QUALITY PAPER

A multiphase acceptance sampling model by attributes to investigate the production interruptions in batch production within tobacco industry

Received 26 March 2021
Revised 14 July 2021
Accepted 21 July 2021

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Abstract

Purpose – This paper aims to create a new decision-making procedure that uses "Lot-by-Lot Acceptance Sampling Plan by Attributes" methodology in the production processes when any production interruption is observed in tobacco industry, which is a significant example of batch production.

Design/methodology/approach – Based on the fish bone diagram, the reasons of the production interruptions are categorized, then Lot-by-Lot Acceptance Sampling Plan by Attributes is studied to overcome the reasons of the production interruptions. Furthermore, managerial aspects of decision making are not ignored and hence, acceptance sampling models are determined by an Analytical Hierarchy Process (AHP) among the alternative acceptance sampling models.

Findings – A three-phased acceptance sampling model is generated for determination of the reasons of production interruptions. Hence, the necessary actions are provided according to the results of the proposed acceptance sampling model. Initially, 729 alternative acceptance sampling models are found and 38 of them are chosen by relaxation. Then, five acceptance sampling models are determined by AHP.

Practical implications – The current experience dependent decision mechanism is suggested to be replaced by the proposed acceptance sampling model which is based on both statistical and managerial decision-making procedure.

Originality/value – Acceptance sampling plans are considered as a decision-making procedure for various cases in production processes. However, to the best of our knowledge Lot-by-Lot Acceptance Sampling Plan by Attributes has not been considered as a decision-making procedure for batch production when any production interruption is investigated.

Keywords Statistical quality control, Total quality management, Lot-by-lot acceptance sampling by attributes, Batch production, Analytical hierarchy process

Paper type Research paper

1. Introduction

In quality management, the lot sentencing is regarded as the decision either to accept or reject the lot. There are three ways for the lot sentencing. The first way is to accept the lot with no inspection, the other way is 100% inspection and the last one is acceptance sampling (Montgomery, 2007). Defective units may be composed of reworkable, scrap and imperfect quality items. No inspection is beneficial when economic justification of the detection of

International Journal of Quality & Reliability Management

0265-671X
DOI 10.1108/IJQRM-03-2021-0078

defective units is not needed or for the suppliers whose processes are almost never outcomes defective units. 100% inspection is most likely beneficial to use when the defective items are surely needed to be found since the launching of them may be extremely high costly in the further steps. Hence, there are different situations in which acceptance sampling is required to be used. These situations are: (1) when the test is destructive for the items, therefore all the units will be demolished due to the testing, (2) when 100% inspection costs at a higher level in comparison with the cost of passing a defective unit, (3) when very similar units will be inspected, (4) when any information about producer's quality does not exist and (5) when the automated inspection is not possible to be implemented (Besterfield, 2008).

Acceptance sampling systems can be generated for various cases such as attributes, continuous production processes and variables. "*Lot-by-lot Acceptance Sampling for Attributes*" has been performed in this study. It fundamentally produces an Acceptance Sampling Plan (ASP) indicating the lot size, the sample size and the acceptance criteria. Another important point for the sampling plan (SP) design is that some quality levels must be known previously. Hence, if the producer's risk (α) and the related acceptance quality level (AQL) are predetermined, then "*Sampling Plans for Stipulated Producer's Risk*" should be generated. Similarly, if the consumer's risk (β) and the related limiting quality (*LQ*) are predetermined, then "*Sampling Plans for Stipulated Consumer's Risk*" should be generated. It is also possible to evaluate both risks at the same plan. Furthermore, the type of SPs can be put into four categories: *single, double, multiple* and *sequential*.

The rest of the paper is organized as follows. Initially, the literature review by depicting the gap in the literature and the contribution of this study are presented Section 2. Then, the problem definition is given in Section 3, and the methodology used is explained in Section 4. Then, an acceptance sampling model is proposed in Section 5. Section 6 consists of the application. While the managerial applications are expressed in Section 7, conclusion and future research directions are expressed in Section 8.

2. Literature review

As seen in the brief introduction, ASPs are practical tools for the quality assurance applications. Several types of ASPs have been studied in the literature. An extensive literature review on the application of acceptance sampling in different fields is represented below.

As a very early study regarding the ASP applications in production systems, the study of Moskowitz *et al.* (1986) generated an economic (Bayesian) model for multi stage-multi attribute serial production ASPs. Their model integrates the multiple-type defects as well as the prior information on the quality of items produced in each stage of a production process. A study on estimation of single-sampling attribute plan for general dependent production processes has performed by Nelson (1993). Then, the minimum sample size to obtain the specified average life, when the life test is truncated, is calculated by assuming that the lifetime variate of test items pursues the log-logistic distribution by Kantam *et al.* (2001). Next, GonzÁLez and Palomo (2003) provided a Bayesian ASP depending on the number of defects per unit of products and it is applied on the paper pulp industry. Next, a single ASP by attributes for post-production quality control of chemotherapeutic batches in a hospital pharmacy is applied and this application is reduced almost 8,000 analyses with respect to the number of batches analyses for six drugs (Borget *et al.*, 2006). A feasible inspection policy is generated for the cases where classical SPs cannot be applied for the products with very low defectives and the policy depends on the exact sampling distribution instead of approximation (Pearn and Wu, 2007). Then, maxima nomination sampling is evolved for the design and the measurement process of the single SP for attributes (Jozani and Mirkamali, 2010). An economic production quantity model, where imperfect quality and inspection assumed in batch manufacturing, is developed, hence the EPQ model finds the optimal lot size for the batches (Al-Salamah, 2016). Using the exponentially weighted moving average (EWMA) statistic as a process capability index, an ASP for the multiple independent manufacturing lines' products is developed (Arif *et al.*, 2017). Next, a time truncated ASP was developed for truncated life tests following a Sushila distribution (Al-Omari *et al.*, 2018). An ASP is developed by EWMA statistic following bivariate normal distribution (Aslam *et al.*, 2018). A Bayesian accelerated ASP is proposed for a lognormal lifetime distribution under Type-I censoring, using the prior information for the elimination of the total testing cost (Li *et al.*, 2018). For the Weibull distribution, based on Type-II censored data with binomial removals, Bayesian reliability SPs have been generated by the derivation of the decision theoretic approach with a total cost function (Salem *et al.*, 2018). Two variable SPs are generated for the purpose of product acceptance determination for multiple manufacturing lines where the sample size, the acceptance value for different producer's risks and consumer's risks and different number of manufacturing lines are procured (Wang and Chu, 2018). Furthermore, a variable SP based on the lifetime-performance index of an exponential population with Type II right-censored data or complete data have been generated (Wu *et al.*, 2018). Finally, a new multiple group dependent state SP that is depending on the process capability indices for one-sided specification is used to develop a variable SP (Yen *et al.*, 2018).

