CSCanada
Management Science and Engineering
Vol. 6, No. 1, 2012, pp. 1-10
DOI:10.3968/j.mse.1913035X20120601.1901

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Cost-Benefit Analysis for the MIL-STD-1916: A Case Study

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Received 5 December 2011; accepted 4 March 2012.

Abstract
The purpose of this study is to numerically investigate the MIL-STD-1916 sampling plans, via the relationships between sampling verification levels and gross profits. The producer's viewpoint, expected sampling inspection costs, costs due to customer rejection and the final gross profits are evaluated in a pseudo data case study. A hyper-geometric distribution compound with Poisson distribution is used to compute the qualifying probability and the customer rejection probability. The empirical results reveal that the industry must pay more attention to the impact of sampling inspection costs; if commercial quality control is not rigorous, gross profits could be seriously eroded.

Key words: Gross profit; Hyper-geometric distribution; MIL-STD-1916 sampling plans; Poisson distribution; Qualifying probability

Shu-Ing Liu, Ho-Tai Liu (2012). Cost-Benefit Analysis for the MIL-STD-1916: A Case Study. *Management Science and Engineering*, *6*(1), 1-10. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/j.mse.1913035X20120601.1901
DOI: http://dx.doi.org/10.3968/j.mse.1913035X20120601.1901

INTRODUCTION

Because of fast technical progress, higher living standards, and consumers' strict request for product quality in recent several years, the zero defective principle has become the ultimate goal of quality control, in particular for electronic products. Product defects cause companies financial loss, and reflect the inefficiency of a company's quality control, therefore the industry must pay serious attention to product component quality and the quality control process. Due to cost, producers are unable to carry out unit-by-unit product examinations, thus sampling surveys have been applied in industry for many years in order to confidently guarantee that quality conforms to customer requests. Referring to the product quality control standards, the most popularly used in industry are either the MIL-STD-105E sampling plans announced in May, 1989, or the MIL-STD-1916 sampling plans announced in April, 1996, both issued by the United States Department of Defense.

The MIL-STD-105E was formerly adopted by the electronics industry, for either materials examination or product inspection before shipping. These sampling plans have an explicitly acceptable quality level (AQL), allowing producers to understand the largest fraction of defective product customers can accept in a batch. The buyer and seller both work out an acceptable quality level, a tolerable threshold for defects in a batch. For example, the "MIL-STD-105E single sampling plan at level-Ⅱ, with an AQL at 0.65%", was popularly used for product inspections; the buyer accepts the batch products, as long as the fraction of defective products did not surpass 0.65%. Small and medium-sized enterprises in Taiwan, used the MIL-STD-105E for years. The sampling inspection principle does permit a certain level of defective products, so long as the defective products were removed, the remaining products could still be shipped. In fact, when defects are detected, the company's management department and purchasing department should enhance vigilance in quality control.

Nowadays, customers increasingly pay attention to product quality, seeking zero defects, therefore the United States Department of Defense issued the more crucial sampling plans, MIL-STD-1916, to substitute for the looser MIL-STD-105E. The MIL-STD-1916 indirectly requests that the producer establish a strict commercial quality control system, and emphasizes that prevention of defects is the primary spirit of quality control. However, changing sampling standard caused producers who used the MIL-STD-105E to be confused by the new standards. Producers may still fall into the AQL puzzle, they may not be familiar with the MIL-STD-1916 regulations which provide different sample sizes for different verification levels. Likewise, they might be confused that any but totally non-defective batches will be returned. The "zero defects" principle of the MIL-STD-1916 attribute has gradually emerged as a major sampling inspection standard for industry to coordinate customer requests on product quality.

The MIL-STD-1916 differentiates the degree of quality control by using different verification levels. However, producers in practice have trouble selecting appropriate verification levels to match the product's quality control requirements. In particular, the impact of the relationship between verification levels among the product's qualifying probability, sampling costs, costs of goods returned and gross profits, are necessary and interesting to analyze thoroughly. Most existing research emphasizes implementing the new sampling plans and distinguishing the differences between the MIL-STD-1916 and the MIL-STD-105E, or discusses operating characteristic curves. Very rarely have investigations focused on the cost risks from the producer's or consumer's viewpoint. Contrary to traditional processes that focus on acceptance probability evaluations, Gershon and Christobek (2006) propose the total cost concept to demonstrate producer and consumer risks via the MIL-STD-105E.

This research will mainly investigate the influences of different verification levels under the MIL-STD-1916 from the producer's viewpoint. In particular, the paper will focus on gross profits. A case study of some computer manufacturing companies was taken as an example, conducting quantitative cost and profit analysis at various verification levels, to provide references for the MIL-STD-1916 users. The numerical demonstrations will cause producers to better understand the impact of product sampling inspection and its serious relationship to producer's gross profits. The rest of the paper is organized as follows: The research designs and methods for investigating the MIL-STD-1916, including the implementation of the hyper-geometric distribution along with the Poisson distribution, for calculating the qualifying probability, the customer's rejection probability and the gross profits, are all introduced in Section 1. In Section 2, a case study is numerically conducted, where pseudo data of some electronic company is applied to investigate the cost-benefit influences on different verification levels in the sampling inspection, in particular, the most interesting theme, final gross profits. Finally, the conclusion is offered.

