSP-100 with a large sample size of 18,571 units (as used in this experiment) would save 6,722,702 minutes of inspection time compared to SSP. This CSP-100 plan also eliminated all transportation time from compared to SSP.

The other achievements of CSP-100 are shown in Table 7. Inspection space was reduced 100%; from 92.82 m^2 to 0 m^2. The number of operators were reduced 100%; from 7 operators to 0 person, a labor cost savings of 8,050 baht per day. The inspection cost of CSP-100 plan at 2,421,710.56 baht was reduced 60.40% or 3,693,730.04 baht less than the inspection cost for the SSP plan at 6,115,440.60 baht.

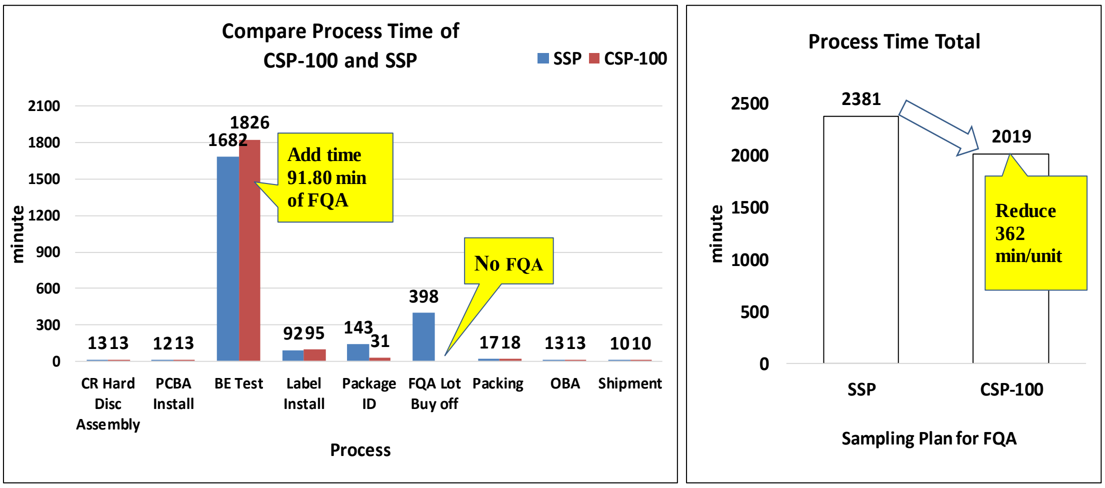

Figure 8 Graph show the process time of SSP and CSP-100

Table 6 The matrices for comparison of sampling plans

Matrices	SSP (BM)	SSP (Experiment)	CSP-100	FOBA	CSP-100 VS SSP
LAR (%)	93.33	93.33	95.50	100.00	⇧ 2.32%
DPPM	111.11	111.11	410.08	175.22	⇧ 269.07%
AOQ (DPPM)	123.86	171.84	23.65	1973.47	⇩ 86.23%
AFI	0.97	0.96	0.99	0.60	⇧ 3.13%

Table 7 The comparison between inspection cost of SSP and CSP-100

Measurement result	SSP (BM)	SSP (Experiment)	CSP-100	FOBA	Summary of CSP-100
Inspection Time (min)	397.78	397.78	91.8	397.78	⇩ 77%
Space (m2)	92.82	92.82	0	46.41	⇩ 100%
Operator (person)	7	7	0	2	⇩ 100%
Manpower cost (baht/day)	8,050	8,050	0	2,300	⇩ 100%
Product (unit)	92,857	92,857	92,857	92,857	Use same number to compare data
FQA Sample (Unit)	18,571	18,571	92,857	9,286	samples base on sampling plan of SSP, CSP-100
FQA Tester (Tester)	44	44	use same production slot	5	⇩ 100%
Tester cost (baht)	44,000,000.00	44,000,000.00	0	5,000,000.00	⇩ 100%
Inspection cost (baht/slot)	328.86	328.86	26.08	328.86	⇩ 92.07%
Total inspection and labor cost (baht)	6,115,440.60	6,115,440.60	2,421,710.56	3,055,995.30	⇩ 60.40%

The inspection cost is calculated from the results of product samples used in the CSP-100 experiment from how many units will be gained from CSP-100 implementation without SSP. And tester cost per slot for SSP and CSP-100 were also compared. Another achievement of CSP-100 is that additional investment for new testers used for quality inspection are no longer required. CSP-100 utilizes testing in the same production slots adding an additional 91.80 minutes of test time. The total cost saving for not purchasing the new testers is 44 million baht (44 testers ~ 1 million baht each).

5. Discussion

CSP-100 has better performance when compared to CSP-C. It showed that AOQ value of 23.65 DPPM value was lower than CSP-C value at 700 DPPM. The AFI value of 0.99 was higher than CSP-C value at 0.97. These were gained from 100% inspection. The CSP-100 performance was also better than SSP with reduced process time and saved inspection costs. The CSP-100 performance will depend on the quality performance of the product so to prevent the quality issues in implementation CSP-100 with other new products experiments will need to be conducted before implementation.

The performance monitoring result of CSP-100 is confirmed by FOBA test and indicated a better result compared with SSP. This FOBA result was considered to be the next process that will be done for the skip lot of continuous sampling plan CSP-100 based on the consistency in the good performance of product.

6. Conclusion

This CSP-100 or continuous quality inspection in Hard Disc Drive production line achieved the new approach and met the objective of this paper. It was able to solve the issue with delayed delivery inspection with the single lot sampling plan to eliminate the transportation process.

The quality performance results of CSP-100 compared to SSP were very good. The LAR value of 95.50% increased 2.32% from SSP LAR value of 93.33%. The CSP-100 DPPM value of 410.08 DPPM increased 298.97 DPPM from SSP DPPM value of 111.11 DPPM indicating that CSP-100 plan was able to screen more defective units by 100% inspection. The CSP-100 AOQ at defective proportion p 0.005 was 23.65 DPPM, which was reduced 148.19 DPPM compared to SSP AOQ value of 171.84 DPPM. The CSP-100 AFI value was 0.99 which was higher than SSP AFI value of 0.97. Both AOQ and AFI values indicated the good performance of the CSP-100. The CSP-100 plan eliminated transportation time, which was a 100% cost reduction due to continued test in the production line. The delivery inspection process time was reduced by 362 minutes or 15% from the SSP process time of 2,381 minutes to 2,019 minutes. A sample lot size of 18,571 units using CSP-100 would save 6,722,702 minutes compared to using SSP. Moreover, from the study it was found that space was reduced by 100%; from 92.82 m^2 to 0 m^2, need for operators was reduced 100%; from 7 operators to 0, and inspection cost was reduced 60.40% or 3,693,730.04 baht. Furthermore, CSP-100 could save cost ~44 million baht by not purchasing new testers for quality inspection with SSP as CSP-100 utilizes the same production slots as manufacturing eliminating the need for new testers. This CSP-100 registered more cost saving for quality inspection with good performance. The CSP-100 plan can be a choice for continuous process of quality inspection of Hard Disc Drive manufacturer.

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