Various studies regarding the ASP applications are presented in the literature in 2019. Al-Omari *et al.* (2019) constructed a new ASP based on Rama distribution of the truncated mean lifetime test. A different method called neutrosophic statistical interval method is implemented when the data may imprecise and even intermediate in order to generate attribute and variable SPs by Aslam (2019a, b), respectively. Moreover, the same method is also carried out in the industry for the lot senescing when observations and parameters are uncertain, indeterminate or unclear by Aslam (2019c). Following, the neutrosophic statistical interval method is carried out while generating ASPs for the two-stage process for multiple lines by Aslam *et al.* (2019). Additionally, different SPs are generated regarding fuzzy and group SPs when it follows various distributions such as exponential log-logistic distribution and Birnbaum–Saunders distribution (Khan *et al.*, 2019; Rao *et al.*, 2019; Sivakumar *et al.*, 2019). Besides, Sommer and Steland (2019) developed a multistage acceptance sampling under nonparametric dependent sampling designs to specify both the stage-wise and overall error probabilities and before inspections start.

Another bunch of studies are performed in 2020. Butt *et al.* (2020) constructed a variable double ASP to increase its efficiency and decrease the expected cost of inspection and to analyze the process yield index. Then, Guha and Bose (2020) provided a review/modification study on the study of Al-Salamah (2016). Guha and Bose (2020) presented two modifications: one for inventory computations and the other for non-destructive testing. The similar argument of truncated mean lifetime test are studied for exponential, Pareto and Weibull distributions in the studies of Ramyamol and Kumar (2020) and Wang *et al.* (2020), respectively. Yen *et al.* (2020) provided a repetitive rectifying SP and process capability index to minimize the total quality cost of sentencing one lot, including inspection cost, internal failure cost and external failure cost.

Recently, the similar argument of truncated mean lifetime test are studied for Birnbaum–Saunders and Weibull distributions by Aslam *et al.* (2021) and for inverse log-logistic distribution by Tripathi *et al.* (2021). Besides, Chen and Chou (2021) developed a variable SP to measure the process characteristics in a continuous scale while consumer's quality is protected. All the articles are summarized regarding the methodology applied and the objective of using ASPs in Table 1.

Author(s)/date	Methodology	Objective of using ASPs
Moskowitz *et al.* (1986)	An economic (Bayesian) multi stage-multi attribute acceptance sampling model	To obtain an efficient inspection plan in serial production systems
Nelson (1993)	Estimation of AS plans	To develop a single SP for dependent production processes
Kantam *et al.* (2001)	A lifetime test following log-logistic distribution	To find the minimum sample size for AS
Gonzalez and Palomo (2003)	Quadratic and the step-loss functions	To derive a Bayesian ASP and apply on the paper pulp industry
Borget *et al.* (2006)	Logistic regression model	To apply single ASP by attributes
Pearn and Wu (2007)	Process capability index	To develop an effective SP to deal with product acceptance determination for low fraction of defectives
Jozani and Mirkamali (2010)	Maxima nomination sampling	To design and measure the process for the single SP for attributes
Al-Salamah (2016)	Destructive and non–destructive testing of the sample items	To develop an EPQ model with imperfect quality, single AS and misclassification errors
Arif *et al.* (2017)	EWMA process capability index	For multiple independent manufacturing lines' products
Al-Omari (2018)	A truncated life test	To develop a time truncated AS following Sushila distribution
Aslam *et al.* (2018)	EWMA statistics of regression estimator	To develop an AS model following bivariate normal distribution
Li *et al.* (2018)	Lognormal lifetime distribution under Type-I censoring	To develop a Bayesian accelerated AS plan
Salem *et al.* (2018)	Weibull distribution based on progressively Type-II censored data with binomial removals	To design Bayesian reliability SPs
Wang and Chu (2018)	Resubmitted scheme, EWMA with yield index	For product acceptance determination for multiple manufacturing lines
Wu *et al.* (2018)	Lifetime performance index of an exponential population with type II right-censored data	To develops ASPs for an exponential population with and without censoring using statistical and decision-theoretic methodologies
Yen *et al.* (2018)	Process capability indices for one-sided specification	To develop a new multiple dependent state SPs
Al-Omari *et al.* (2019)	A new ASP based on Rama distribution	To develop a time truncated AS following Rama distribution
Aslam (2019a)	A new attribute SP using neutrosophic statistical interval method	To improve the quality lot of the product when the data may imprecise and even intermediate
Aslam (2019b)	A variable ASP using neutrosophic statistical interval method	To improve the quality lot of the product when the data may imprecise/even intermediate
Aslam (2019c)	Neutrosophic statistical interval method	For product acceptance determination measurement
Aslam *et al.* (2019)	Neutrosophic statistical interval method	For the two-stage process for multiple lines
Khan *et al.* (2019)	Fuzzy SP	To calculate the proportion of defective items when fuzzy data follows a Birnbaum-Saunders distribution
Rao *et al.* (2019)	Two-stage group ASP	To develop a lifetime of the test units when it follows odds exponential log-logistic distribution

Table 1.
Literature review on ASPs

(*continued*)

Author(s)/date	Methodology	Objective of using ASPs
Sivakumar *et al.* (2019)	A group ASP	To develop a lifetime of the test units when the lifetime of the items follows odd generalized exponential log-logistic distribution
Sommer and Steland (2019)	Multistage ASP under nonparametric dependent sampling designs	To specify both the stage-wise and overall error probabilities
Butt *et al.* (2020)	Variable double ASP	To increase efficiency, decrease the expected cost of inspection and analyze the process yield index
Guha and Bose (2020)	Destructive and non–destructive testing of the sample items	To modify the results of the study of (Al-Salamah, 2016)
Ramyamol and Kumar (2020)	Optimal reliability ASP	For exponential distribution based on data obtained from the progressive type-II censoring
Wang *et al.* (2020)	A variables-type multiple-dependent-state SP	For Weibull distribution based on data obtained from the progressive type-II censoring
Yen *et al.* (2020)	A repetitive rectifying SP and process capability index	To minimize the total quality cost of sentencing one lot, including inspection cost, internal failure cost, and external failure cost
Aslam *et al.* (2021)	Multiple dependent state SP	To develop a truncated mean lifetime of the test based on generalized Birnbaum–Saunders and Weibull distributions
Chen and Chou (2021)	A variable SP	To measure the process characteristics in a continuous scale while consumer's quality is protected
Tripathi *et al.* (2021)	Double and group ASPs	To develop a truncated mean lifetime of the test based on generalized inverse log-logistic distribution

Table 1.

