Savings of the Inspection Cost in Acceptance Sampling

Jindřich Klůfa [1] | *University of Economics, Prague, Czech Republic*

Abstract

This paper refers to the rectifying sampling inspection plans with given lot tolerance percent defective (denoted LTPD). The LTPD sampling plans minimizing mean inspection cost per lot of process average quality, when the remainder of rejected lots is inspected, were originally designed by Dodge and Romig for inspection by attributes (each inspected item is classified as either good or defective). The corresponding rectifying plans for inspection by variables were created by author of this paper. Comparison of these two types of the LTPD plans from economical point of view is presented herein. Using the LTPD plans by variables we can reach fundamental savings of the inspection cost. In this paper we analysed the situations in which the rectifying LTPD plans by variables are more economical than the corresponding attribute sampling plans. A criterion for deciding if inspection by variables is to be used instead of inspection by attributes is suggested and calculated for input parameters of acceptance sampling.

Keywords

Acceptance sampling, rectifying LTPD plans, inspection by variables, single quality characteristic, one specification limit

JEL code

C44, L15, C83

INTRODUCTION

The rectifying LTPD single sampling plans for inspection by attributes are acceptance sampling plans (n, c) which minimize the mean number of items inspected per lot of process average quality:

$$I_s = N - (N - n) \cdot L(\overline{p}; n, c), \tag{1}$$

under the condition:

$$L(p_t; n, c) = \beta, \tag{2}$$

where N is the number of items in the lot (the given parameter), $\overline{p}$ is the process average fraction defective (the given parameter), p_t is the lot tolerance fraction defective (the given parameter, $P_t = 100\, p_t$ is the lot tolerance per cent defective, denoted LTPD), n is the number of items in the sample ($n<N$, the search parameter), c is the acceptance number (the search parameter).

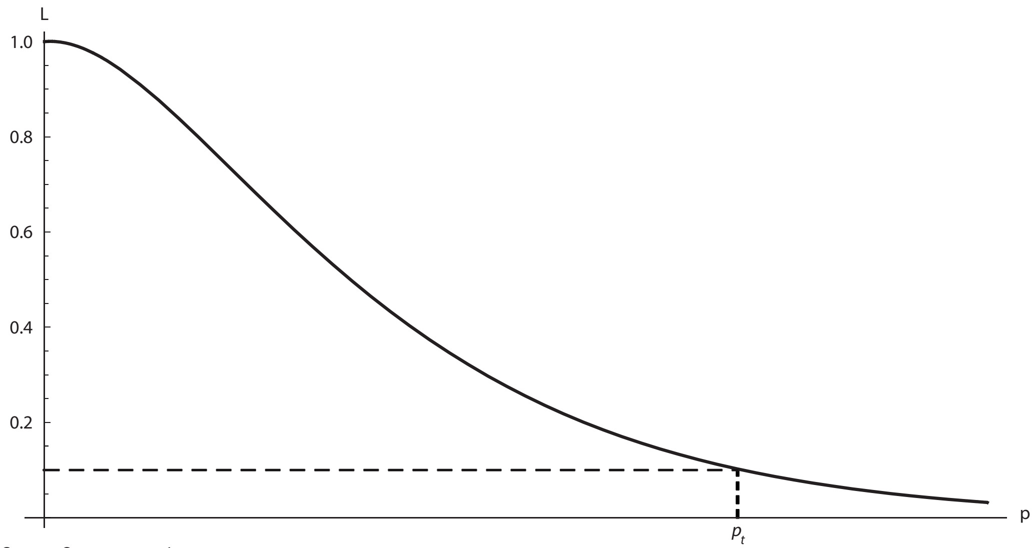
The inspection procedure: The lot is rejected when the number of defective items in the sample is greater than c (see e.g. Hald, 1981).

[1] Department of Mathematics, Faculty of Informatics and Statististics, University of Economics, W. Churchill Sq. 4, 130 67 Prague 3, Czech Republic. E-mail: klufa@vse.cz.

The function $L = L(p;n,c)$ is the operating characteristic. For given acceptance plan (n,c) the $L(p;n,c)$ is probability of accepting a submitted lot with fraction defective p – see Figure 1.

