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The Efficiency of Automatic Detection and Correction of Errors in Individual Observations as Compared with Other Means for Improving the Quality of Statistics

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C O N T E N T

1. Introduction

The aim of this paper is to study the effect on survey results of automatic detection and correction of individual errors in statistical observations and make comparisons with other methods in order to improve the quality of statistical results. Our studies are based on live data with artificially generated errors. We shall, however, try to give the error generator such a form that our artificial data will have properties which may be accepted as realistic for the set of statistical units.

The objective of a statistical survey is in general to obtain information about aggregates of values characterizing the indivudual units of the set investigated. We shall call the values obtained statistics. By the quality of statistics we mean an inverse measure of the deviation between the statistics and the true values of the aggregates which the users assume these statistics represent. There are several factors jointly determining the quality among which are the sample size, in case of sampling, the efforts spent on accurate observation and processing, the time between the observation and presentation of the results, the editing method, the specification of the results and the resources available.

From sample survey theory we know how to take error effects of sampling into account and how to control them (2). The non-sampling errors in the results may have many sources, but their common cause is that it is usually prohibitive to measure each unit according to the ideal procedure. The more efforts are spent on measurement of each unit the less error effects are likely to remain. A technique of separating those units which seem to need particular efforts in measurement, may be used. If this separation is performed by programmed machines we shall call it automatic detection, and if the additional efforts consist of computer treatment, we may call them automatic correction of non-random errors.

The time spent on collecting and processing observations may be called production time. The available statistics are frequently used to draw inference about present or future situations. In a set of units with characteristics changing over time, statistics with a long production time may therefore be of reduced value, even though they perhaps describe the past situation very accurately.

A common assumption is that joint effect of sampling and non-sampling errors is less on statistics from large sets than from small sets. The statistics are therefore frequently specified only for main subsets. Those interested in smaller subsets, will have to draw inference from the results for the main sets to which the respective subsets belong. The difference between a certain true aggregate for the main subset and the corresponding aggregate for a smaller subset may, however, be larger than the increase in inaccuracy which specification of smaller subsets would have introduced. In this sense, statistics which are both accurate and rapidly available, may be of low quality because needed details are not available.

Quality cannot be improved unlimited because this requires recources. A mathematical model of the relations between the quality, the determining factors and the resource requirements and restrictions may in the simple cases give analytical solutions for the most efficient survey design. The approach of this paper is, however, numerical. It is based on information about a set of establishments for which we study, by simulation experiments, the effect of the different factor combinations which we believe represent interesting alternatives. The more general and difficult problem of the optimum design is not raised in this paper (4).

2. Model

2.1 Individual variables

We consider a finite set of N units each of which is characterized by K variables, X_{ik} $(i = 1 \ldots N,\ k = 1 \ldots K)$. Assume that these N sets of values can be regarded as the "true" values in the sense that they are only obtained if the ideal or approximately ideal procedure of measurement is followed.

The variables may change over time. We assume that the change from one period or point of time, t-1, to another, t, is defined by:

$$(1) \qquad X_{ik}(t) = X_{ik}(t-1) \cdot (1 + e_{ik}(t)) \qquad \text{for} \begin{cases} i = 1 \ldots N \\ k = 1 \ldots K \end{cases}$$

where the variables e_{ik} are assumed to be stochastic with a joint probability function

$$(2) \qquad G\,(e_{11}(1) \ldots e_{NK}(1), \ldots, e_{11}(T) \ldots e_{NK}(T))$$

By convention, $t = 0$ in the period for which the population is observed, and we omit the time argument when referring to this period. T is the period in which the results of a survey is available.

Let Y_{ik}, (i = 1 .... N, K = 1 .... K) denote another set of variables which represent the values obtained when the units are observed. These variables we define as:

$$(3) \qquad Y_{ik} = X_{ik} (1 + (1 - q_{i1}) \cdot r_{ik}) \cdot q_{io} \qquad \text{for } \begin{cases} i = 1....N \\ k = 1....K \end{cases}$$

where r_{ik} are the observation error factors, and q_{io} and q_{i1} are binary variables with values 0 or 1. The values $q_{io} = 1$ indicates that i-th unit is observed, while $q_{io} = 0$ means that it is unobserved. The second variable indicates that i-th unit is observed according to an ideal procedure when $q_{i1} = 1$, while $q_{i1} = 0$ represents the application of a less accurate observation procedure. We then have:

$$Y_{ik} = \begin{cases} 0 \text{ if the i-th unit is not measured} \\ X_{ik} \text{ if it is measured by the ideal procedure} \\ X_{ik} (1 + r_{ik}) \text{ if the ideal procedure is not used} \end{cases}$$