As seen from Table 1, the studies related with the production systems are the studies of Moskowitz *et al.* (1986), Aslam (2019c) and Aslam *et al.* (2019). They developed ASPs to inspect lots in various serial production lines. Apart from the studies mentioned in Table 1, Filz *et al.* (2020) constructed a simulation-based assessment of quality inspection strategies on manufacturing systems to analyze the disturbances leading to longer production cycles, or additional quality inspections, etc. They conclude that the configuration of quality inspections can have a significant impact on the performance of the overall manufacturing system. Nevertheless, Hamrol *et al.* (2020) developed quality inspection plans together with a mathematical model to calculate the quality cost on multistage manufacturing processes where their model allows an extensive analysis to be carried out within the manufacturing processes and provides a support for managers to optimize the conditions for progress in the production and in the inspection itself. Finally, Rivera-Gómez *et al.* (2020) has integrated the production, quality SP and preventive maintenance planning problems simultaneously by concluding that the optimal control parameters for the inventory level and the quality sampling fraction are dynamic. Thus, the findings of these three studies lead us to research on the generating ASPs in batch production environment.

To summarize the gap in the literature, "Acceptance Sampling Plans" has not been considered as a decision-making procedure for batch production when any production interruption is required to be investigated, to the best of our knowledge. Hence, this paper aims to create a new statistical based decision-making procedure that uses "Lot-by-Lot Acceptance Sampling Plan by Attributes" methodology in the production processes when any production interruption is observed in tobacco industry, which is a significant example of batch production.

3. Problem definition

The aim of the paper is to investigate the reasons of production interruptions and to take both preliminary and corrective actions to minimize losses caused by production interruptions in tobacco industry with the aid of statistical decision making. Hence, the research objective of the study is to generate a statistical-based decision procedure to investigate the reasons of production interruptions. The specific case studied in this paper presents the need of a statistical-based investigation procedure in production processes when production interruptions occur because this problem is a common phenomenon in tobacco industry. Thus, the problem definition is expressed within the framework of tobacco industry. Both the tobacco leaf and non-tobacco materials (NTM) are used in production processes. Cigarette papers, filter papers, filter adhesives, monogram inks, filtration materials, aluminum and stretch films are some examples of NTMs purchased from external suppliers. Within incoming material inspection process, an inspection has been performed on NTMs, but some defective NTMs might not be detected at this stage. Hence, these might be launched to the production process to be used in further processes. The defective NTMs, which could not be detected in the incoming materials inspection process, can lead to production interruptions. Moreover, the maintenance requirements of fully automated machines or the high machine speed might be the reasons of production interruptions. Hence, the main reason of the production interruptions cannot be determined by engineers without a statistical investigation procedure. Hence, three possible reasons of production interruptions can be summarized as follows:

(1) Defective NTMs.

(2) Maintenance requirements of fully automated machines.

(3) High machine speed.

Then, according to the reason of production interruption, some decisions are required to be taken. However, there is not any statistical-based decision-making procedure at this stage, in the tobacco industry. Mostly, the decision is taken after an interruption is observed, based on the experiences of engineers about the batch that is in the process. Three possible decisions, which engineers may take, are summarized below:

(1) Production can continue with the same batch.

(2) The batch can be reused in a slower machine.

(3) Maintenance requirements of machines can be checked.

(4) The batch can be changed, and production can be continued with another batch of that material. Then, the defective batches are returned to supplier or demolished.

The decisions given by the engineers are solely based on their experiences and the following cases can be seen. If the supplier of the NTM batch is often problematic, the decision might be returning the batch to the supplier. If there is a suspicion about the maintenance requirement of the machines, then the maintenance conditions of the machines are checked. Lastly, if it is believed by the engineers that the machine speed is very high for this batch, the decision might be reusing the batch in slower machines. Hence, the experience dependent decision-making procedure needs to be changed. Therefore, the following research questions are asserted:

RQ1. (a) Does the batch fully consist of non-defective materials?
(b) Does the incoming materials inspection process allow some non-defective materials to launch in the process?

RQ2. (a) Is the slower machine going to solve the problem?
(b) Is the high machine speed, the reason of the production interruption?

RQ3. (a) Is it possible to know whether the maintenance is the reason for the production interruption?
(b) Are maintenance conditions of the machines adequate to continue the production?

RQ4. (a) Does the NTM batch fully consist of defective materials?
(b) Is it possible to prevent any unnecessary returns to supplier or demolish of batches?

The procedure that stands solely on experiences causes overall cost of quality increases. This study is conducted to figure out the main reason(s) of the production interruptions and hence, to decide the necessary actions to be taken according to those main reason(s). The main goal of this paper is to replace the approach used in the investigation of the production interruption reasons, which specifically stands on experience-based decision-making mechanism, with a statistical-based decision-making procedure, in tobacco industry. Hence, the use of statistical-based decision procedure to investigate the reasons of production interruptions will lead the factory to take necessary actions in a systematic manner. Therefore, an acceptance sampling model that uses "Lot-by-lot Acceptance Sampling by Attributes" for the non-tobacco materials is proposed.

4. Lot-by-lot acceptance sampling by attributes

Acceptance sampling is conducted by the design of a SP (Montgomery, 2007), where is studied for both the attributes and the variables (Besterfield, 2008). Among the ASPs, one of the most frequently used sampling is "Lot-by-Lot Acceptance Sampling by Attributes". It is utilized in a systematic way within the framework of batch production, in this study. Hence, it will bring a sequential decision flow to be used by managers. It is chosen because it is the most appropriate method yielding a sequential statistical decision flow mechanism for the problem studied.