1. RESEARCH DESIGNS

In this section, cost-benefit appraisal flows based on a probability model will be introduced to conduct numerical evaluations. As usual, the hyper-geometric distribution is used to describe the possibility of selecting defective items, when the defective numbers in a batch were assumed known in advance. However, in practical applications, the defective numbers in a batch are unknown, thus randomness is introduced. The number of defective products in a batch is assumed to follow a Poisson distribution. Thus the hyper-geometric distribution accompanied with a Poisson distribution is the core probability model utilized to perform the cost-benefit analysis. Before giving a detailed description of the probability model, firstly, a brief introduction of the discussed MIL-STD-1916 will be introduced:

According to the MIL-STD-1916, taking a single sampling as the standard, the batch of products will be accepted only if the sampled items contain no defects; otherwise, the products will be returned. Applying the MIL-STD-1916, the verification level for sampling inspection should be decided first. Customers and producers must agree on the chosen verification level before signing a contract. The verification levels have seven possible levels from I to Ⅶ, with I being the loosest quality control level, and Ⅶ being the strictest. Next, based on the selected verification level and a specified lot size, the corresponding code letter can be determined from Table 1. The code letter symbols are identified by the first five letters of the alphabet A to E.

Table 1
Code Letters for the MIL-STD-1916 Attribute Sampling Plans

Lot Interval Size	Verification Levels						
	Ⅶ	Ⅵ	Ⅴ	Ⅳ	Ⅲ	Ⅱ	Ⅰ
2-170	A	A	A	A	A	A	A
171-288	A	A	A	A	A	A	B
289-544	A	A	A	A	A	B	C
545-960	A	A	A	A	B	C	D
961-1632	A	A	A	B	C	D	E
1633-3072	A	A	B	C	D	E	E
3073-5440	A	B	C	D	E	E	E
5441-9216	B	C	D	E	E	E	E
9217-17408	C	D	E	E	E	E	E
17409-30720	D	E	E	E	E	E	E
Above 30720	E	E	E	E	E	E	E

Notes: Summarized from the MIL-STD-1916 attribute sampling plans

Table 2
Sample Sizes for the MIL-STD-1916

Code Letter	Verification Levels						
	Ⅶ	Ⅵ	Ⅴ	Ⅳ	Ⅲ	Ⅱ	**I**
A	1280	512	192	80	32	12	5
B	1536	640	256	96	40	16	6
C	2048	768	320	128	48	20	8
D	2560	1024	384	160	64	24	10
E	3072	1280	512	192	80	32	12

Suppose the lot size is set as 1,600 and the verification level is selected, as level "I", then the corresponding code letter found from Table I, is "E". Next, from the listed code letters in Table 2, with an "E" code letter and an "I" verification level, the necessary sample size is "12". Adopting the similar procedure, when the verification levels are ranged from level I to level Ⅶ, the corresponding seven code letters are E, D, C, B, A, A and A respectively, by inspecting Table 1. Furthermore, from Table 2, the corresponding sample sizes are seen to be 12, 24, 48, 96, 192, 512, 1,280 in order. In this paper, cost-benefit discussions focus on cases where the lot sizes are 1,600 and the respective sample sizes are from 12 to 1,280, with seven chosen sample sizes.

1.1 Acceptable Probability for the MIL-STD-1916

For quantitative analysis of quality control, a hypergeometric distribution is often used to describe the probability of selecting some defective items from a sample where the underlying number defective products are known: Suppose a lot, with size N, contains s defective and N-s non-defective units. Adapting the non-replacing principle, n items are randomly chosen, then the number of defective units among the n chosen items being a random variable, denoted by X_n, can be described by a hyper-geometric distribution. Let $\Pr(X_n = x \mid S = s)$ denote the probability of selecting x defective items among the n randomly selected items, given that the lot actually contains s defective units. Applying the hyper-geometric distribution property, it follows that

$$\Pr(X_n = x \mid S = s) = C_x^s C_{n-x}^{N-s} \Big/ C_n^N , \qquad (1)$$

here N is the lot size, n is the sample size, s is the number of defective items in the lot, x is the number of defective items in the random sample, and $C_m^n = n! \big/ [m!(n-m)!]$. Moreover, the inequalities must be satisfied, $\max\{0, n-(N-s)\} \le x \le \min(n,s)$. In the following discussions, N=1,600 is set.