The error factors are also assumed to be stochastic and their probability function is denoted by:

$$(4) \qquad H (r_{11} \text{ .... } r_{NK})$$

The third set of variables we want to introduce consists of the variables from which we derive our statistics. These variables are defined as:

$$(5) \qquad Z_{ik} = Y_{ik} (1+q_{i3} \cdot u_{ik}) \cdot (1-q_{i2}) + q_{i2} \cdot X_{ik}, \qquad \text{for } \begin{cases} i = 1....N \\ k = 1....K \end{cases}$$

where u_{ik} is a correction factor and q_{i2} are binary variables. $q_{i2} = 1$ indicates that the measurement of the i-th is repeated under ideal conditions while $q_{i3} = 1$ indicates that the observed value is corrected automatically by u_{ik}. We get:

$$Z_{ik} = \begin{cases} X_{ik} \text{ if the measurement of the i-th unit is repeated under ideal conditions} \\ Y_{ik} \text{ if the value is uncorrected} \\ Y_{ik} (1 + u_{ik}) \text{ if corrected} \end{cases}$$

2.2 Data reduction

The results of a statistical survey are usually presented in tables. Let:

(6) $$\bar{Z}_r = \bar{Z}_r \; (Z_{11} \ldots\ldots Z_{N_oK}, q_4) \; ,$$

denote the relation between the statistic in table cell r and the Z_{ik} values for period t = 0 of the $N_o \leqq N$ units included in the survey. q_4 is another binary variable which indicates with a value 1 that a higher degree of specifications is applied in the tables, while $q_4 = 0$ represents lower degree of specification. We shall call these two degrees of specification for full and limited specification, respectively. Let:

(7) $$\bar{X}_r \; (T) = \bar{X}_r \; (X_{11}(T) \ldots\ldots\ldots\ldots X_{NK} \; (T))$$

denote the aggregates of the true values corresponding to high specification at the time T at which the survey results are available.

2.3 Quality and costs

The quality of the whole measurement is assumed to be a function of the values of the statistics and the aggregates of the true values at the time the former are available:

(8) $$Q = Q \; (\bar{Z}_1 \ldots\ldots \bar{Z}_R, \bar{X}_1 \; (T) \ldots\ldots \bar{X}_R \; (T)$$

The units included in the survey may be classified according to the q-variables. The number of units in each class will be:

(9) $$N_g = \sum_i^N q_{ig} \qquad\qquad (g = 0, \ldots\ldots 3)$$

In the tabulation of the statistics all N_o units observed are assumed treated in the same way and the number of units processed at the higher level specification is therefore:

(10) $$N_4 = N_o \cdot q_4$$

that is:

$$N_4 = \begin{cases} 0 \text{ if limited specification applies} \\ N_o \text{ if full specification applies} \end{cases}$$

The cost of the measurement is assumed to be a function of the number of units in each class and the production time T:

$$(11) \qquad C = C\ (N_o,\ N_1,\ N_2\ N_3\ N_4,\ T)$$

In general, cost is depending on the size of the sample, N_o, the treatment of the units, $N_1 \ldots N_4$, and the production time, T.

The above model is the frame within which the studies reported in the empirical part of this paper is only one of many possible applications.

3. Scheme for the simulation study

3.1 Outline

The empirical part of this paper is a simulation study of different survey designs based on the model described. The statistical units are mining and manufacturing establishments and the variables observed are of the type usually included in a census of establishments. From a set of live data representing true individual values for the initial period, observations with errors are generated and processed in different ways. The statistics obtained are compared with true aggregates for the period before the statistics will be available according to the cost structure of the respective survey designs. The true aggregates for periods after the initial are obtained by generating changes in the individual true values in the basis set of live data.

3.2 Mining and manufacturing establishments

We are studying the mining and manufacturing establishments with in average 5 or more persons engaged in 1962. This set contained 9550 units in 1962 for which a large number of characteristics including employment, wages and salaries, value of production, repairs, contract work etc., cost of materials, fuels, value of inventories, investment, quantity and value of products of each kind and consumption of raw material and geographical location, was observed. Industry classification was derived from the informations observed. The production time was about 1 year, and the observations were collected by mail, edited in a system of mixed manual and automatic control and correction.

The results were tabulated by group of industry and geographical region in addition to totals cumulated for the whole population.

We shall restrict our study to the following variables:

X_{i1} : True 2-digit industry code (ISIC).
X_{i2} : True wages and salaries, (excl. wages to home workers).
X_{i3} : True average number of persons engaged (incl. self employed owners).
X_{i4} : True 1-digit geographical region.
X_{i5} : True gross value of production.
X_{i6} : True cost of raw materials.

We assume that a register for all establishments with information about industry and regional code is available on which the surveyes we simulate could have been based.