The set of inspection tables for the lot-by-lot acceptance sampling by attributes was initially developed by Dodge and Romig (1929). Lot-by-lot acceptance sampling considers a prespecified number of units of a sample from each lot. This sample is to be inspected rather than inspecting whole batch/lot. At this point, a predetermined minimum number of defective items (acceptance number) should be considered. A predetermined number of units (sample) from each lot is inspected by attributes and the number of nonconforming units are analyzed. If the number of nonconforming units in the sample is less than the predetermined acceptance number, then the lot will be accepted; otherwise, the lot will not be accepted. The acceptance number of that sample is the limit of being accepted or not. Also, there is always a relationship between producer and consumer. While the producer prefers all the conforming lots are accepted, the consumer prefers all nonconforming lots are not accepted. At this point, some statistical terms such as *Producer Risk* and *Consumer Risk* carries high importance. Producer risk is the probability of nonacceptance of a conforming lot (Type I error) and consumer risk is probability of acceptance of a nonconforming lot (Type II error). All of these are summarized in Table 2.

Two more statistical terms are required to be used in ASPs: *Acceptable Quality Level*, which is related with the α, is the worst tolerable quality level on the lot and *Limiting Quality* (Lot Tolerance Percent Defective), which is related with the β, is the maximum tolerable percent nonconforming in a lot. All the notations are given in Table 3.

Depending on the information given, SPs can be generated in different ways. However, in this study, the factory that is in tobacco industry are the consumers of non-tobacco materials since the nontobacco materials are supplied from their producers. Furthermore, LQ is determined by the factory, namely by the consumer of the NTM's. Because of this, the proposed SP is required to be generated from the factory's point of view by using predetermined β and LQ levels. As a result, "Lot-by-Lot Acceptance Sampling by Attributes" is generated by "*Sampling Plans for Stipulated Consumer's Risks*".

5. Proposed acceptance sampling model

In this section, the proposed acceptance sampling model is presented, and the aim of the model is explained. This model has been created to solve the current problem that is, there is no any statistical-based decision-making process when the production interruptions are analyzed in the facility that the study is conducted. Defective units may arise from both process and product variability, in which the process variability is caused by factors like material, tools, machines, etc. and whereas product variability is related with fulfilling the necessities of the product design. In this study, the basic reasons of the production interruptions and the related actions to be taken are investigated. To achieve, a fish bone diagram (Figure 1) is used for the investigation of the production interruptions' reasons.

Table 2.
Summary of type I and type II errors

Decision matrix		Decision Reject Ho	Fail to reject Ho
Actual	Ho is true	Type I error producer risk (α) False positive	Correct decision confidence interval $= 1-\alpha$
	Ha is true	Correct decision Power $= 1-\beta$	Type II error consumer risk (β) False negative

Ho: Null hypothesis, Ha: Alternative hypothesis

Table 3.
The Notation table for the lot-by-lot acceptance sampling for attributes

Notation	Explanation
N	Lot size
n_x	Sample size on the xth sample
Ac	Acceptance number
Re	Nonacceptance number
α	Producer risk
AQL	Acceptable quality level
β	Consumer risk
LQ	Limiting quality

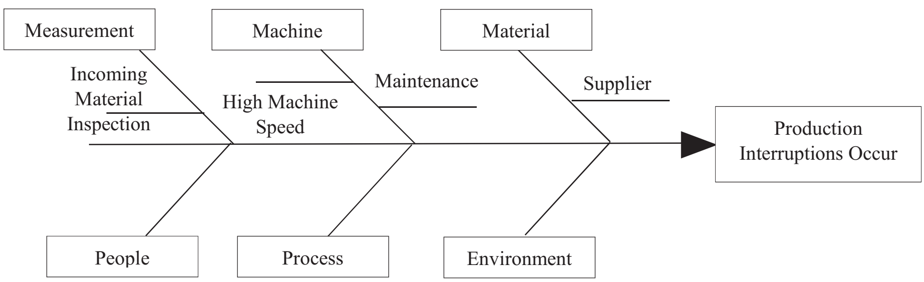

Figure 1.
Fish bone diagram for the problem

This fish bone diagram constructs a base for the phases of the proposed acceptance sampling model. Measurement, machine, material, people, process and environment are the main reasons of the production interruption. People dimension of fish bone will not be considered in the model, since the production process and all machines within production are fully automated. Process and environment dimensions are not investigated due to decision of the management. Hence, only measurement, machine and material dimensions are left with their sub dimensions. Therefore, the actions that can be taken after any production interruption depend on three main dimensions. Thus, the proposed model consists of three phases: 1st Acceptance Sampling Plan, 2nd Acceptance Sampling Plan and 3rd Acceptance Sampling Plan. In each phase of proposed model, managers must apply the relevant ASP and then they must take the relevant action regarding the result of the ASP.

In the proposed acceptance sampling model, "*Lot-by-Lot Acceptance Sampling Plan by Attributes*" methodology is applied in a systematic way yielding a sequential decision flow and based on statistical quality control, to be used by managers. The proposed acceptance sampling model can be found in Figure 2.

First phase, named as 1st ASP, is the most critical phase of the process because it is the initial decision point which will affect the usage of that batch in the same machine. This phase considers the failure of incoming material inspection process. Depending upon the predetermined β level and the LQ level, the sample size and the Ac of the lot will be obtained. Upon the 1st ASP, if defective units are less than the determined Ac, then the lot will be accepted, and it will continue to be used in the production. Since continuing the production with a defective lot carries an extreme risk for product quality and efficiency, deciding to continue the production with that batch becomes a critical decision. Thus, first ASP of the model allows management not to accept the defective lot and hence, prevents the production to continue with that defective lot. If the number of defective units is more than the determined Ac, then the lot will not be accepted. Therefore, the reason of the production interruption is required to be analyzed and then 2nd ASP must be applied.