Formula (2) protects the consumer against the acceptance of a bad lot: the probability of accepting a submitted lot of tolerance quality p_t (consumer's risk) shall be β (see Figure 1). The LTPD plans for inspection by attributes are extensively tabulated in Dodge and Romig (1998), value $\beta = 0.1$ is used for consumer's risk in this book.

Figure 1 Typical graph of the operating characteristic $L = L(p)$



Source: Own construction

The rectifying LTPD plans for inspection by variables with the same protection of the consumer were created in Klůfa (1994), using for calculation of the operating characteristic L normal distribution as an approximation of the non-central t distribution. Exact LTPD plans for inspection by variables, using non-central t distribution for calculation of the operating characteristic L, were calculated in Klůfa (2010). Similar problems are solved in Chen and Chou (2001), Wang (2016), Kaspříková and Klůfa (2015), Chen and Chou (2013), Yazdi, Fallah, Shishebori, Mostafaeipour (2016), Aslam et al. (2015), Balamurali et al. (2014), Yen et al. (2014), Wang and Lo (2016), Chen (2016), Yazdi and Fallahnezhad (2017).

The dependence savings of the inspection cost (using the LTPD plan for inspection by variables instead of the corresponding LTPD plan for inspection by attributes) on input parameters of acceptance sampling is analysed in this paper. Moreover, a criterion for deciding if inspection by variables is supposed to be used instead of inspection by attributes, is suggested in present paper.

This paper follows the paper Klůfa (2015a) and the paper Klůfa (2015b) in which the combined inspection (the sample is inspected by variables, remainder of rejected lot is inspected only by attributes) is considered instead of inspection by variables which is in present paper.

1 LTPD PLANS FOR INSPECTION BY VARIABLES

In paper Klůfa (1994) the problem to find LTPD plans for inspection by variables was solved under the following assumptions:

Measurements of a single quality characteristic X are independent, identically distributed normal random variables with unknown parameters μ and σ^2. For the quality characteristic X is given either an upper specification limit U (the item is defective if its measurement exceeds U), or a lower specification limit L (the item is defective if its measurement is smaller than L). It is further assumed that the unknown parameter σ is estimated from the sample standard deviation s.

The inspection procedure is as follows. Accept the lot if:

$$\frac{U-\overline{x}}{s} \geq k\,, \quad \text{or} \quad \frac{\overline{x}-L}{s} \geq k, \tag{3}$$

where:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i\,, \quad s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}\,. \tag{4}$$

Like Dodge and Romig we shall look for the acceptance plan (n, k) minimizing the mean number of items inspected per lot of process average quality:

$$I_m = N - \left(N-n\right)\cdot L\left(\overline{p};n,k\right)\,, \tag{5}$$

under the condition $L(p_t;n;k) = \beta$. This condition is the same one as used for protection the consumer Dodge and Romig.

The problem of finding of the LTPD plans for inspection by variables was solved in Klůfa (1994), using for calculation of the operating characteristic L normal distribution as an approximation of the non-central t distribution (approximation of the non-central t distribution by normal distribution is based on the approximation of the distribution s/σ by normal distribution with expected value 1 and dispersion $1/(2n-2)$, see Johnson and Welch, 1940). Exact calculation of the LTPD plans for inspection by variables when the non-central t distribution is used for calculation of the operating characteristic was explained in Klůfa (2010). Now, we shall study economical aspects of these plans.

2 ECONOMICAL ASPECTS

As a measure of economic efficiency of the LTPD single sampling plans for inspection by variables we shall use parameter E defined by relation:

$$E = \frac{I_m}{I_s}100, \tag{6}$$

where $I_m = N - \left(N-n\right)\cdot L\left(\overline{p};n,k\right)$ is mean number of items inspected per lot of process average quality for inspection by variables and $I_s = N - (N-n)\cdot L(\overline{p};n,c)$ is mean number of items inspected per lot of process average quality for inspection by attributes. The parameter $E < 100$ because the sample size in acceptance sampling plans for inspection by variables is always less than the sample size in acceptance sampling plans for inspection by attributes (see e.g. Cowden, 1957). On the other hand, the cost of inspection of one item by variables c_m^* is usually greater than the cost of inspection of the same item by attributes c_s^*, i.e. usually is:

$$c_m = \frac{c_m^*}{c_s^*} > 1\,. \tag{7}$$

For the economical comparison of these plans the parameter c_m, i.e. the ratio of the cost of inspection of one item by variables to the cost of inspection of this item by attributes, must be determined in every real situation (e.g. according to the time of inspection, the cost of the inspection devices etc.). According to (6) and (7):

$$E \cdot c_m = \frac{I_m c_m^*}{I_s c_s^*} 100, \tag{8}$$

where $I_m c_m^*$ is the mean cost of inspection by variables and $I_m c_s^*$ is the mean cost of inspection by attributes (there are no restrictive assumptions on the cost function). Therefore, if c_m is determined and $E \, . \, c_m < 100$ then the LTPD plans for inspection by variables are more economical than the corresponding Dodge-Romig LTPD plans for inspection by attributes. Difference:

$$s = 100 - E \cdot c_m = (1 - \frac{I_m}{I_s} c_m) \cdot 100 \tag{9}$$

then represents the percentage of *savings of the inspection cost* when sampling plan for inspection by variables is used instead of the corresponding plan for inspection by attributes. If:

$s > 0$,

then the LTPD plans for inspection by variables are more economical than the corresponding Dodge-Romig LTPD plans for inspection by attributes, if:

$s < 0$,

then the LTPD attribute sampling plans are more economical than the LTPD plans for inspection by variables.

Example 1. We have chosen for acceptance sampling the lot tolerance fraction defective $p_t = 0.01$ (i.e. the LTPD is 1%). Let the lot size $N = 4\,000$, the process average fraction defective $\overline{p} = 0.002$ and $c_m = 1.4$ (the cost of inspection of one item by variables is higher by 40% than the cost of inspection of one item by attributes). We shall look for the LTPD plan for inspection by variables. Furthermore, we shall compare this plan and the corresponding LTPD plan for inspection by attributes from economical point of view.

For given parameters $p_t = 0.01$, $N = 4\,000$, $\overline{p} = 0.002$ we shall compute the LTPD plan for inspection by variables – see Klůfa (2010):

$n = 183$, $k = 2.5233$,

and $E = 27$. The corresponding LTPD plan for inspection by attributes we find in Dodge and Romig (1998). For these parameters we have:

$n = 510$, $c = 2$,

(the sample size for inspection by attributes is greater than the sample size for inspection by variables). For $c_m = 1.4$ the economical parameter s is:

$s = 100 - 37.8 = 62.2$.

From this result it follows that under the same protection of consumer the LTPD plan for inspection by variables (183, 2.5233) is more economical than the corresponding Dodge-Romig LTPD attribute sampling plan (510, 2). Since $s = 62.2$, using the LTPD plan for inspection by variables instead of the corresponding plan for inspection by attributes, approximately **62% saving of the inspection cost** (see Table 1) can be expected.

The percentage of savings of the inspection cost when sampling plan for inspection by variables is used instead of the corresponding plan for inspection by attributes, s depends on acceptance sampling parameters p_t, N, $\overline{p}$ and c_m, i.e. s is a function of these parameters:

$$s = s(p_t, N, \overline{p}, c_m). \tag{10}$$

Values of this function for some parameters p_t, N, $\overline{p}$ and c_m are in Table 1. From Table 1 and from the results of numerical investigations it follows that under the same protection of consumer the LTPD plans for inspection by variables are in many situations *more economical* (saving of the inspection cost is 70% in any cases) than the corresponding Dodge-Romig attribute sampling plans.