The individual data for 1962 with the values they had before final tabulations are assumed to be approximately true and will be used as true values for period t = 0. Compared with the tabulated results for 1961, the 1962 statistics indicate an annual increase in totals from about 1 to 10 per cent. Owing to difficulties in identifying and collating the individual data for each establishment for both years, we have no accurate measures of the individual changes. The changes over time are, however, assumed to be the effect of a set of M different stochastic impulses:

$$(12) \qquad e_{ik}(t) = \sum_{m}^{M} a_{mk} \cdot b_{mi}(t)$$

where $b_{mi}(t)$ is the m-th impulse being either 0 or 1, and a_{mk} is the effect of such an impulse on the k-th characteristic. The G-distribution is specified as:

$$(13) \qquad G\,(e_{11}(1) \ldots e_{NK}(1), \ldots, e_{11}(T) \ldots e_{NK}(T)) = \prod_{t}^{T} \prod_{i}^{N} \prod_{m}^{M} P_m(b_{mi}(t))$$

where P_m is the cumulative distribution function:

$$(14) \qquad P_m(b_{mi}) \doteq b_{mi} + (1 - p_m) \cdot (1 - b_{mi})$$

The true values of the periods t = 1,2 ... , i.e. the years 1963, 1964, ..., are obtained by Monte Carlo generations according to this model and the numerical specifications in table 1. The probabilities p_m, and the effects a_{mk} are specified numerically in such a way that the mean effects on the variables considered are equal to the observed average changes from 1961 to 1962. We are not considering any changes in the code of industry or the code for geographical location of the establishment. The changes are assumed not to be observable before the end of the year since this is the time period the variables refer to. Statistics presented within a year will therefore be compared with the true aggregates for the observation period, while statistics available after more than one, but less than two years after the end of the observation period, will in our evaluation be compared with the true aggregates of the period following the observation period.

Because there are never two effect coefficients on the same line in table 1, the change distributions of the error factors are all independent. It is likely to be more realistic to assume that there are a certain relations between the changes of variables over time. The individual change impulses used are not based on accurate data and should be considered as one out of many possible explanations for the observed changes in totals from 1961 to 1962 which we assume to be valid also for the years to come.

3.3 Error factors

The generation of errors will require specification of the H distribution. Very little information has, however, been compiled yet about the type, size and nature of individual errors in observations of mining and manufacturing establishments. Investigations carried out previously indicate that individual errors may affect totals by as much as ± 5 per cent or more.

Not all types of errors are equal importance, and it has been pointed out that the error types may be classified according to their importance in the following classes:

1. Rare and small errors.
2. Frequent and small errors.
3. Rare and large errors.
4. Frequent and large errors.

The two first classes contains errors which are relatively unimportant. Even though class four is likely to be the most important, the existence and causes of these errors are easily recognized and the necessary precautions may be taken. It is the errors belonging to class 3 which really seems to cause difficulty since they occur so seldom that we learn about them too late.

We shall use this classification for the specification of the H distribution as given by the following formulas and table 2. It is assumed that each r_{ik} is composed by the effect of a set of R random error impulses:

$$(15) \qquad r_{ik} = \sum_{r}^{R} a_{rk} \circ b_{ri}$$

where b_{ri} is the r-th impulse which is either 0 or 1 and a_{rk} is the effect of such an impulse on characteristic k. The H-function is assumed to be:

$$(16) \qquad H\,(r_{11} \ldots r_{NK}) = \prod_{i}^{N} \prod_{r}^{N} P_r\,(b_{ri})$$

where P_r is the cumulative distribution function:

$$(17) \qquad P_r\,(b_{ri}) = b_{ri} + (1 - p_r) \cdot (1 - b_{ri})$$

In other words, we assume that the error factors of one observation are stochastically independent of errors in any other observation, but that errors within any set of values from the same unit may be correlated.

In table 2 the probabilities p_r and the effects a_{rk} are given The mean effects of error factors are supposed to be known from the experience of the previously mentioned investigations. According to this model the Y_{ik} values corresponding to those obtained by unintensive observation, will be generated by means of Monte Carlo techniques.

The values with generated errors will be denoted by:

Y_{i1} : 2 - digit industry code.
Y_{i2} : Observed salaries and wages.
Y_{i3} : Observed average number of persons engaged.
Y_{i4} : 1 - digit region.
Y_{i5} : Observed gross value of production.
Y_{i6} : Observed cost of raw materials.

The formal similarities between the change and the error generation models are obvious and emphasize the assumption that both can be assumed to be composed of a set of stochastic impulses. In contrary to change factors, the errors are, however, assumed to be correlated, i.e. if an error impulse affects one variable it may also affect the other as well.