Let $d(n|s)$ denote the disqualifying probability for any inspection sample with size n, given that the batch contains s defective products under the MIL-STD-1916. That is

$$d(n \mid s) = \sum_{x=1}^{\min(n,s)} \Pr(X_n = x \mid S = s) = \sum_{x=1}^{\min(n,s)} C_x^s C_{n-x}^{1600-s} \Big/ C_n^{1600}$$

On the other hand, the qualifying probability, denoted by a $a(n|s)$ is just

$$a(n \mid s) = 1 - d(n \mid s) = \Pr(X_n = 0 \mid S = s) = C_n^{1600-s} \Big/ C_n^{1600} \qquad (2)$$

In practical applications, industry usually uses the same sampling standards, for raw materials importation or finished product import/export, therefore, the producer and customer's qualifying probabilities are consistent for the same lot. Let $r(n|s)$ denote the customer rejection probability:

Customer rejection probability

= producer's qualifying probability $\times$ customer's disqualifying probability,

that is $r(n|s)=d(n|s)\times a(n|s)$.

Nowadays, industry still often uses the old standard "MIL-STD-105E single sampling with an AQL of 0.65%" as a sampling criterion; that is when the lot size is 1,600, then the number of defective units cannot exceed 10, 1,600×0.65%=10.4 On the other hand, with the MIL-STD-1916, if there are any defective units, the entire lot will be returned by the customer. Thus, one defective unit and eleven defective units are the respective critical points for the new and old sampling plans. In the next subsection, cases with known defective units, say s=1 or s=11 will be preliminarily discussed.

1.2 Analysis for Cases with *s*=1 or s=11 under the MIL-STD-1916

The MIL-STD-1916 takes the verification level as a standard to discriminate the degree of quality control. For cases with a lot size of 1,600, the corresponding sample size for the prescribed seven verification levels corresponds respectively to 12, 24, 48, 96, 192, 512 and 1,280. For each designed sample size, the conditional disqualifying probability, qualifying probability, and customer rejection probability are computed and displayed in Table 3. As expected, the conditional qualifying probabilities decrease as the sample sizes increase. On the other hand, the conditional customer rejection probabilities increase as sample sizes increase; however, if sample sizes are large enough, the rejection probabilities decrease instead. According to contract requirements, once defective products are found on the producer's end, then the producer must inspect each item in the batch. Under these circumstances, since the products have been inspected completely before shipping, thus customer rejection probabilities tend to decrease.

Table 3
Conditional Risks (%) under the MIL-STD-1916

Sample size	Defective unit=1				Defective units=11		
	VL	$a(n\|1)$	$d(n\|1)$	$r(n\|1)$	$a(n\|11)$	$d(n\|11)$	$r(n\|11)$
12	I	99.25	0.75	0.74	92.03	7.97	7.34
24	II	98.50	1.50	1.48	84.64	15.36	13.00
48	III	97.00	3.00	2.91	71.45	28.55	20.40
96	IV	94.00	6.00	5.64	50.52	49.48	25.00
192	V	88.00	12.00	10.56	24.39	75.61	18.44
512	VI	68.00	32.00	21.76	1.41	98.59	1.39
1280	VII	20.00	80.00	16.00	0.00	100.00	0.00

Note: 1. $a(n \mid s)$ denotes the qualifying probability when the lot contain *s* defective units.
2. $d(n \mid s)$ denotes the disqualifying probability when the lot contain *s* defective units.
3. $r(n \mid s)$ denotes the customer rejection probability when the lot contain *s* defective units.
4. Lot size *N*=1,600; VL: Verification level.

The producer faces two risks when the product batch contains defective items: The first risk happens when the producer carries on the sampling inspection before shipping the products out and defective units are found in the random sample. According to the MIL-STD-1916 sampling standard, the producer must inspect each unit in the batch before products shipping out, instead of just conducting a sampling examination. Therefore, the producer faces a complete inspection risk. The second risk is that defective products are not discovered during the producer's sampling survey, however, defective products are found by the customer. Then the producer suffers the risks that the customer may return all the goods even if only one defective unit was found in the inspection sample. This article utilizes a simple case study to quantify the aforementioned risks in terms of costs and profits under different verification levels.

2. A CASE STUDY

Industry is used to neglecting the influence of sample survey expenses on production costs, frequently only including direct costs, like material costs, artificial production costs, management expenses and established product profits in their price quotes. However, ignoring inspection expenses and losses due to detecting defective products, will cause gross profits to be seriously reduced. On the other hand, if one lowers the sampling survey standards, no doubt producer's inspection expenses will also drop, however this will automatically downgrade product quality. Therefore investigations into the influence of sample surveys on expenses and losses due to defective products effect on gross profits, are worth discussing quantitatively. Hopefully, this will provide references to industry for sampling confirmation standard designed.

The case study was carried out at a local company specializing in manufacturing electronic products, computer hinges. The company will be coded as Company A throughout the following discussion. Company A is located in Taipei, Taiwan, just like many other local electronic product manufacturers, and it is a mid-sized company with 60 employees and is export oriented. The discussions consisted of, determining the cost of implementing sampling inspection, studying the risk analysis from the producer's side, and finally, examining the gross profits under different verification levels. Because the product was a high tech product component, the unit price was quite expensive, therefore, the material inspection expenses can not be neglected. For convenience, in the following discussions, from the materials inspection to the finished products examination in the producer's side, all used the same verification level as in the customer's contract.