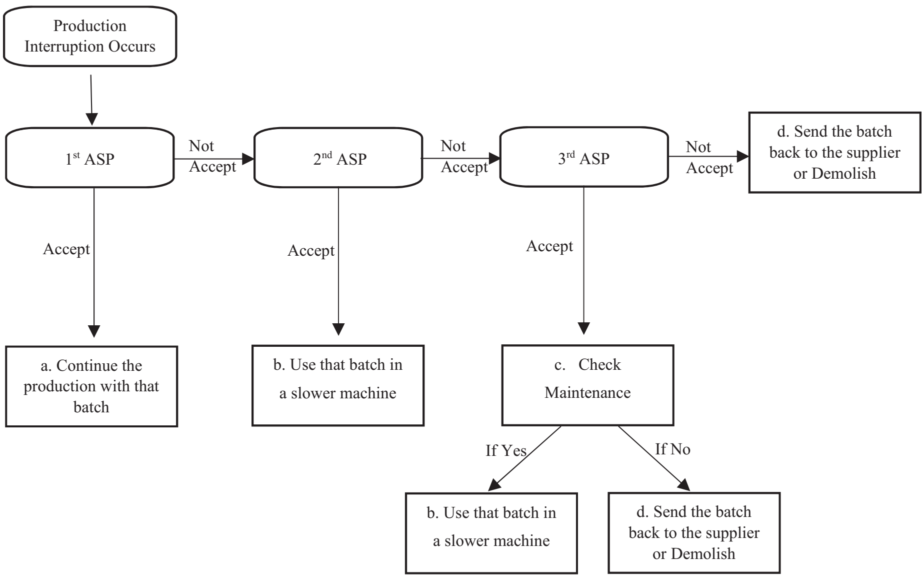

Figure 2.
The proposed acceptance sampling model

In second phase, 2nd ASP will be applied and then the action to be taken is decided regarding the predetermined β level and the LQ level. This phase considers the high machine speed level and deals with it using batches in slower machines. Upon 2nd ASP, if the observed defective units are less than Ac, then the lot is accepted. If the observed number of defective units is greater than or equal to the determined Ac, the lot will not be accepted therefore 3rd ASP has to be applied. Hence, it can be understood that the lot which was not accepted in the 1st ASP, might be accepted in the 2nd ASP phase. The reason of this acceptance might be high machine speed. Accordingly, if the lot is accepted in 2nd ASP, then it can be transferred to a slower machine performing the same duty. As a result, the reason of sending the batch to a slower machine turns to a statistical-based decision. Upon 2nd ASP, if observed defective units are more than the Ac of the plan, then the lot will not be accepted so that 3rd ASP phase must be applied.

3rd ASP is constituted as the last step in the proposed acceptance sampling model. Finally, this phase considers the maintenance requirements and supplier defaults. Based on the decision taken in this phase, the reason of the production interruptions is investigated as to see whether if it is because of the factory-based conditions or the supplier. For this reason, based on the predetermined β level and LQ level, 3rd ASP will decide whether to check maintenance or send the batch back to the supplier. If the defective units are less than the Ac, then the lot can be accepted which reveals that the management must check the maintenance requirements of the machines. The reason of this acceptance is that the lot still satisfies the quality levels. If there is a need for maintenance, the maintenance procedure may need to be revised. Then, the lot can be used again in a slower machine. If there is no need for maintenance, it means that all the alternatives of the factory have been tried. In that case, the batch should be sent back to the supplier. Finally, if the lot is not accepted in 3rd ASP, then the batch should be sent back to the supplier, or it should be demolished.

To conclude, there are four various actions in the proposed acceptance sampling model as follows: (1) continue the production with that batch, (2) use that batch in a slower machine, (3) check maintenance requirements, (4) send the batch back to the supplier or demolish. All these actions are the possible actions when production interruptions occur, therefore proposed acceptance sampling model provides a statistical-based decision-making model for the possible actions.

6. Application

In this section, the application of the proposed model is explained, within the framework of statistical quality control. Firstly, all combinations of ASPs are provided in Section 6.1 and chosen combinations among all are presented in Section 6.2. Next, the statistical results of the chosen ASPs are represented in Section 6.3. Then, the application of Analytical Hierarchy Process (AHP) on the indicators is reported in Section 6.4. Finally, the statistical results of the five acceptance sampling models, which AHP concludes, are represented in Section 6.5.

6.1 All combinations of proposed acceptance sampling model

According to the proposed sampling model in Section 5, all combinations of proposed sampling model are given in detail, in Appendix 1 (Table A1). All appendices can be achieved on the website https://data.mendeley.com/datasets/sdyrcn2tt6/1. For *Type of Sampling*, there are three different alternatives to be considered: *Single, Double* and *Multiple*. For *General Inspection Levels*, three possible alternatives exist: *I*, *II* and *III*. Furthermore, there are 3 phases in the proposed sampling model: 1st *ASP*, 2nd *ASP Plan and* 3rd *ASP*. Ultimately, there exists nine alternatives for each ASP. Hence, there are 729 (9^3) different alternatives for the proposed sampling model. However, since it is very hard to apply all these alternatives on the lots, some of them are chosen and the chosen combinations among all are presents in Section 6.2.

6.2 Chosen combinations among all

For each sampling model, the proposed model should be relaxed toward the end of the model. Namely, there should be at least one relaxation when the process passes from 1st ASP to 2nd ASP or from 2nd ASP to 3rd ASP. Note that, for type of sampling, Multiple is more relax than Double, and Double is more relax than Single; for the general inspection level, I is more relax than II, and II is more relax than III. Therefore, the 38 alternatives are chosen among 729 alternatives by stated idea. The chosen combinations are represented in Table 4.

6.3 The statistical results of 38 acceptance sampling models

According to Table 4, there are 38 alternative acceptance sampling models for the proposed acceptance sampling model. The acceptance sampling results of these models are represented in Appendix 1 (Table A2). In this subsection, as an example only the quality results of 18th acceptance sampling model *(S-III, D-II, M-I)* is explained in detail. All other results of acceptance sampling models follow the same procedure as this plan.