3.4 Computation of statistics and quality measure

We assume that the information wanted by the users is statistics representing the payment of salaries and wages, number of persons engaged, gross value and cost of raw materials all for a two-dimentional cross-classification by industry group and geographical region representing a total of 500 statistics (4 characteristics x 25 industry groups x 5 regions.

The aggregates of true values for which information are wanted are:

(18) $$\bar{X}_T\ (g, r, k) \qquad \text{for} \begin{cases} g = 1 \ldots\ldots 25 \\ r = 1 \ldots\ldots 5 \\ k = 1 \ldots\ldots 5 \end{cases}$$

where g now represents industry code, r region code, and k characteristic. k = 1 is used to denote number of units, while k = 2 .... 5 denote salaries and wages, number of persons engaged, gross value of production and cost of raw materials, respectively.

The corresponding statistics are obtained by building the sums of the individual Z_{ik} values for the establishments in the respective subsets. In the case of a sample survey the sums are inflated by the inverse sampling fraction.

The statistics obtained are representing our full specification and are denoted by:

(19) $$\bar{Z}_1\ (g, r, k) \qquad \text{for} \begin{cases} g = 1 \ldots\ldots 25 \\ r = 1 \ldots\ldots 5 \\ k = 1 \ldots\ldots 5 \end{cases}$$

Owing to restricted resources, secrecy requirements, random variations etc. the statistical office may decide to give the survey results with limited specifications represented by statistics for the marginal subsets, f.ex. for establishments in industry g in all regions and for establishments in region r in all industries. We denote these statistics by:

(20) $\bar{Z}_g\ (g,\ k)$ and $\bar{Z}_r\ (r,\ k)$ for $\begin{cases} g = 1 \ldots\ldots 25 \\ r = 1 \ldots\ldots 5 \\ k = 1 \ldots\ldots 5 \end{cases}$

Users who need statistics for $\bar{X}\ (g,\ r,\ k)$ when only statistics of limited specification are available, will have to reformulate their problems in such a way that they can make use of the available statistics. We shall assume that in this case the following expressions are used instead of $\bar{Z}_1\ (g,\ r,\ k)$:

(21) $$\bar{Z}_0\ (g,\ r,\ k) = \frac{\bar{Z}_o\ (g,\ k) \cdot \bar{Z}_o\ (r,\ k)}{\bar{Z}_o\ (k)}$$

where

(22) $$\bar{Z}_o\ (k) = \sum_{g}^{25} Z_o\ (g,\ k)$$

As an inverse indicator of the quality of a single statistics we use the squared difference between the statistic and the corresponding true aggregate for period T:

(23) $$Q_{q_4}\ (g,\ r,\ k) = (\bar{Z}_{q_4}\ (g,\ r,\ k) - \bar{X}_T\ (g,\ r,\ k))^2$$

and as an overall measure for characteristic k:

(24) $$Q_{q_4}\ (k)\ \sum_{g}^{25}\ \sum_{r}^{5}\ Q\ (g,\ r,\ k) \qquad \text{for } k = 2 \ldots\ldots 5$$

These indicators may be regarded as weighted mean square errors which are often used as quality indicators. Our rough quality index for the survey is:

(25) $$Q_{q_4} = \sum_{k=2}^{5} Q_{q_4}\ (k)$$

3.5 Editing methods

A large number of methods for detecting and correcting individual errors in statistical observations has been proposed and discussed (5). The basis for all methods is the assumption of some relationship among the variables observed. Some relations are exact because they are definitional while others are approximate. Partly knowledge about these relations, may enable the statistician to decide with a predescribed risk whether an observation comes from a set of units in which the relations do not exist, i.e. a set different from the one investigated, and if so how the observation may be substituted by another with a predescribed risk of introducing a new and larger error.

We consider in this context the actual automatic editing as a two stage process. First, an observation is controlled the result of which is either acceptance or rejection. In the second stage, those variables which cause the rejection are identified, and finally corrected. It may be necessary to repeat the process to check whether a satisfactory correction has been done and the editing process will in this case be iterative.

Before editing it is necessary to specify the editing method numerically. We will do this specification on basis the true values of a random sample of 350 establishments.

Ratio control

Among the many control methods the ratio method was frequently used in pre - EDP times by the editing clerks and is also widely used as the basis for automatic editing. According to this method which will also be used in this study, ratios of observed variables are computed and compared with upper and lower limits.

$$\underline{G}_{kl} \leqq Y_{ik} / Y_{il} \leqq \bar{G}_{kl} \tag{26}$$

The limits are defining a tolerance interval usually assumed to vary from one industry to another. We shall derive special tolerance intervals for most of the 2-digit industry groups.

The actual control process is described in a so-called logical decision table by means of a FORTRAN-like language. Decision table A, reproduced in table 3, of the Appendix has six relations, seven decision columns and two actions. Three pairs of upper and lower tolerance interval limits are specified for each industry group in a preparatory part of the table which is, however, omitted in table 3 because of the lack of space.