2.1 Data Backgrounds

When measuring the contribution of a single product to a company's gross profit, producers usually take material costs, labor of assembly, management and marketing costs, into account. Sampling inspection costs, though perhaps relatively small, still could affect the product's gross margins under different sampling verification levels. For the study's purposes, the lot size of Company A's products was set at *N*=1,600 units. Some basic costs of a unit product are listed as follows:

- The sales price is NT$ 50 per unit.
- The direct cost per unit
  = material cost per unit+labor cost per unit.
  = NT$30.00+NT$ 3.20=NT$33.20.
- The management and marketing cost per unit =NT$2.3.
- The material inspection cost per unit=NT$6.5.
- The finished product inspection cost per unit =NT$10.5.

Usually, the initial costs only contain the direct costs, such as, material costs, labor costs and management and marketing expenses, therefore,

Producer's initial costs=material inspection costs + production costs + management and marketing costs.

Here, material inspection costs=sample sizes × NT$6.5,

Production costs = 1,600 × NT$33.20 = NT$53,120, and

Management and marketing costs =1,600 × NT$2.30 = NT$3,680.

Then, producer's initial costs= sample sizes × NT$6.5+NT$53,120+NT$3,680; and

Producer's initial profits= [1- producer's initial costs / (1,600 × NT$50)] × 100%.

Presumably the number of defective units in the batch is known, the resulting losses and gross profits, under various sampling sizes, are presented in Table 4.

Table 4
Conditional Producer's Profit Analysis under the MIL-STD-1916

Sample size	Initial profit (%)	Defective unit=1			Defective unit=11		
		Sampling loss(%)	Rejection loss(%)	Gross profit(%)	Sampling loss(%)	Rejection loss(%)	Gross profit(%)
12	28.90	0.31	0.20	28.39	1.82	2.02	25.07
24	28.81	0.63	0.41	27.77	3.49	3.58	21.74
48	28.61	1.24	0.80	26.57	6.45	5.61	16.56
96	28.22	2.44	1.55	24.23	11.03	6.87	10.32
192	27.44	4.74	2.90	19.80	16.49	5.07	5.88
512	24.84	11.29	5.98	7.57	20.80	0.38	3.66
1280	18.60	20.16	4.40	-5.96	21.00	0.00	-2.40

Notes: 1. Producer's initial profit(%)=(1-producer's initial cost/total sale prices)×100%
2. Producer's sampling losses(%)=(producer's sampling lost amounts/total sale prices)×100%
3. Customer rejection losses(%) =(lost amounts via customer rejection/total sale prices)×100%
4. Producer's gross profit(%)=producer's initial profit- producer's sampling losses-customer rejection losses

2.2 Profit Analysis for the MIL-STD-1916 with Fixed Defective Number

Under different verification levels, the initial product profits are affected by various sampling inspection expenses. As mentioned before, producers must face two types of sampling inspection losses. When the producer conducted sampling inspection before shipping products out, defective products might be found in the batch, then the whole batch must be inspected. Producers should undertake this potential loss risk, the type I risk. Even if the batch passes through the first sampling inspection checkpoint, defective units still may be discovered at the second checkpoint, the customer's sampling inspection. Once any defective unit is found at the customer's side, the producer suffers risks to the company's reputation and goods may be returned by the customer, which may cause considerable expense. This is the type Ⅱ risk. In this case study, both kinds of risk will be investigated numerically via a case study.

2.2.1 The Type I Risk-Producer's Sampling Losses

In order to reduce type I risks, the producer may intend to conduct a looser level of sampling inspection, consequently type II risks will be enhanced. On the other hand, in order to reduce type II risks, the producer may adopt a stricter sampling standard, then the sampling inspection expenses will increase and cause the product profits to be directly reduced. How to obtain a balance between the two types of risk, is an interesting problem for the producer. When there are s defective units in the lot and a random sample with sizes n is selected, then the expected sampling inspection sizes that the producer must undertake, denoted by, $E(n|s)$, are

$$E(n \mid s) = a(n \mid s) \times n + d(n \mid s) \times 1{,}600 .$$

The first term represents the expected sampling inspection sizes when the batch is qualifying acceptable; the second term denotes the expected sampling inspection sizes when the batch is disqualified and must be examined completely. The detailed formulae for $d(n|s)$ and $a(n|s)$ are referred to in formula (2).

Speaking of the producer, sampling inspection expenses belong to essential costs; along with the changing of verification levels, the expected sampling inspection sizes and the induced risks will vary simultaneously. Under each verification level, the expected inspection sampling size multiplied by testing expense per unit, convert to profit losses. That is, let $EC(n|s)$ represent the expected inspection expenses for the producer, then

$EC(n|s)=E(n|s)\times$ testing expense per unit$=E(n|s)\times$ NT$10.5.