Table 1 The percentage of savings s for $p_t = 0.01$, $c_m = 1.4$

$\overline{p}$\N	100	500	1 000	4 000	10 000	50 000	100 000
0.00025	52	64	68	76	80	78	80
0.00050	43	57	64	71	73	75	75
0.00075	36	51	61	69	71	78	73
0.00100	30	47	59	69	69	82	78
0.00125	24	43	57	65	68	71	72
0.00150	20	38	55	64	66	69	69
0.00175	16	36	54	62	66	69	69
0.00200	12	31	51	62	68	71	71
0.00225	8	29	44	59	64	66	68
0.00250	5	24	41	59	62	66	68
0.00275	2	20	38	58	62	68	69
0.00300	–1	17	36	58	62	69	72
0.00325	–4	13	33	54	59	64	65
0.00350	–5	10	29	52	59	64	64
0.00375	–8	6	26	50	58	64	65
0.00400	–9	2	23	48	59	65	66
0.00425	–11	–1	19	47	55	61	65
0.00450	–13	–5	16	45	54	61	66
0.00475	–15	–8	12	43	54	61	68
0.00500	–16	–12	9	41	54	64	71

Source: Own construction

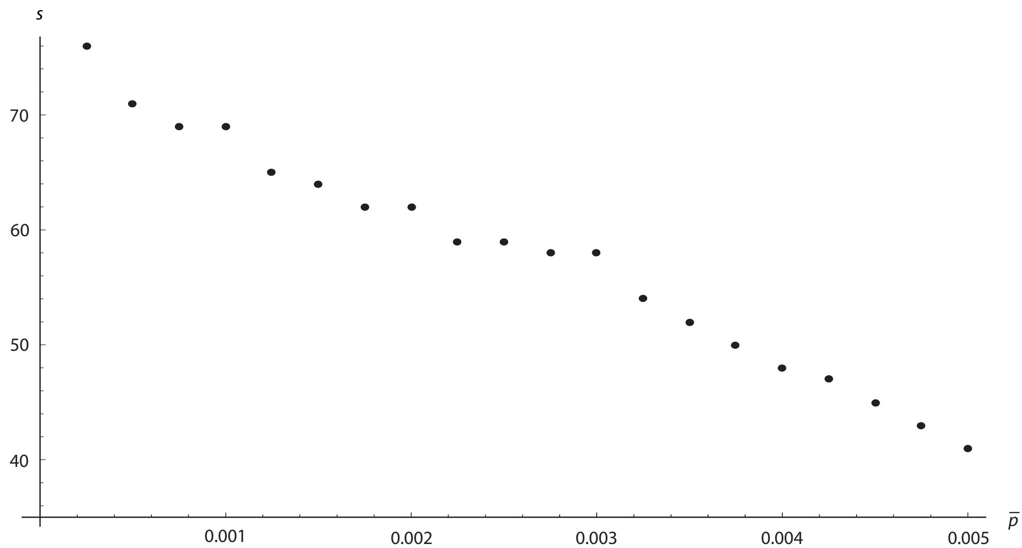
Now, we shall study the dependence savings of the inspection cost (using the LTPD plan for inspection by variables instead of the corresponding LTPD plan for inspection by attributes) on input parameters of acceptance sampling N, $\overline{p}$ and c_m.

Dependence of the percentage of savings s on the lot size N:
In the first step we shall study the dependence savings of the inspection cost (using the LTPD plan for inspection by variables instead of the corresponding LTPD plan for inspection by attributes) on the lot size N. Let p_t, $\overline{p}$, c_m be given parameters. For these given parameters the function s in (10) is a function

of one variable N. This function has an increasing trend in N (it is confirmed by numerical investigations – see also Table 1). Therefore, using the LTPD plan for inspection by variables instead of the corresponding plan for inspection by attributes, *the savings of the inspection cost increases when lot size N increases.*

Dependence of the percentage of savings s on $\overline{p}$:
In the second step we shall study the dependence savings of the inspection cost (using the LTPD plan for inspection by variables instead of the corresponding LTPD plan for inspection by attributes) on the process average fraction defective $\overline{p}$. Let p_t, N, c_m be given parameters. For these given parameters the function s in (10) is a function of one variable $\overline{p}$. This function has mostly decreasing trend in $\overline{p}$ (it is confirmed by numerical investigations – see also Table 1 and Figure 2). Therefore, using the LTPD plan for inspection by variables instead of the corresponding plan for inspection by attributes, *the savings of the inspection cost mostly increases when the process average fraction defective* $\overline{p}$ *decreases.*