After statements recording the ISIC classification code in Y(1) to a successive industry code from 1 to 25, the six relation follow. If any of these relations are found to be false (N) when applied on an observation, the complete observation is rejected and re-observed intensively. This process is simulated by substituting the Y-values with the X-values. When all relations are true (Y) the observation is accepted. In both cases the corrected or accepted values are transferred for further processing.

The first three relations require that neither salaries and wages, number of persons engaged or gross value of production are zero or negative. Cost of raw materials may, however, be zero in an establishment performing contract work only. The last three relations are composite relations, which require that the ratios: 1. (salaries and wages / (persons engaged), 2. (gross value of production - cost of raw materials used) / (persons engaged), and 3. (cost of raw materials) / (gross value of production) all are within their respective tolerance intervals.

The decision table also specifies a count of the number of re-observed units, IN = N2, since it is component of the cost function.

Identification and hot deck correcting

The problem of identifying the wrong variable or variables in a rejected observation may be solved by establishing a reliability index for each variable. In the applications of automatic correcting we shall assume that the observed number of persons engaged is in general more reliable than gross value of production, salaries and wages and cost of raw materials, etc. A set of rules is established which determines the wrong variable in case of rejection.

The correction is carried out according to a modified version of the American hot deck method. According to this method a variable value which has been decided to be wrong is corrected by substitution with the value of the corresponding variable from the last accepted observation having similar classification characteristics.

Table 4 is a decision table which specifies a complete automatic editing with automatic ratio control and a hot deck type of correction. The preparatory part of the table, which is omitted here, specifies the tolerance limits G (I,J) and initial hot deck values necessary for the correction. The table has 8 relations, 12 actions and 23 decision rules. The relations are similar to those in table 3 with addition of Y (6).GT.0 and K.EQ.5. Even though Y (6) frequently has a valid zero value and never occurs as a demominator, we want to separate the case when it is positive since a positive cost of raw materials may be used when it is the only information obtained. The last relation is introduced to avoid indefinite looping.

There is no need for commenting the actions and decisions in details since the table should be self explanatory. A few remarks may, however, be usefull. We consider again the 25 industry groups and for each the values of the last uncorrected accepted observation are stored. The testing of the relations is performed in two steps. The four (>0) relations are tested and if the first three are true, the ratio relations are tested. If one or more of the three first relations are false, the variables are estimated from the values of the last accepted observation in the same industry group and the accepted values, if any, of the considered observation. Then the ratio-relations are tested and corrections made if necessary. After each correction the procedure of the table is repeated. The editing may therefore be iterative, but to avoid indefinite looping only 5 iterations are alloved. After the fifth unsuccessfull iteration the rejected observation is substituted completely by the hot deck. The correction factor u_{ik} is thus depending on the values of the observation as well as those of the last accepted unit in the same industry.

Numerical specification of editing parameters

The tolerance limits and the initial hot deck values are usually set up on a priori knowledge. We have assumed that equivalent knowledge is obtained by investigating a sample of 350 establishments intensively.

This is not considered as a part of the survey procedures, but as a simulation of the state of knowledge of the survey designers. All establishments, also the 350, are therefore edited in editing stage and the specification process is not assumed to cost anything.

The initial hot deck values are computed as the averages from the 350 unit sample specified by industry:

$$\text{(27)} \qquad HD\ (g,k) = \frac{1}{n_g} \sum_{j=1}^{N_g} \cdot X_{jkg}$$

where g here denotes industry, n_g is the number of units within the sample belonging to industry g and X_{jkg} $(j=1..n_g)$ are the values of the characteristics of these units.

The limits of the tolerance intervals required by the automatic control and correction are computed as

$$\text{(28)} \qquad \begin{aligned} \underline{G}_{eg} &= R^{min}_{eg}/W \\ \bar{G}_{eg} &= R^{max}_{eg} \cdot W \end{aligned} \qquad \text{for} \quad \begin{cases} e = 1,\ 2,\ 3 \\ g = 1\ \ldots .\ 25 \end{cases}$$

where R^{min} and R^{max} are the extreme values for each of the following three expressions and industry group found within the sample

$$\text{(29)} \qquad \begin{aligned} R_{1g} &= X_{i2} \,/\, X_{i3} \\ R_{2g} &= (X_{i5} - X_{i6}) \,/\, X_{i3} \\ R_{3g} &= X_{i6} \,/\, X_{i5} \end{aligned}$$

If the distributions of the R's were approximately normal, the above procedure with W = 1 will in the case of an average sample of 14 units per industry give tolerance intervals which would cover about 95 per cent of the units in the industries with a confidence coefficient 0.95 (1,6). When the sample is less than the average the coverage of the interval is less than 95 per cent, while same computation from a sample larger than 14 give a higher coverage. The philosophy is that we want relatively more narrow tolerance intervals for industries with few establishments than for industries with many establishments.

