
The effect of the incidence of defect on orange inspection time

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Pasternak, H., Lidror, A. and Engel, Hava. 1989. **The effect of the incidence of defect on orange inspection time.** *Can. Agric. Eng.* 31: 131-134. An industrial experiment was carried out to investigate the influence of inspection time and blemished fruit rate on inspection performance of orange fruit. Forecasting equations specified from an existing theory were developed. The equation parameters were estimated, based on 188 sorting tests, for two different classes of slight and serious fruit defects. It was found that the inspection time required for the 'slight defects' class was much greater than that for the 'serious defect' class. This result should be taken into consideration, especially when the ratio between the defect classes differs greatly from the usual, such as in forecasting human labor required to complete inspection performed by a harvesting crew or vision equipment. The findings indicate that the blemished fruit rate does not affect inspection performance.

INTRODUCTION

The inspection function plays an important role in a quality control system. The success of this function generally has a profound effect on the profitability of the enterprise. Although recent advances have been made in developing computer-controlled vision equipment for inspecting and grading fruits and vegetables (Drury and Sinclair 1983), most of the inspection operations of agricultural products are still performed manually. Estimation of human inspection performance may aid in both manufacturing design and in forecasting the human labor needed to complete the inspection performed by vision equipment.

The influence of certain factors on inspection performance has been extensively reported in the literature. Essentially, it was found that environmental conditions and personality variables affect work efforts (Drury 1982).

Deviations from the optimal levels of air temperature and relative humidity, noise level and illumination were found to reduce inspector efficiency. Product pacing rate, viewing time, work space and layout play important roles in the detection of non-conforming items (Meadows et al. 1959; Megaw and Bellamy 1979; Drury 1982; Jokl 1982).

The level of the inspector's experience and training and the duration of the inspection task were found to have influence on inspector performance. Most textbooks continue to recommend that a single inspector task should be limited to 30 min. On the other hand, it was found that initially there is warm-up period in the performance of chicken inspectors followed by a gradual fall in performance only over a 2-h period (Drury and Sinclair 1983).

A detailed description of orange fruit defects has been published by the Organisation for Economic Co-operation and Development (OECD 1980). 'Slight defects' do not seriously impair the general appearance or keeping properties of the fruit. Hence slightly defective fruit is of current marketable quality

and satisfies the minimum requirement for inclusion in class 2, but does not qualify for inclusion in the good quality classes (OECD 1980). 'Serious defects' severely harm the general appearance or conservation of the fruit. Hence, seriously defective fruit are not of current marketable quality and do not satisfy the minimum requirements of class 2 (OECD 1980).

The objective of the research reported here was to develop a forecasting equation that specifies the relationship between human effort and inspection performance in the sorting of orange fruit. This equation should be particularly useful in evaluating the performance of vision equipment for inspection because the ratio between seriously and slightly defective fruit, in the accepted group after mechanical sorting, is likely to be different from the ratio in the ingoing fruit. We believe that the results may be also of value in evaluating the inspection tasks of other fruit and vegetables.

MATERIAL AND METHODS

The experiments were carried out in a packing house in Israel, during the winter and early spring. Ambient air temperature and relative humidity were not controlled. However, the climate in these seasons is moderate. Ambient temperature ranged from 14 to 23°C with relative humidity levels between 61 and 82%. The illumination level was close to the optimal 1000 lx (Parker and Wiant 1955), and the noise level was 90 decibels.

The inspection task was performed on roller tables with forward speed of 0.15 m/s which is close to the optimal rate (Malcom and Degarmo 1953; Gale and Lawton 1970). The fruit pacing rate (forward speed) was determined accordingly. Two inspectors were stationed on opposite sides of each table.

All the tests were carried out by the same team of four experienced female inspectors. The tests were carried out throughout a normal 8-h working day. No test was conducted in the first or last 2 h of the working day, since it had been found that inspector efficiency differs significantly during these time periods.

The inspector's task is to detect and to remove the nonconforming fruit. 'Conforming' fruit satisfies the minimum requirement for inclusion in class 1 or higher (good quality or superior quality). 'Nonconforming' fruit are slightly or seriously defective fruit and hence do not meet the minimum requirement of class 1 (OECD 1980).

The response variable was selected to be the rate of nonconforming fruit in the accepted group. The explanatory variables were (1) inspection time and (2) rate of nonconforming fruit in the ingoing fruit.

Since the pacing rate of fruit was constant, inspection time was controlled by the fruit supply rate. Four levels of supply rates were designed. The actual supply rates were measured by

stop-watch and generally found to be close to the programmed one. The rate of defective fruit in the ingoing fruit was set at four levels (10, 25, 35 and 50%) with equal ratios of slightly and seriously defective fruit at each level. The ingoing fruit samples were presorted by a highly trained expert and the necessary percentage adjustments were made.

The inspectors were unaware of a test being performed, or of the rate of defective fruit in the ingoing samples. Conforming fruit and slightly or seriously defective fruit were marked accordingly with fluorescent dye. The outgoing fruit were illuminated with a 'Black-Light' (long-wave ultra-violet). All the marked fruit were collected and accounted for.