Figure 2 Dependence of savings s (in %) on $\overline{p}$ for $p_t = 0.01$, $N = 4\,000$, $c_m = 1.4$



Source: Own construction

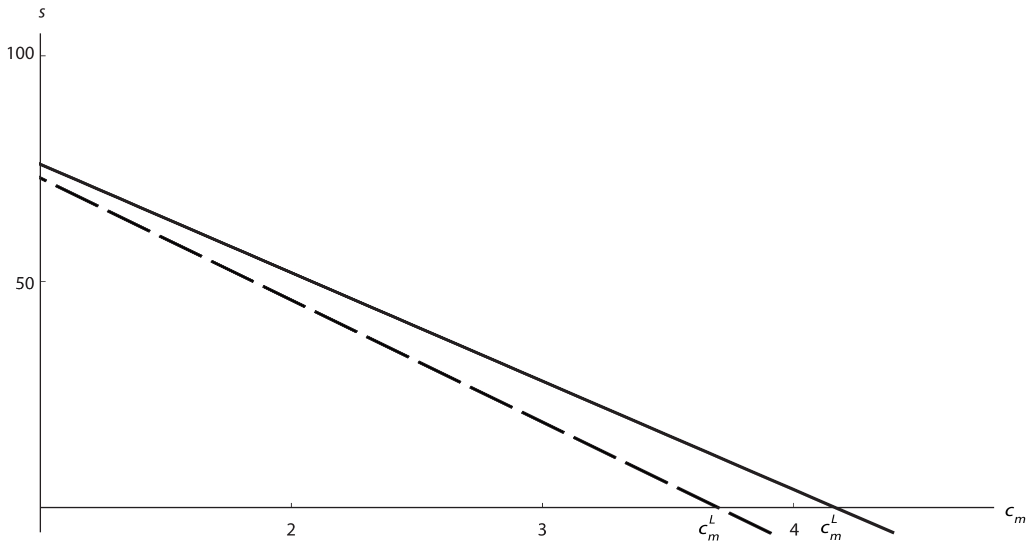
Dependence of the percentage of savings s on the relative cost parameter c_m:
Now, we shall study dependence of the percentage savings of the inspection cost (using the LTPD plan for inspection by variables instead of the corresponding LTPD plan for inspection by attributes) on c_m. Naturally, we can expect that when the ratio of the cost of inspection of one item by variables to the cost of inspection of the same item by attributes c_m increases, then savings of the inspection cost s decreases.

Let p_t, N, $\overline{p}$ be given parameters. Function (10) for given p_t, N, $\overline{p}$ is a function of one variable c_m. Since E in (6) for given p_t, N, $\overline{p}$ is a constant function of c_m (E does not depend on c_m) the function:

$$s = 100 - E \cdot c_m \tag{11}$$

is a linear function of c_m. Due to $E > 0$ this function is decreasing (see Figure 3, the parameter E is the slope of the line). It means that *when c_m increases, then savings of the inspection cost s linearly decreases.*

Figure 3 Dependence of savings s (in %) on c_m for N = 4 000, $\overline{p}$ = 0.002 and p_t = 0.01 (dashed line), p_t = 0.02 (full line)



Source: Own construction

For some value of c_m (denoted c_m^L) is the saving of the inspection cost $s = 0$ (see Figure 3), i.e. mean inspection cost per lot of process average quality for inspection by variables is equal to mean inspection cost per lot of process average quality for inspection by attributes. From the equation $s = 0$ (see (11)) we have:

$$c_m^L = \frac{100}{E} = \frac{I_s}{I_m}. \tag{12}$$

The parameter c_m^L defined by Formula (12) can be used for deciding if inspection by variables is considered in place of inspection by attributes. If:

$$c_m < c_m^L, \tag{13}$$

then $s > 0$ (see Figure 3), i.e. the LTPD plans for inspection by variables are more economical than the corresponding Dodge-Romig LTPD attribute sampling plans. On the other hand, if:

$$c_m > c_m^L, \tag{14}$$

then s < 0 (see Figure 3), i.e. inspection by attributes is better than inspection by variables.