The initial hot deck values and the tolerance interval limits for W = 1 are given in table 5 and 6, respectively. For some groups, none or only one establishment occured in the sample. In the case of automatic control and accurate re-observation, all establishments in these groups with exception for those with observed values identical with the true values of the one in the sample will be rejected and reobserved since in these groups there will probably be so few units that errors might have a relatively strong effect on the values of the statistics. In the scheme including also automatic correction the same initial values and tolerance limits will be used for these small groups as for larger, but related industry groups.

Additional schemes with W = 3/2 are also considered. In these the tolerance intervals are wider while the initial hot deck is the same as above. We shall call the schemes based on W = 1 intensive, automatic control while those implying W = 3/2 will be called unintensive since their tolerance intervals are wider.

3.6 Resources and alternative survey designs

For 1962 the cost of the industrial statistics was about 500.000 NKR. of which about 150.000 NKR. represented cost invariable to changes in factors considered here except for production time.

We assume that an unintensive observation costs about 20 NKR. per unit excluding editing and tabulation. The additional unit cost which the higher degree of specification requires, is assumed to be 5 NKR.

Accurate observation requires close contact with the establishments and is therefore expensive. The additional cost is assumed to be 70 NKR. per unit intensively observed, either originally or as a repeated observation.

Automatic control and correction of the observations will be relatively inexpensive since the costs of getting the data into the computer have already been taken into account. The additional cost is the computer time spent on editing. It is assumed to be not more than 10 NKR. per unit.

The complete cost function for the industrial statistics becomes:

$$C = (150.000 + 20 \cdot N_0 + 70\gamma \cdot N_1 + 70\gamma \cdot N_2 + 10 \cdot N_3 + 5 \cdot N_4)/T \qquad (30)$$

where we assume that if we allow T f.ex. to increase from 1 to 2 years the costs will be reduced by 50 per cent owing to more smooth utilization of the statistical capasity. With given resources, the cost function will determine the production time T. The integer part of T determines the period of which the true aggregates should be used for the quality evaluation.

We shall assume that the resource restrictions are 500.000 NKR. for the whole survey and study the following alternative survey designs.

Alt. 1: Unintensive, automatic control and limited specification

In the following four survey designs automatic control with wide tolerance intervals is applied. We are not able to say how many of the establishments will be rejected, but we expect that the number will be larger than 3000. In this case the first two surveyes can not be completed within a year because of the relative expensive reobservation implied. The results must therefore be compared with the true aggregates for a later period depending on the number of rejections. Alternative 1 has the following parameters:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 > 3000$ (rejection and reobservation)
$N_3 = 0$ (no automatic correction)
$N_4 = 0$ (limited specification)
$T > 1$
$W = 3/2$ (wide tolerance intervals)

Alt. 2: Unintensive, automatic control and full specification

In contrast to the previous alternative, this assumes that the detailed specification is given:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 > 3000$ (rejection and reobservation)
$N_3 = 0$ (no automatic correction)
$N_4 = 9550$ (full specification)
$T > 1$
$W = 3/2$ (wide tolerance intervals)

Alt. 3: Unintensive, automatic control and correction, and limited specification

The rejected observations are here automatically corrected according to the hot deck method. This design will always be completed within a year, with the given resources:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 = 0$ (no reobservation)
$N_3 \leq 9550$ (automatic correction)
$N_4 = 0$ (limited specification)
$T < 1$
$W = 3/2$ (wide tolerance intervals)

Alt. 4: Unintensive, automatic control and correction, and full specification

The automatically edited observations are here used to in a detailed specification:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 = 0$ (no reobservation)
$N_3 \leq 9550$ (automatic correction)
$N_4 = 9550$ (full specification)
$T < 1$
$W = 3/2$ (wide tolerance intervals)

Alt. 5: Intensive, automatic control and limited specification

This alternative is characterized by the following values of our N-parameters.

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 > 3000$ (rejection and reobservation)
$N_3 = 0$ (no automatic correction)
$N_4 = 0$ (limited specification)

$T > 1$
$W = 1$

Alt. 6: Intensive, automatic control and full specification

This alternative is the one which is probably most similar to the procedure followed in the actual production of Industrial statistics:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 > 3000$ (reobservation of rejections)
$N_3 = 0$ (no automatic correction)
$N_4 = 9550$ (full specification)
$T > 1$
$W = 1$

The actual procedure does not, however, imply accurate reobservations to the same extent as this alternative.