As the application of the proposed acceptance sampling model, 100,000 units of batch have considered for further analysis. The β and LQ is set to 10 and 2% by the management, respectively. According to 18th acceptance sampling model, in 1st ASP, type of the SP is single, and general inspection level is III. In ISO 2859–2, "Sample Size and Code Letters Table" shows that the lot consisting of 100,000 units will take P code letter when the general inspection level is III (ISO 2859–2, 1985). Then, "Sample Size, AQL Values of ISO 2859–1 and LQ Levels Relationship Table" illustrates that the P code letter will have 800 sample sizes and 0.65 AQL at 2.0% LQ level (ISO 2859–2, 1985). Later, in ISO 2859–1, "Single SP for Normal Inspection Table" demonstrates that P code letter will conclude that Ac equals to 10 and Re equals to 11 at 0.65 AQL (ISO 2859–1, 1999). Therefore, it means that 800 units of sample will be analyzed in the 100,000 units of lot. If there are at most 10 defective units in the sample, the

Sampling model	1st ASP, 2nd ASP, 3rd ASP	Sampling model	1st ASP, 2nd ASP, 3rd ASP
1	S-III,S-II,S-I	20	S-II,D-II,M-II
2	S-III,S-II,D-II	21	S-II,D-II,M-I
3	S-III,S-II,D-I	22	S-II,D-I,M-I
4	S-III,S-I,D-I	23	S-I,D-I,M-I
5	S-II,S-I,D-I	24	S-III,M-III,M-II
6	S-III,S-II,M-II	25	S-III,M-III,M-I
7	S-III,S-II,M-I	26	S-III,M-II,M-II
8	S-III,S-I,M-I	27	S-III,M-II,M-I
9	S-II,S-I,M-I	28	S-II,M-II,M-I
10	S-III,D-III,D-II	29	D-III,D-II,D-I
11	S-III,D-III,D-I	30	D-III,D-II,M-II
12	S-III,D-II,D-I	31	D-III,D-II,M-I
13	S-II,D-II,D-I	32	D-III,D-I,M-I
14	S-III,D-III,M-III	33	D-II,D-I,M-I
15	S-III,D-III,M-II	34	D-III,M-III,M-II
16	S-III,D-III,M-I	35	D-III,M-III,M-I
17	S-III,D-II,M-II	36	D-III,M-II,M-I
18	S-III,D-II,M-I	37	D-II,M-II,M-I
19	S-III,D-I,M-I	38	M-III,M-II,M-I

Table 4. Chosen combinations of proposed acceptance sampling model

lot will be accepted, and production will continue with that batch. However, once the 11th defective unit is observed, the lot will not be accepted, and 2nd ASP will start.

According to 18th acceptance sampling model, in 2nd ASP, type of the SP is double, and general inspection level is II. According to the ISO 2859–2, "Sample Size and Code Letters Table" indicates that the lot consisting of 100,000 units will take *N* code letter when the general inspection level is II. Then, N code letter will have 500 sample sizes and 0.40 AQL value at 2.0% LQ level (if the SP is single) according to "Sample Size, AQL Values of ISO 2859–1 and LQ Levels Relationship Table". Also, in ISO 2859–1, "Single SP for Normal Inspection Table" demonstrates that N code letter will reveals that 5 is the Ac and 6 is the Re at 0.40 AQL (if the SP is single). Since the type of SP is double in this phase, the sample size, Acs and Res should be converted into the double SP type. In ISO 2859–1, from "The Equivalent Acs for Single, Double, Multiple Plans Table" the sample size should be multiplied by 0.63(500*0.63 = 315) (ISO 2859–1, 1999). Thus, the sample size in both phases is 315. Moreover, the single SP with 5 Ac and 6 Re will be equal to double SP with 2 Ac and 7 Re in the first sample and 6 Ac (cumulative) and 7 Re (cumulative) in the second sample. Consequently, if there are at most four defective units in the first 315 units of sample, the lot will be accepted, and it will be used in a slower machine. However, if the fifth defective unit is observed in the first sample, then the second sample should be taken. If there are six defective units in the 630 units of sample, then the lot will still be accepted, and it will be used in a slower machine. Once the 7th defective unit is observed in the 630 sample, then the lot will not be accepted, and 3rd ASP will start.

In 3rd ASP, type of the SP is multiple, and general inspection level is I. In ISO 2859–2, "Sample Size and Code Letters Table" shows that the code letter of a lot consisting of 100,000 units will be L when the general inspection level is I. Next, from "Sample Size, AQL Values of ISO 2859–1 and LQ Levels Relationship Table", code letter L's sample size is 200 and code letter L's AQL is 0.25 at 2.0% LQ level (when it is single sample). Furthermore, in ISO 2859–1, "Single SP for Normal Inspection Table" demonstrates that code letter L's Ac is 1 and Re is 2 at 0.25 AQL (when the SP is single). However, type of SP of this phase is multiple. All needed terms should be converted into the multiple SP type. In ISO 2859–1, from "The Equivalent Acs for Single, Double, Multiple Plans Table" the sample size should be multiplied by 0.40(200*0.40 = 50). Thus, the sample size in all sampling phases is 50. Later, again from the same table, the equivalent Acs and Res for all phases are found as follows: *(acceptance of the lot is not allowed even with 0 defectives)-2 in the first sample; *(acceptance of the lot is not allowed even with 0 defectives)-2 in the second sample; 0–2 in the third sample; 0–3 in the fourth sample; 1–3 in the fifth sample; 1–3 in the sixth sample; 2–3 in the seventh sample. Namely, there is no Ac in the first and second sampling. However, if there is 0 or 1 defective unit in the first sample, then the second sample should be taken. Also, if 2 defective units are observed in the first 50 units of sample, then the lot will not be accepted. In the second sampling, since there is no Ac, if there is still 0 or 1 defective unit (in 100 units of sample), then the third sample should be taken. However, if there are two defective units (in 100 units of sample), then the lot will not be accepted, and it will be sent back to the supplier or demolished. Next, if there is 0 defective unit (in 150 units of sample), then the lot will be accepted, and the maintenance conditions will be checked. If there is one defective unit (in 150 units of sample), the fourth sample must be taken. But, if two defective units are observed (in 150 units of sample), the lot will not be accepted, and it will be sent back to the supplier or it will be demolished. This procedure will follow until the end of the last sampling. All the detailed quality results of 18th acceptance sampling model can be seen in Table 5.