For example, the sample size for level I is 12, and from Table 3, the disqualifying probability is 0.75%, given that there is only one defective item, then the expected losses due to inspection sampling are [12×(1-0.75%)+1,600×0.75%]×NT$10.5=NT$251.06. If the batch actually contains 11 defective items, then the disqualifying probability is 7.97%; thus the expected losses due to inspection sampling are [12×(1-7.97%)+1,600×7.97%]×NT$10.5=NT$1,454.92. The expected lost profits are thus converted, dividing the expected lost amounts, NT$1,454.92, by the total sale prices, say, NT$50×1,600=NT$80,000.

The expected lost profits due to sampling inspection under other verification levels were similarly calculated and listed in Table 4. No matter whether the underlying defectives are 1 or 11, the lost profits will increase as the inspection sampling sizes expand. After the risk assessment due to defective products have been done, the producer's expected surplus profits are the initial profits minus the expected lost profits,

Expected surplus profits(%)=initial profits(%)-expected lost profits(%).

Since the expected lost profits will increase along with increases to inspection sampling sizes, thus the expected surplus profits will be reduced as the sampling inspection sizes increase, even if losing money condition.

2.2.2 The Type Ⅱ Risk-Losses Due to Customer's Goods Returned

When the producer does not discover defective products in the batch and ships the goods to the customer directly, the type Ⅱ risk might occur. Producers face the risk that the customer might find defective units in their sampling inspection and return the goods. Therefore, the customer rejection probability is the probability that two events occur independently: One, the batch, though containing defective products passes through the sampling inspection before shipping; second, the sampling inspection conducted by the customer is failed. If a batch of products is returned, the producer must completely inspect each unit, instead only a random sampling inspection, pay the fine for delayed delivery, approximately one percent of the total sales price per day, for a total of four days. Also the producer must pay the round trip freight costs, for the goods return to the producer and redelivery to the customer. An estimate of NT$1, 000 for each trip was used. In summary, the producer bears the following losses:

Expected lost amounts from customer rejection

$=r(n|s)$ ×1,600×NT$10.5+1,600×NT$50×4%+2×NT$1,000)= $r(n|s)\times$NT$22,000

Again for the level I case, the customer rejection probability was 0.74%, given that there was only one defective item, therefore expected losses from the customer's rejection were

0.74%×(1-0.74%)×NT$22,000=NT$161.60.

After transforming to a loss percentage, the result is 161.60/(1,600×50)×100%=0.20%. For the other verification levels, the producer's expected lost profits due to customer returned goods, and gross profits, are demonstrated in Table 4. In the case where either the defective products totaled 1 or 11, the gross profits decreased as sampling inspection sizes increased. If the shipment sizes were large, gross profits dropped gradually, even in a losing money situation. The overall flow of the corresponding expected losses are quantitatively exhibited in Figure 1.

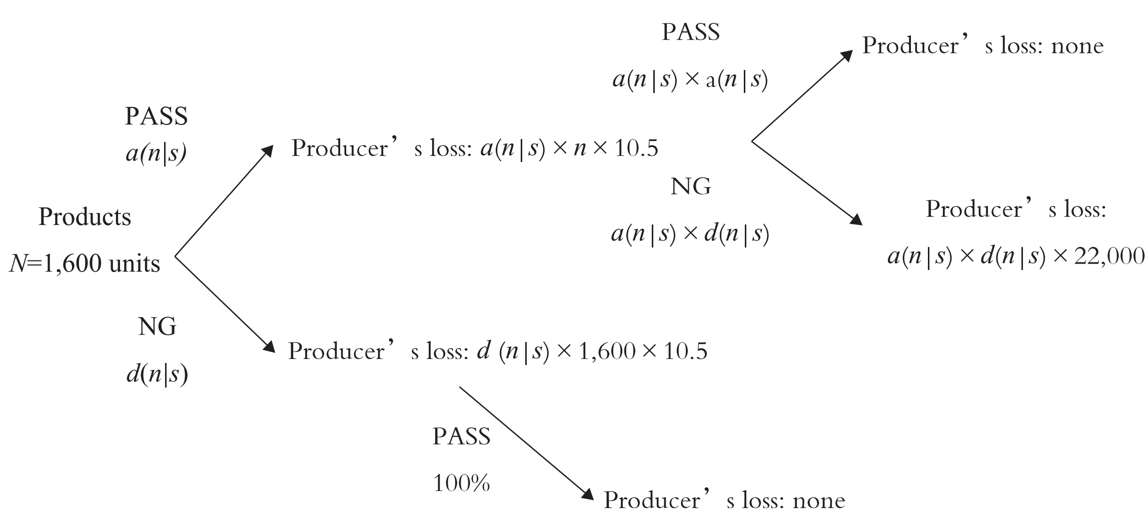

Figure 1
Producer's Loss Diagram

2.3 Profit Analysis for the MIL-STD-1916 with a Random Number of Defects

The aforementioned risk analysis is calculated under the assumption that the defective numbers in the batch will be known in advance. In practice, the defective numbers in the batch would be random, however, the producer, from former sampling experience, may have historical data of the defective records. This data helps to estimate the distribution of the company defective products and to process the cost-benefit analysis further. Suppose the defective number follows a Poisson distribution, with parameter λ, representing the mean number of defective products, which could be estimated by historical data. For a designated sample size in a contract, say, n, the probability that a batch with 1,600 units has x defectives is:

$$\Pr(X_n = x) = \sum_{s=x}^{N-n+x} \Pr(X_n = x \mid S = s) \times \Pr(S = s)$$

$$= \sum_{s=x}^{1600-n+x} \left(C_x^s C_{n-x}^{1600-s} \Big/ C_n^{1600} \right) \times \left(e^{-\lambda} \lambda^s \Big/ s! \right)$$

Different values of λ would provide information about the quality of the products, and the probability of selecting defective units in a sampling inspection can be computed.