Alt. 7: Intensive, automatic control and correction, and limited specification

The unintensively observed variables are controlled and corrected automatically as in alternative 3 but now with narrow tolerance intervals:

$N_0 = 9550$ (complete survey)
$N_1 = 0$ (unintensive observation)
$N_2 = 0$ (no reobservation)
$N_3 = 9550$ (automatic correction
$N_4 = 0$ (limited specification)
$T < 1$
$W = 1$

The statistics are given for a limited specification.

Alt. 8: Intensive, automatic control and correction, and full specification

Alternatively, the above design is applied, but with detailed specification:

N_0 = 9550 (complete survey)
N_1 = 0 (unintensive observation)
N_2 = 0 (no reobservation)
N_3 = 9550 (automatic correction)
N_4 = 9550 (full specification)
$T < 1$

Alt. 9: Accurate observation of a sample and limited specification

A 20 per cent sample is intensively observed. Because of the small sizes of the subsets, statistics are given only for marginal subsets:

N_0 = 1900 (sample survey)
N_1 = 1900 (accurate observation)
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 0 (limited specification)
$T < 1$

The a priori known information about the establishments' industry and regional codes is not used for stratification, but is used in the estimation process.

Alt. 10: Accurate observation of a sample and full specification

The same sample observations are used for estimating totals for the detailed specification:

N_0 = 1900 (sample survey)
N_1 = 1900 (accurate observation)
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 1900 (full specification)
$T < 1$

Alt. 11: Complete, unintensive observation and limited specification

This design represents a primitive approach:

N_0 = 9550 (complete survey)
N_1 = 0 (unintensive observation)
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 0 (limited specification)
$T < 1$

This is the design with the shortest production time. It may be chosen when the resources are scarce and only a few main figures are wanted.

Alt. 12: Complete, unintensive observation and full specification

This alternative is a fast production by unintensive observation and no editing but with high specification. The design is relatively inexpensive and is likely to be efficient if the error effects are small:

N_0 = 9550 (complete survey)
N_1 = 0 (unintensive observation)
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 9550 (full specification)
$T < 1$

Alt. 13: Complete, accurate observation and limited specification

This design is based on complete and intensive observation but with low specification:

N_0 = 9550 (complete survey)
N_1 = 9550 (accurate observation)
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 0 (limited specification)
$T > 2$

The accurate observation is very expensive and with the given resourses the production will require more than two years.

Alt. 14: Complete, accurate observation and full specification

This scheme requires more than two years and there will be two changes during the period. It is used when the aim is to obtain accurate results and when changes from one period to another are assumed to be unessential.

N_0 = 9550 (complete survey)
N_1 = 9550 (accurate observation
N_2 = 0 (no editing)
N_3 = 0 (no editing)
N_4 = 9550 (full specification)
$T > 2$

The 14 alternative survey designs represent each a different way to dispose available resources which may give statistics of varying quality in the sense we have defined this concept here. We shall discuss the designs in more detail in connection with the empirical results.

3.7 The computer programs

The simulations were performed by means of a Control Data Corporation 3600 computer and a set of programs were developed for this purpose.

These are:

Error and change generation program
Sampling program
Tolerance interval and initial hot deck estimating program
Generatlr program for editing routines
Tabulation and evaluation program

The same program was used both for generation of errors and changes based on a regular random number generating subroutine. The sampling program extracts a systematic sample. The tolerance interval and tabulation programs are straight forward program needing no explanation.

A program of general interest is the generator program for editing routines based on the decision table approach already mentioned. The generator can handle multi-table problems, logical as well as arithmetical relations and allows relations which refer to discrete sets.

4. Results from the study

4.1 General remarks

For each of the 14 simulated survey designs, there has been obtained a complete set of statistical tables as well as true aggregates referring to the period before the one in which the statistical process was completed. In addition, the final individual values for each alternative were available on tapes for inspection if required.

Table 7 summarizes the main findings of the study including production time and quality indicators. For some alternatives, i.e. alternatives 1, 2, 5 and 6 the production time depended on the frequency of rejections and the production times were unknown untill the numbers of rejections were obtained.

Each quality indicator, Q (k), gives the sum of the squared deviations between statistics and compatible true aggregates for 125 subsets. The true values of the totals for all subsets are of order 10^7. .

The alternative designs may be ranked in accordance with the quality indicators. Such a ranking indicates that alternative 2 seems to be the best while alternative 7 is at the bottom of the rank. The ratio between the root mean square deviation of these two alternatives is of the size order 10^{-1}.

Alternatives 13 and 14 represent the most expensive, or time-consuming, designs, while alternatives 11 and 12 are of lower cost and can be completed within shorter time. According to the last two designs, all units are unintensively observed and the values obtained are accepted and used without any treatment. Concerning salaries and wages we came to the result that with given resources for the survey these designs are yielding a better outcome than the more time-consuming alternatives based on accurate observations. This should also be expected from the change- and error-models adopted. These indicate that the change effect in this variable is more important than the error effect. As to the other statistics it seems to be more important to fight errors than time changes leading to the conclusion that accurate but time-consuming observations are the better solution.