Example 2. We have chosen for acceptance sampling the lot tolerance fraction defective p_t = 0.01 (i.e. the LTPD is 1%). Let the lot size N = 4 000 and the process average fraction defective $\overline{p}$ = 0.002. We shall find the values of the relative cost parameter c_m for which the LTPD plan for inspection by variables is more economical than the corresponding Dodge-Romig LTPD attribute sampling plan.

We shall determine deciding point c_m^L (a limit value of parameter c_m) according to (12). For given parameters p_t, N, $\overline{p}$ we have E = 27 (see Example 1). Therefore, the deciding point c_m^L = 3.7. The LTPD plan for inspection by variables is more economical than the corresponding Dodge-Romig LTPD attribute sampling plan when the ratio of cost of inspection of one item by variables to cost of inspection of this item by attributes:

$c_m < 3.7.$

In this situation we can recommend inspection by variables (usually is $c_m^* < 3.7 c_s^*$, where c_s^* is the cost of inspection of one item by attributes, c_m^* is the cost of inspection of the same item by variables).

The relative cost parameter c_m is not known in practice. Therefore, for deciding if the LTPD plan for inspection by variables is more economical than the corresponding Dodge-Romig LTPD plan for inspection by attributes we shall calculate the parameter c_m^L. According to c_m^L you can get an idea of whether the inspection by variables is better than the inspection by attributes (see Example 2). If c_m^L is high, then inspection by variables is usually better than inspection by attributes and using the LTPD plan by variables can bring significant savings of the inspection cost. In this situation, it makes sense to determine the relative cost parameter c_m and to find s.

The parameter c_m^L in Formula (12) is a function of three parameters p_t, N, $\overline{p}$, i.e. $c_m^L = c_m^L(p_t, N, \overline{p})$ Values of this function for some parameters $p_t, N, \overline{p}$ are in Table 2 and Table 3.

Table 2 Values of parameter c_m^L for $p_t = 0.01$

$\overline{p}$\N	100	500	1 000	4 000	10 000	50 000	100 000
0.00025	2.9	3.8	4.3	5.9	7.1	6.3	7.1
0.00050	2.4	3.2	3.8	4.8	5.3	5.6	5.6
0.00075	2.2	2.9	3.6	4.5	4.8	6.3	5.3
0.00100	2.0	2.6	3.4	4.5	4.5	7.7	6.3
0.00125	1.9	2.4	3.2	4.0	4.3	4.8	5.0
0.00150	1.8	2.3	3.1	3.8	4.2	4.5	4.5
0.00175	1.7	2.2	3.0	3.7	4.2	4.5	4.5
0.00200	1.6	2.0	2.9	3.7	4.3	4.8	4.8
0.00225	1.5	2.0	2.5	3.4	3.8	4.2	4.3
0.00250	1.5	1.9	2.4	3.4	3.7	4.2	4.3
0.00275	1.4	1.8	2.3	3.3	3.7	4.3	4.5
0.00300	1.4	1.7	2.2	3.3	3.7	4.5	5.0
0.00325	1.4	1.6	2.1	3.0	3.4	3.8	4.0
0.00350	1.3	1.6	2.0	2.9	3.4	3.8	3.8
0.00375	1.3	1.5	1.9	2.8	3.3	3.8	4.0
0.00400	1.3	1.4	1.8	2.7	3.4	4.0	4.2
0.00425	1.3	1.4	1.7	2.6	3.1	3.6	4.0
0.00450	1.2	1.3	1.7	2.6	3.0	3.6	4.2
0.00475	1.2	1.3	1.6	2.4	3.0	3.6	4.3
0.00500	1.2	1.3	1.5	2.4	3.0	3.8	4.8

Source: Own construction

Now, we shall study for given lot tolerance fraction defective p_t the dependence c_m^L on input parameters of acceptance sampling.

Dependence of the limit value c_m^L on the lot size N:
Let p_t and $\overline{p}$ be given parameters. For given parameters p_t and $\overline{p}$ the function c_m^L in (12) is a function of one variable N, which has increasing trend in N (it is confirmed by numerical investigations – see also Table 2 and Table 3). Therefore, *when lot size N increases, then the limit value* c_m^L *increases* (using the LTPD plan for inspection by variables instead of the corresponding plan for inspection by attributes can be efficient).