MODEL DEVELOPMENT

Inspection is a complex job and many schemes have been proposed for suitable components. Attributes inspection involves the following tasks: (1) visual search for detection of imperfections on the fruit; (2) decision making as to whether the imperfections are sufficiently severe to reject; (3) manual movements to remove the rejected fruit.

Visual search is the most time-consuming part of an inspection task. In visual search, almost all of the information taken in by the inspector is taken in during eye fixations, which average about one-third of a second in duration and account for most of the search time (Drury 1982). In each fixation, an inspector can detect information in an area of the item called a visual lobe. Eye movement studies have shown a very random appearing search pattern in some tasks, whereas others show some systematic search component, in addition to a random pattern (McGaw and Bellamy 1979). In a systematic search model, it is assumed that the i th fixation is constrained to fall on an area not fixated in the preceding fixations, while a random search model is based upon the contrary assumption, that a previously fixated area is as likely to be refixated as any other area. Although a systematic search is always more efficient, data studies indicate that the real search performance lies between these models (Morawsky et al. 1980). Morawsky et al. (1980) developed a model combining the two assumptions described. It seems that their results may be approximated by an exponential function.

Many researchers believe that performance measured by the probability of detection of an imperfection in a given time can be predicted best by assuming random search. Drury (1982) suggested a model relating probability $P(t)$ of detection of an imperfection in a given time t .

$$P(t) = 1 - \exp(-D \times t) \quad (1)$$

where D is the reciprocal of the mean search time needed to detect one imperfect object and t is the inspection time per object.

A similar model was assumed for attributes inspection of orange fruit based on two assumptions: The inspection time needed for decision making may be neglected. Such a situation is characterized by a relatively low rate of good fruit in the rejected group (Drury 1982) (the average rate for these tests was found to be 4% good fruit in the rejected group). The other assumption, that inspection time is the same for rejected and accepted fruit, was established statistically.

A forecasting equation was derived from this model, and its parameters were estimated for slight and serious defect cases.

$$Z = C \times A \times \exp(-B \times t) \quad (2)$$

where:

Z = rate of nonconforming fruit in the accepted group (usually called type 2 error),

C = rate of nonconforming fruit in the ingoing fruit (decimal fraction),

A = parameter to be determined,

B = parameter to be determined, and t = the inspection time (measured in minutes per 1000 fruit).

It should be noted that

$$1 - (Z/C) = 1 - A \times \exp(-B \times t)$$

is the probability of a nonconforming fruit being rejected and is a well-known measure of inspection performance.

The NLIN procedure of the Statistical Analysis System Institute, Inc. was employed to estimate the parameters of this equation. The data are the result of 188 tests, in each of which 1000 orange fruit were sorted.

RESULTS

The relatively high value of R^2 (coefficient of determination) indicates that the variation of the deviations of the response variable from the forecasting line is relatively small. The forecasting equations, therefore, are adequately representative of reality (Table I). Comparison of the predicted with the measured values of the probability of rejecting nonconforming fruit leads to the same conclusion (Table II).

The standard error of the estimated parameters is relatively low, t values are highly significant, and their confidence interval indicates that the maximum probable error associated with the estimators is relatively small.

The assumption that the rate of defects in the ingoing fruit affects inspection efficiency measured by $(1 - (Z/C))$ was tested by estimating the parameters of the model:

$$Z = A \times C^H \times \exp(-B \times t) \quad (3)$$

The null hypothesis tested is that H is equal to 1.0. The value of H was estimated to be 0.99; hence, statistical evidence does not support rejection of this hypothesis. Therefore, one is led to believe that the true value of H is 1.0 and consequently that inspection efficiency is relatively unaffected by the percentage of defective specimen over a range of 10-50%. A similar result was reported by Malcolm and Degarmo (1953).

Based on the results, the inspection time needed to obtain a required rate of nonconforming fruit in the accepted group (t^*) can be estimated. Let C_e and C_d denote the rate of the seriously and slightly defective fruit, respectively, in the ingoing fruit (decimal fraction) and let Z_e and Z_d represent the same classes in the accepted group (Table I), with Z the rate of the defective fruit in the accepted group. Then Eq. 4 can be derived as

$$Z = Z_e + Z_d = 0.762 \times \exp(-0.0784 \times t) \times C_e + 0.958 \times \exp(-0.0267 \times t) \times C_d \quad (4)$$

Z is a strictly monotonic decreasing function of t , and therefore there is exactly one solution t^* for given values of Z , C_e , C_d (Stummel and Hainer 1983).