Let $a(n)$ denote the qualifying probability under the MIL-STD-1916 with sample size n, then

$$a(n) = \Pr(X_n = 0) = \sum_{s=0}^{N-n} a(n \mid s) \times \Pr(S = s)$$

$$= \sum_{s=0}^{1600-n} \left(C_n^{1600-s} \Big/ C_n^{1600} \right) \times \left(e^{-\lambda} \lambda^s \Big/ s! \right)$$

$d(n)$ denotes the disqualifying probability, $d(n) = \sum_{s=0}^{N-n} d(n \mid s) \times \Pr(S = s)$; and $r(n)$ denotes the customer rejection probability, $r(n)=a(n)\times d(n)$. Take λ =1.0 as an example, means that the averaged number of defective products in a lot, with N=1,600, is 1.0. The qualifying, disqualifying, customer rejection probability and producer's profits can be re-computed according to the unconditional probabilities, $a(n)$, $d(n)$ and $r(n)$. When sampling inspection sizes increased, the producer's sampling costs were aggravated, however, the customer rejection probability also increased, therefore, the producer's gross profits were gradually reduced. Those unconditional results are organized and exhibited in Table 5.

Table 5
Producer's Profit Analysis for the MIL-STD-1916 (λ =1.0)

Sample size	Qualifying probability $a(n)$ (%)	Disqualifying probability $d(n)$ (%)	Rejection risk $r(n)$ (%)	Surplus profits (%)	Returned losses (%)	Gross profits (%)
12	99.25	0.74	0.73	28.59	0.20	28.39
24	98.51	1.49	1.47	28.18	0.40	27.78
48	97.04	2.96	2.87	27.38	0.79	26.59
96	94.17	5.83	5.49	25.81	1.51	24.30
192	88.69	11.31	10.03	22.83	2.76	20.07
512	72.61	27.39	19.89	14.21	5.47	8.74
1280	44.93	55.07	24.74	-0.51	6.80	-7.31

Notes: 1. Surplus profits(%)=initial profits(%)-(producer's sampling lost amounts/total sale prices)×100%
2. Customer rejection losses(%)=(lost amounts via customer rejection/total sale prices)×100%
3. Producer's gross profits(%)=surplus profits(%)-customer rejection losses(%)

The customer rejection probability plays a crucial role to the producer's gross profits. By definition, the risks were introduced when the products were certified by the producer, but disqualified by the customer. That is

Risk of customer rejection=qualifying probability× (1-qualifying probability)×100%.

Mathematically, the function, $f(x) = x(1-x)$, for $0 \le x \le 1$, attains maximal at $x = 0.5$, thus as the qualifying probability closes on 50%, the customer rejection risk would approach the maximal value. In more detail, when the qualifying probability, starting from 100%, gradually drops, the customer rejection risk gradually increases. When the qualifying probability closes on 50%, the qualifying probability and disqualifying probability are even, and the risk to the producer is at its greatest level. Immediately, after the disqualifying probability surpasses the qualifying probability, defective products would be discovered more often by the producer's side before shipping. In this situation, the producer might inspect products unit-by-unit, therefore, the customer rejection risks almost disappear, in fact, the customer rejection probability should drop to approximately zero.

Next, the relationships between the averaged defective number, λ , and the customer rejection risk was investigated. When the averaged number of defective units was quite small, say, $\lambda \le 1$, along with the increasing sample size, the disqualifying probability also increased. Therefore, even though the producer did not discover defective products during the sampling inspection, they might still be detected by the customer when sampling sizes increased. Hence, the risks of returned goods were also relatively enhanced when the sample sizes increased. Contrarily, when the averaged number of defective products got moderately large, along with the increase in sample sizes, the disqualifying probability also increased. According to the contract, once any defective product is detected, the producer must completely examine the batch. Therefore, goods returned from the customer would not occur, and, automatically, the customer rejection risk would gradually drop, even vanish.

The changing patterns of gross profits were slightly different than the discussed customer rejection risks. For each fixed value of λ, as sample sizes increase, the gross profits always drop. This phenomenon even appears when profits fall below zero. On the other hand, as the values of λ increase, as long as sample sizes remained low, say less than 100, gross profits also gradually drop. When both sample sizes and λ values became rather larger, the chance of detecting defects on the producer's side increased. Now losses are concentrated on paying full inspection expenses, quite fixed disbursements, thus gross profits tend to be stable. All the discussed phenomena are shown in Table 6.