6.4 AHP and its application

Since chosen 38 sampling models are still quite large, a further analysis is required to eliminate some of the alternatives. Some indicators are investigated to decide which sampling

Sampling Model	Phases	*N*	Beta	LQ	Code Letter	*n1*	*n2*	*n3*	*n4*	*n5*	*n6*	*n7*	AQL	Ac1-Re1	Ac2-Re2	Ac3-Re3	Ac4-Re4	Ac5-Re5	Ac6-Re6	Ac7-Re7
18	**S-III**	100.000	10%	2%	P	800							0.65	10-11						
	D-II	100.000	10%	2%	N	315	315						0.4	2-5	6-7					
	M-III	100.000	10%	2%	L	50	50	50	50	50	50	50	0.25	*–2	*–2	0–2	0–3	1–3	1–3	2–3

Table 5.
Quality results of the 18th acceptance sampling model

model is the best, or which sampling models are better than the others. The investigated indicators for the sampling models are as follows:

(1) Sum of Number of Samples

(2) Maximum Number of Sampling

(3) Maximum Average Sample Size

(4) AQL Difference Between 3rd and 1st phase

(5) Re in the Last Phase Divided by Total Sample Size of the Last Phase

Firstly, the sum of number of samples is an important indicator because the higher the sample size, the higher the sampling time. Secondly, the maximum number of sampling is another important indicator since the number of sampling determines the number of sampling analysis conducted on batches which will eventually affect the time spent on sampling analysis. Next, maximum average sample size is a hybrid indicator since it is calculated by dividing sum of number of samples by maximum number of sampling. This indictor enables to analyze the effects of the simultaneous changes. Then, AQL difference between third and first phase is significant because it contributes to the persistence of the acceptance quality level during the sampling phases. Finally, the Re in the last phase is divided by total sample size of the last phase is significant. Because in the last phase (3rd ASP), it is going to be decided whether to send the batches to their suppliers or not. The indicators for each 38 acceptance sampling models are calculated and all the results are given in Appendix 2 (Table A3).

The AHP is applied on indicators and then their weights are calculated to decide which sampling models are better than the others. AHP is a tool that ranks the decision alternatives and assign weights to each decision alternative or select the one which has the highest weight as the best (Saaty, 1988, 1990). In this study, AHP is used to assign weights to each indicator where the indicators are the decision alternatives. In this study *(1) cost, (2) quality and (3) time* are used as criteria for the determined five indicators. Four experts, who has more than 5 years of experience, work in the production department and has high level of information on the non-tobacco materials, are chosen to evaluate these indicators. They give preferences for each indicator under cost, quality and time criteria. For example, the preference relationship table for Expert 1 under the cost criterion is given in Table 6. According to this table, expert 1 gives three times more importance to *Maximum Average Sample Size* indicator than the *Sum of Number of Samples*. This means that *Maximum Average Sample Size* indicator has been preferred three times more than the *Sum of Number of Samples* indicator by expert 1.

Existence of four experts and three criteria leads to 12 different preference tables. Each expert's preferences about the five indicators under three criteria have been analyzed and represented in Appendix 2 (Table A4). Consistency rate calculations are done for all

Table 6.
Expert 1 – preference table based on cost criterion

Criterion – (i) Cost

	Indicators	1	2	3	4	5
Expert1	1	1	1	3	1	7
	2	1	1	3	1	5
	3	1/3	1/3	1	1/3	3
	4	1	1	3	1	5
	5	1/7	1/5	1/3	1/5	1
	Sum	**3,476**	**3,533**	**10,364**	**3,530**	**21,000**

preference tables and all succeeded the consistency check because all the consistency rates are less than 0.10.

Since, there are four experts in this study, the geometric averages of the preferences are calculated under each criterion and the results are obtained as can be seen in Table 7.

Then, the geometric averages in each cell are proportioned by the sum of columns, then the sum of rows are calculated for each indicator under three criteria. Hence, these calculations give the final preference table and it can be seen in Table 8.

The same analysis is applied on the criteria and one example is given in Table 9. According to this table, one can understand that *time* criterion is three times more important than ***cost*** criterion. Similar with the indicator's analysis, four experts rank all criteria, and the overall table is attached in Appendix 2 (Table A5).

Then, the geometric averages are proportioned by the sum of columns, then the sum of rows are calculated for each criterion. Therefore, the results give the final importance score table and it can be seen in Table 10.

The values in Tables 8 and 10 are now ready to be combined to find the weights for each indicator and the results are given in Table 11.

Finally, these weights will be used to find which SPs are better than the others within the 38 acceptance sampling models.

6.5 The last statistical results of five acceptance sampling models

The indicators of each acceptance sampling model were calculated in Appendix 2 (Table A3). All indicators' values are normalized with their lower and upper bounds, and thus a normalized score is assigned to each indicator of all acceptance sampling models. Then, these normalized scores are multiplied with the weights which are obtained by AHP. Finally, all these multiplications for each acceptance sampling models are summed and a finalized weighted sum of all the scores is obtained for 38 ASPs (See Appendix 3 (Tables A6 and A7)). According to the finalized weighted sum of all the scores, acceptance sampling model *5* has the highest weighted score with 4,385 and acceptance sampling models *23*, *9*, *22*, *13* follow with the scores of 4,267, 4,126, 4,126, and 4,013 respectively. Consequently, we conclude with five acceptance sampling models by considering the ideas of all experts and management. The ASPs of five models are represented in Table 12.

7. Managerial implications

Important managerial implications for the factory are suggested related to the proposed acceptance sampling model. The proposed acceptance sampling model is applicable in tobacco industry when production interruptions are observed to analyze the reason of the production interruptions. The managerial implications can be summarized according to the decisions as the output of the phases.

(1) In 1st ASP: either *the production will continue with the same batch* or *there is not enough evidence to accept the lot in the process*. Thus, the research questions 1a and 1b are answered yielding the risk of continuing the production with a fully defective batch will be eliminated.

(2) In 2nd ASP: either *the batch will be used in a slower machine* or *there is not enough evidence to accept the lot to proceed with the slower machines*. Hence, the research questions 2a and 2b are answered yielding the excessive use of slower machines will be reduced.

(3) In 3rd ASP: either *the maintenance requirements of machines are needed to be checked* or *the batch can be changed with another batch of that material, and production may*

Table 7.
Geometric averages of experts for indicators under three criteria

Indicators	Criterion – (1) cost					Criterion – (2) quality					Criterion – (3) Time				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	1	0.76	3.873	1.844	1.884	1	0.439	3.873	0.861	1.432	1	0.508	2.59	4.213	2.141
2	1.316	1	3.708	1.627	1.968	2.28	1	4.213	1.627	1.968	1.968	1	3	3.201	4.401
3	0.258	0.27	1	0.613	1.21	0.258	0.237	1	0.41	0.508	0.386	0.333	1	0.997	1.136
4	0.542	0.615	1,631	1	1.404	1.161	0.615	2.438	1	1.291	0.237	0.312	1.003	1	0.76
5	0.531	0.508	0.827	0.712	1	0.699	0.508	1.968	0.775	1	0.467	0.227	0.88	1.316	1
Sum	3,647	3,152	11,038	5,795	7,466	5,397	2,799	13,492	4,672	6,199	4,059	2,381	8,473	10,728	9,437

continue. Then, the defective batches can be returned to supplier or demolished. In first option, the research questions 3a and 3b are answered yielding the unnecessary maintenance controls will be eliminated. In latter, the research questions 4a and 4b are answered yielding the transportation cost, transportation time and the labor work, which are due to the unnecessary returns to suppliers, will be eliminated.