Table 3 Values of parameter c_m^L for $p_t = 0.02$

$\overline{p}$\N	100	500	1 000	4 000	10 000	50 000	100 000
0.0005	2.5	3.1	3.7	4.0	4.5	5.0	4.8
0.0010	2.1	2.8	3.7	3.7	3.7	3.8	3.8
0.0015	1.9	2.6	3.7	3.8	3.6	3.7	4.3
0.0020	1.7	2.6	3.7	4.2	3.8	4.3	5.9
0.0025	1.6	2.4	2.7	3.1	3.3	3.4	3.7
0.0030	1.5	2.4	2.6	3.0	3.1	3.2	3.3
0.0035	1.4	2.3	2.6	2.9	3.1	3.2	3.3
0.0040	1.4	2.2	2.5	2.9	3.2	3.4	3.6
0.0045	1.3	1.9	2.2	2.8	2.9	3.1	3.1
0.0050	1.3	1.8	2.2	2.6	2.9	3.1	3.1
0.0055	1.2	1.7	2.1	2.6	2.9	3.2	3.4
0.0060	1.2	1.7	2.0	2.6	3.0	3.6	4.0
0.0065	1.2	1.6	2.0	2.5	2.7	2.9	2.9
0.0070	1.2	1.5	1.9	2.4	2.6	2.9	2.9
0.0075	1.1	1.5	1.8	2.4	2.6	2.9	3.0
0.0080	1.1	1.4	1.8	2.4	2.7	3.1	3.3
0.0085	1.1	1.4	1.7	2.3	2.5	2.8	2.8
0.0090	1.1	1.4	1.6	2.2	2.4	2.7	2.8
0.0095	1.1	1.3	1.6	2.2	2.4	2.8	2.9
0.0100	1.1	1.3	1.5	2.2	2.4	2.9	3.2

Source: Own construction

Dependence c_m^L on the process average fraction defective $\overline{p}$:
Let p_t and N be given parameters. For given parameters p_t and N the function c_m^L in (12) is a function of one variable $\overline{p}$, which has mostly a decreasing trend in $\overline{p}$ (it is confirmed by numerical investigations – see also Table 2 and Table 3). Therefore, *when the process average fraction defective $\overline{p}$ increases, then the limit value c_m^L decreases.*

CONCLUSION

Using the LTPD plans for inspection by variables instead of the corresponding Dodge-Romig LTPD attribute sampling plans we can achieve significant savings of the inspection cost (under the same protection of consumer). For chosen value of the lot tolerance percent defective LTPD the savings of the inspection cost depends on input acceptance sampling parameters N (the lot size), $\overline{p}$ (the process average fraction defective) and the relative cost parameter c_m (the ratio of the cost of inspection of one item by variables to the cost of inspection of the same item by attributes). The results of present paper suggest that the savings of the inspection cost increases when lot size N increases and the process average fraction defective $\overline{p}$ decreases. Naturally, the saving of the inspection cost is greater when c_m is close to one (usually is $c_m > 1$, for $c_m \leq 1$ the LTPD plans for inspection by variables are evidently most economical).

The limit value of parameter c_m (denoted c_m^L) was suggested in this paper as a criterion for deciding if inspection by variables is considered instead of inspection by attributes. When $c_m < c_m^L$ then the LTPD plans for inspection by variables are more economical than the corresponding Dodge-Romig LTPD attribute sampling plans, i.e. inspection by variables is efficient especially for high values of c_m^L. Values of parameter c_m^L depend (for chosen value of the LTPD) on the lot size and the process average fraction defective. Similarly, the limit value c_m^L increases when the lot size N is increasing and when the process average fraction defective $\overline{p}$ decreases.

Further savings of the inspection cost can be achieved by using the LTPD plans for inspection by variables and attributes (all items from the sample are inspected by variables, remainder of rejected lot is inspected only by attributes) – see Klůfa (2015b). However, the application of these LTPD plans for inspection by variables and attributes is a little more complicated. For determination of the LTPD plan for inspection by variables and attributes we first need to estimate the relative cost parameter c_m.

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