A first approximation can be calculated by modifying Eq. 4 to the approximated form of Eq. 5.

$$t = - \frac{\{ \ln(1/0.958 - 0.196 \times PR + \ln(Z/(C_e + C_d))) \}}{(0.0267 + 0.0517 \times PR)} \quad (5)$$

where $PR = C_e / (C_e + C_d)$

Table I. Estimates of the parameters of Eq 2 (computed from data of 188 tests)

Parameter	Slight defects		Serious defects	
	A	B	A	B
Estimate	0.96	0.03	0.76	0.08
Asymptotic† standard error	0.02	0.003	0.04	0.01
Asymptotic† 95% confidence interval	0.92 -1.00	0.02 -0.03	0.69 -0.83	0.06 -0.09
Nonlinear coefficient of determination (R^2)‡	0.91		0.74	
Asymptotic† correlation coefficient of the parameters	-0.87		-0.84	

†All asymptotic statistics are approximated.

‡The nonlinear coefficient of determination is generally given by $1-RSS/QY$, where RSS is the residual sum of squares, and QY is the sum of squares of the deviations of the dependent variable.

Table II. The relationship between forecasted† and measured values of the probability of rejection of nonconforming fruit as a function of inspection time (mean values)

Sample (no. of tests)‡	Inspection time (min/1000 fruit)		Probability of rejecting nonconforming fruit			
			Serious defects§		Slight defects§	
			Mean	SD	Actual	Forecast
70	3.6	0.90	0.464	0.425	0.136	0.130
46	6.9	0.83	0.588	0.556	0.211	0.203
30	9.7	0.89	0.600	0.643	0.245	0.260
42	13.9	1.13	0.721	0.743	0.375	0.338

†Forecast values were estimated by setting the actual inspection time of each test in Eq. 2. See also Table I.

‡In each test 1000 fruit were sorted.

§Note that the ratios of slight and serious defects in the ingoing fruit are equal in all tests (see text).

SD = standard deviation.

Application of Eqs. 4 and 5 to forecasting inspection time is demonstrated by the following example. The rate of nonconforming fruit in the ingoing fruit is 0.3 ($C_e = 0.25$, $C_d = 0.05$). The required rate in the accepted group is $Z=0.1$. The inspection time t^* (min per 1000 fruit) has to be estimated, applying the 'nested interval' method of finding a root of an equation (Stummel and Hainer 1983). By setting $PR=0.8333$ ($0.25/(0.05+0.25)$) in Eq. 5 a first approximation of the inspection time $t_0 = 19.04$ min is obtained. Setting $t = 19.04$ in Eq. 4 yields $Z_0 = 0.07$, which suggests that $0 < t^* < 19.04$. The midpoint of this range is determined to be the second approximation of the inspection time (t_1). With $t_1 = 9.52$ we find $Z_1 = 0.128$ and consequently $9.52 < t^* < 19.04$. After six iterations, t^* is found to be within the range 13.24 - 13.39, and t^* is estimated to be the mid point with the value of 13.32 min.

DISCUSSION

Most of the known factors affecting inspection performance were determined to be at the same level throughout the experiment, and most of them were considered to be close to the optimal.

The most important factors that were not controlled were ambient temperature and relative humidity. The experiment was carried out in winter and early spring with moderate weather prevailing. However, there is evidence in the literature that these factors have a significant influence on inspector performance, especially so on female inspectors who carried out all the inspection tests (Jokl 1982). However, the combination of the predictor levels in each test was randomly selected, and was independent

of ambient weather conditions. Therefore, the omission of the ambient temperature and relative humidity factors may affect the results, and is liable to increase the variance of the residual (the difference between the observed value and the value predicted by the forecasting line). In the case of slight defects, this variance is estimated to be less than 10% of the response variable variance in comparison with 26% in the serious defects case. (These values may be derived using the following equation: $RV/QV = 1 - R^2$, where RV is the variance of the residual, QV is the variance of the response variable, and R^2 is the coefficient of determination.

The method used to estimate the parameters of the forecasting equations is to minimize the error sum of squares between the actual response variable values and the values predicted by the equation. In the nonlinear situation, the error sum of square function is not a convex function of the parameters. Therefore, the algorithm employed may yield only a local minimum rather than the global one and there is no guarantee that the parameters estimated correspond to the global minimum. In practice, starting values of the parameters must be estimated. Different starting points sometime produce significantly different estimates of the parameters and coefficient of determination (R^2).

Despite the awareness of these difficulties, one can judge how close the forecasting equation represents reality (Table II). In addition, owing to the large sample size and 188 tests performed, one can rely on the forecasting ability of the equations even in the presence of nonlinearity. On the other hand, it is difficult to judge how close a specific estimated parameter is to the

parameter corresponding to the global minimum. Therefore, the extent to which one can rely on the estimated parameters in theoretical considerations (such as the effect of imperfection rate on inspection performance) is limited.

CONCLUSIONS

(1) The model proved its merit in obtaining industrially acceptable estimates of inspection efficiency as a function of inspection time. The forecasting equation developed explains more than 80% of the inspection efficiency variation.

(2) The inspection time needed to reject slightly defective fruit is up to 300% higher than with seriously defective fruit. This result should be taken into consideration in estimating the required inspection time, especially when the ratio of slight and serious defects differs greatly from the usual, such as when completing inspection performed by a harvesting crew, or when fluctuations occur in the mentioned ratio due to environmental conditions.

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