8. Conclusion and future research directions

In conclusion, a proposed acceptance sampling model within the framework of "Lot-by-lot Acceptance Sampling Plans by Attributes" is constituted to deliver creative solutions to the current experience dependent decision-making process when production inceptions occur in tobacco industry. By the proposed model, the managers will know the reasons of production interruptions and easily make the decision about the batches in the production. In 1st ASP, a

Indicators	Cost	Criteria Quality	Time
1	0.287	0.209	0.277
2	0.312	0.351	0.405
3	0.103	0.075	0.113
4	0.170	0.208	0.096
5	0.129	0.157	0.109
Sum	1,000	1,000	1,000

Table 8. Final preference table of experts for indicators under three criteria

	Criteria	Cost	Quality	Time
Expert1	**Cost**	1	3	1/3
	Quality	1/3	1	1/5
	Time	3	5	1
	Sum	**4,333**	**9,000**	**1,533**

Table 9. Expert 1 – importance scores for criteria

	Criteria	Scores
Geometric averages	Cost	0.350
	Quality	0.172
	Time	0.478
	Sum	1,000

Table 10. Geometric averages – importance scores for criteria

Indicators	Weights
1	0.269
2	0.363
3	0.103
4	0.141
5	0.124
Sum	1,000

Table 11. The weights for each indicator

Table 12.
ASPs of 5 models

Sampling models	Phases	*N*	Beta	LQ	Code letter	*n*1	*n*2	*n*3	*n*4	*n*5	*n*6	*n*7	AQL	Ac1–Re1	Ac2–Re2	Ac3–Re3	Ac4–Re4	Ac5–Re5	Ac6–Re6	Ac7–Re7
5	S-II	100.000	10%	2%	N	500							0.4	5–6						
	S-I	100.000	10%	2%	L	200							0.25	1–2						
	D-I	100.000	10%	2%	L	125	125						0.25	0–1	1–2					
9	S-II	100.000	10%	2%	N	500							0.4	5–6						
	S-I	100.000	10%	2%	L	200							0.25	1–2						
	M-I	100.000	10%	2%	L	50	50	50	50	50	50	50	0.25	*–2	*–2	0–2	0–3	1–3	1–3	2–3
13	S-II	100.000	10%	2%	N	500							0.4	5–6						
	D-II	100.000	10%	2%	N	315	315						0.4	2–5	6–7					
	D-I	100.000	10%	2%	L	125	125						0.25	0–1	1–2					
22	S-II	100.000	10%	2%	N	500							0.4	5–6						
	D-I	100.000	10%	2%	L	125	125						0.25	0–1	1–2					
	M-I	100.000	10%	2%	L	50	50	50	50	50	50	50	0.25	*–2	*–2	0–2	0–3	1–3	1–3	2–3
23	S-I	100.000	10%	2%	L	200							0.25	1–2						
	D-I	100.000	10%	2%	L	125	125						0.25	0–1	1–2					
	M-I	100.000	10%	2%	L	50	50	50	50	50	50	50	0.25	*–2	*–2	0–2	0–3	1–3	1–3	2–3

very critical decision will be given about the lot: either continuing to use the lot in same machine or not. So, this phase prevents the management to accept the defective lot. Then, in 2nd ASP, the reason is decided as the high machine speed therefore the accepted lot will be used in a slower machine. 3rd ASP considers the maintenance requirements and the supplier defaults. Regarding the decision taken in this phase, the reason of the production interruptions is investigated as to see whether if it is because of the factory-based conditions or the supplier. If there is a need for maintenance, then the maintenance procedure may need to be revised so that the lot can be used in a slower machine. If there is no need for maintenance, then the batch should be sent back to the supplier. Hence, there are four various actions in the proposed acceptance sampling model as follows: (1) continue the production with that batch, (2) use that batch in a slower machine, (3) check maintenance requirements, (4) send the batch back to the supplier or demolish.

The contributions of this study are listed as follows.

(1) An acceptance sampling model is proposed within the framework of "Lot-by-lot Acceptance Sampling Plans by Attributes" to deliver creative solutions to the current experience dependent decision-making process when production inceptions occur in tobacco industry.

(2) The proposed model is very useful for the determination of the reasons of the production interruptions and it will assist the decisions taken afterwards, in tobacco industry.

(3) Thus, the proposed acceptance sampling model carries an extreme importance since all the research questions of this study can be answered with the guidance of the proposed acceptance sampling models.

(4) The analyses of the reasons of the production interruptions through statistical quality control in tobacco industry have been conducted by the application of the proposed model in industry.

(5) The decisions taken will be based on a statistical decision-making procedure with the guidance of the proposed acceptance sampling models.

(6) Moreover, an AHP analysis is conducted to choose the ideal acceptance sampling models among all, and five acceptance sampling models are provided.

Limitations of the study can be listed as follows. During the generation of ASPs, the possible reasons of production interruptions are analyzed, and hence the decisions to be taken when the productions interruptions occur are considered. Thus, the proposed ASPs are only constructed within the framework of responding this situation. When another reason for production interruptions is considered or when another decision is taught to be applied in the production process, the proposed plans might be revised. Another limitation of this study is that the ASPs must be generated from the factory's point of view by using predetermined β and the LQ levels. Hence, any lack of knowledge about the predetermined β and the LQ levels might cause delays on the application of the SPs during the production.

For future research directions, different expert opinions can be evaluated so that different acceptance sampling models can be obtained according to the necessities, aims and unique features of each company for AHP analysis. Also, some other techniques such as Multi Criteria Decision Making (MCDM) can be used to determine the weights for each acceptance sampling model. Another direction is that the "*Sampling Plans for Stipulated Producer's Risk*" can be applied as a variant of the studied application when α and its corresponding AQL are preferred. Moreover, "*Lot-by-lot Acceptance Sampling Plans by Variables*" can be performed on batches as another future research direction.

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Appendix

The Appendix is available online for this article.

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