Table 6
Risks and Profits Analysis (%) under the MIL-STD-1916

λ	Sample size						
	12	**24**	**48**	**96**	**192**	**512**	**1280**
0.1	0.08	0.15	0.30	0.60	1.18	3.05	7.10
	(28.71)	(28.48)	(27.84)	(26.68)	(24.38)	(16.83)	(-0.48)
0.3	0.22	0.45	0.89	1.75	3.41	8.32	16.79
	(28.64)	(28.27)	(27.55)	(26.13)	(23.33)	(14.53)	(-3.71)
0.5	0.37	0.74	1.47	2.87	5.49	12.60	22.10
	(28.56)	(28.13)	(27.27)	(25.59)	(22.34)	(12.54)	(-5.66)
1.0	0.74	1.47	2.87	5.49	10.03	19.89	24.74
	(28.39)	(27.78)	(26.59)	(24.30)	(20.07)	(8.74)	(-7.32)
2.0	1.47	2.87	5.49	10.03	16.79	24.93	16.11
	(28.03)	(27.09)	(25.28)	(21.97)	(16.36)	(4.51)	(-5.98)
3.0	2.18	4.21	7.87	13.77	21.10	23.62	8.25
	(27.68)	(26.42)	(24.06)	(19.92)	(13.53)	(2.81)	(-4.29)
5.0	3.55	6.71	12.00	19.22	24.77	16.09	1.80
	(27.00)	(25.15)	(21.84)	(16.55)	(9.76)	(2.29)	(-2.82)
10.0	6.72	12.02	19.23	24.77	21.01	3.89	0.03
	(25.39)	(22.30)	(17.40)	(11.22)	(6.21)	(3.35)	(-2.41)
15.0	9.55	16.14	23.14	24.10	13.71	0.80	0.01
	(23.89)	(19.87)	(14.21)	(8.59)	(5.70)	(3.74)	(-2.40)t
20.0	12.05	19.27	24.78	20.96	8.15	0.16	0.00
	(22.51)	(17.80)	(11.93)	(7.36)	(5.85)	(3.82)	(-2.40)
25.0	14.25	21.57	24.91	17.20	4.64	0.03	0.00
	(21.24)	(16.05)	(10.33)	(6.85)	(6.07)	(3.84)	(-2.40)
30.0	16.19	23.18	24.06	13.62	2.58	0.01	0.00
	(20.06)	(14.57)	(9.21)	(6.69)	(6.22)	(3.84)	(-2.40)
40.0	19.34	24.80	20.87	8.04	0.77	0.00	0.00
	(17.97)	(12.25)	(7.92)	(6.75)	(6.37)	(3.84)	(-2.40)

Note: 1.The 1st entry denotes customer rejection risks; the 2nd entry inside the parenthesis denotes gross profits.

2.4 Comparisons between the MIL-STD-1916 and the MIL-STD-105E

In this subsection, the customer rejection risk and its influence on gross profits were discussed by comparing differences between the later MIL-STD-1916 and the former MIL-STD-105E. Suppose the company formerly used the MIL-STD-105E, with an AQL of 0.65% for the discussed different sample sizes. It is worthy of note that if the sample size is lower than 153, the two sampling plans follow the same protocol, the "one rejected/zero accepted" principle. When sample sizes gradually increase, the disqualifying threshold becomes looser than in the new plans; for example, for the MIL-STD-105E, one defective is allowed for n=192, three defects for n=512, and eight defects for n=1,280. Different sample sizes correspond to various qualifying probabilities, taking n=512 as an example, the qualifying probability for MIL-STD-105E is

$$\Pr(X_n \le 3) = \Pr(X_n = 0) + \Pr(X_n = 1) + \Pr(X_n = 2) + \Pr(X_n = 3)$$

When sample sizes were 12, 24, 48 or 96, the two sampling plans had the same rejection principle, "one rejected/zero accepted", therefore comparisons concentrate only on other sample sizes, 192, 512 and 1,280.

Imitating the analyses presented in Table 6, the customer rejection risks and gross profits were calculated respectively. The impact of λ, or sample sizes were similar to those under the MIL-STD-1916. Since the threshold of acceptability in the MIL-STD-105E is low, under small averaged defects, say, $\lambda<5$, the risk of customer rejections were significantly lower and the producer's gross profits were higher than with the MIL-STD-1916. However, when values for λ gradually increased, the qualifying probabilities were higher than the MIL-STD-1916. Possibly this was caused the producer negligently shipping goods, but then suffering the penalty of returned goods. Therefore, for larger values of λ, the customer rejection risks under the MIL-STD-105E were obviously higher than with the MIL-STD-1916, and the gross profits were also inferior to the MIL-STD-1916. It is worthy of note that as the value of λ grew large, the opportunity to detect defects did increase. In particular, when sampling sizes were very large, the producer faced the necessity of paying nearly full inspection expenses, instead of sampling inspection expenses.

The complete examination losses are approximately

$$\text{Full examination losses} = \frac{NT\$10.5 \times 1,600}{NT\$50 \times 1,600} \times 100\% = 21\%.$$

Taking λ =40 and n=512 as an example, initial profits and gross profits are

Initial profits

$$= \left[1 - \frac{NT\$35.5 \times 1,600 + NT\$6.5 \times 512}{NT\$50 \times 1,600}\right] \times$$

100%=24.84%, and gross profits=3.84%.

Furthermore, taking λ=40 and n=1,280 as another example, then

Initial profits

$$= \left[1 - \frac{NT\$35.5 \times 1,600 + NT\$6.5 \times 1,280}{NT\$50 \times 1,600}\right] \times$$

$$100\% = 18.60\%$$

and gross profits=-2.4%.

Therefore, whether applying the MIL-STD-1916 or the MIL-STD-105E, when the number of defective products are rather large, and sample sizes approximately reach one third of the lot size or above, then gross profits tend to be stable: When n=512, gross profits attained approximately 3.84%, and as sample sizes expanded to n=1,280, gross profits dropped to -2.4%. The analyzed comparisons results are summarized in Table 7.

Table 7
Comparisons on Returned Goods Risks and Gross Profits

n	λ							
	0.1	1.0	3.0	5.0	10	15	24	40
	Customer rejection risks (%)							
192	1.18	10.03	21.10	24.77	21.01	13.72	4.64	0.77
	(0.01)	(0.66)	(4.84)	(10.69)	(22.36)	(24.86)	(15.82)	(4.40)
512	3.05	19.89	23.62	16.09	3.89	0.80	0.03	0.00
	(0.00)	(0.03)	(1.63)	(7.24)	(23.95)	(20.73)	(3.99)	(0.12)
1280	7.10	24.74	8.25	1.80	0.03	0.01	0.00	0.00
	(0.00)	(0.00)	(0.09)	(2.09)	(24.14)	(13.08)	(0.21)	(0.00)
	Gross profits (%)							
192	24.38	20.07	13.53	9.76	6.21	5.70	6.07	6.37
	(24.92)	(24.62)	(22.65)	(19.73)	(12.53)	(8.14)	(5.73)	(6.08)
512	16.83	8.74	2.81	2.29	3.35	3.74	3.84	3.84
	(18.12)	(18.11)	(17.44)	(15.01)	(5.86)	(2.33)	(3.34)	(3.83)
1280	-0.48	-7.32	-4.29	-2.82	-2.41	-2.40	-2.40	-2.40
	(1.80)	(1.80)	(1.77)	(1.14)	(-6.55)	(-5.35)	(-2.45)	(-2.40)

Note: 1. The 1st entry denoted the result under the MIL-STD-1916; while the 2nd entry in the parenthesis denoted the result under the MIL-STD-105E.
2. Customer rejection risks and producer's gross profits were same as that defined in Table 5.

At present, most company's management level or purchasing department, admit that the "one rejected/zero accepted" principle will become a trend for the development of future sample survey systems. In order to strive for effectiveness, the producer may perform full inspections before shipping products, instead of applying sampling inspection techniques. In particular, the high tech electronic entrepreneur may frequently adopt this strategy. Let's consider an extreme case: Suppose the producer did not perform sampling inspection on raw materials, but made full inspections for each finished product instead, then approximate gross profits would be

$$\left[1-\frac{(NT\$35.5+NT\$10.5)\times 1,600}{NT\$50\times 1,600}\right]\times 100\% = 8\%$$

This profit level might not be adequate for the producer pursued. In other words, 8% could almost be regarded as the minimum acceptable gross profit level. In general, the producer should establish effective quality control processes to achieve a system to prevent defective products, to increase product quality, and to efficiently suppress defective products from reaching the customer. Also, there are unquantifiable losses, like lost future orders and damage to reputation, which producers should prudently assess. Nowadays, producing perfect products should be the ultimate goal for industry.

CONCLUSIONS

This article provides some cost-benfit analyses via case studies on the MIL-STD-1916 sampling plans, which are gradually being adopted by industry. From the producer's viewpoint, the quantitative evaluations including sampling inspection costs, losses due to customer rejection, and the total gross profits are presented. The numerical results reveal that when the defective pieces in a batch are rare and the sampling inspection sizes are small, the producer still has some anticipated gross profits; but when the sampling numbers increase, the gross profits also wither. In particular, if defective products in a batch are quite a lot, the producer will lose money. In order to meet customer quality demands, the sampling inspection may cause considerable extra expenses arising from defects occurring. Therefore, if the producer does not very thoroughly conduct the product quality control, total gross profits could be seriously reduced. The producer may appraise whether adjusting material purchasing, improves the production line and reduces defects, or if promoting quality control effectively prevents the defects from reaching client's sides. Besides considerations of visible disbursements, the producer must also pay attention to invisible losses, losses due to failure in satisfying customer's quality requests, the injury to prestige due to goods being returned, and the order forms outflow in the future.

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