4.2 Editing efficiency

Two different editing methods are applied. The first is based on ratio control with accurate reobservation of rejected observations the second with automatic correction of rejected observations. Each method is carried out with both wide and narrow tolerance intervals in the control process.

Table 7 indicates that especially the ratio controls with accurate reobservation are very efficient methods even though they require more than one years production time. The designs based on this methods gave all results with higher quality than the results from the time-consuming accurate observations of all units. It is surprising to find that the version with wider tolerance intervals yields the best results in spite of the fact that it rejects about 4000 observations for accurate reobservation compared with 6000 for the version with narrow intervals. This means that the average effect of the remaining errors is smaller in the first case, even though the number of individual errors is larger than in the second, because of the form of the error distribution. Still better results might have been obtained by using wider tolerance intervals. Quality will therefore not always be improved by increasing the number of accurately observed units.

Automatic control with correction led to about 17000 and 30000 corrections, including iterations, for the versions with wide and narrow intervals, respectively. These figures are both so high that they should warn against use of the designs. Even though the designs based on this method give fast results they are ranking lower than those based on unintensive observation without any editing at all. In other words, the automatic corrections as carried out have destroyed information. A different conclusion might have been reached if the tolerance intervals had been made wider.

It should be remembered that automatic correction only can contribute to improve quality if the experience on which the correcting model is constructed, also is relevant in the set of observations processed.

4.3 Sampling efficiency

It is not likely that sampling would be used in real situations under the conditions assumed in this paper. We still find it interesting to study the results to see what the effects of sampling are under these conditions.

The sample used was a 20 per cent systematic sample drawn from a register of the establishments. For each establishment the register was assumed to contain information about industry and geographical location. This information was not used for stratification purposes, but for computing sampling fractions in the estimation procedure.

When we compare the results of the sample survey designs with the complete survey based on accurate observation, we find that the sampling error effects on the former are much more serious than the changes over time implied in the evaluation of the latter. A similar conclusion is reached when we compare the sample survey results with the results of the complete, unintensive observation designs. The non-sampling errors of the latter have less influence on the quality than the sampling errors.

The results of the sample survey designs show another interesting fact. The quality of the limited specification alternative is superior to that of full specification. Recalling how the quality of the limited specification results is evaluated when information of the full specification is needed, the explanation is that the biases which use of limited specification statistics may introduce are less important than the differences in sampling error effects in full and limited specification statistics.

4.4 Specification efficiency

Except for the sample survey designs already commented, the results show a marked improvement in quality from the limited to the full specification alternatives. Using modern data processing equipment, the tabulation represents a relatively less important part of the survey costs than it did when conventional equipment was used. This is emphasized here by the fact that the additional costs of full specification compared with limited specification in none of our designs force the completion of the survey to be transferred into the next period.

The method by which the limited specification statistics are evaluated, must be kept in mind. The different ways by which users utilize limited specification statistics may of course lead to different evaluations and ranking.

4.5 Conclusions

The conclusions of the above discussion may be summarized as follows:

a) It is important to take the time aspect into account when comparing the quality of survey designs with different production time. For the actual problem studied in this paper it seems to be more fruitful to fight the errors than the changes due to time.

b) Automatic control with accurate reobservation seems to be an efficient method to separate those units which call for special attention. Care should be taken in fixing tolerance intervals to avoid that they screen out only errors of a certain type which counteracted the effects of other errors.

c) As demonstrated in this paper the results of automatic correction may be dangerous.

d) Sample surveyes represent no real alternative under the conditions specified, particularly is the full specification requirement prohibitive for sample surveyes.

e) Full specification gives considerable higher quality than the limited specification. With modern equipment specification is relatively cheap and the statistical office should meet the specification requirements as far as possible.

5. Final remarks

Improving statistical quality is not only a question about introducing ingenious, automatic editing methods. It is a complex problem involving observation techniques, sampling, editing and estimation methods, specification of the results, available resources, etc. Some aspects of this problem have been discussed in this paper, but there are many others remaining. Among the most important is continnous observation and cumulation of data for general statistical readiness as an alternative to periodic surveyes. Another important aspect related to the evaluation of the statistical system, is the influence of statistics on the decisions determing the general development which will be reflected in future values of the variables observed.

This study has been carried out as simulation experiments owing to the complex nature of the problem. The simulation approach seems to be an interesting and promising approach to the type of problems consideres in this paper as well as to other problems in statistical methodology.

Résumé

La qualité de la statistique est définie ici comme une mesure qui diminue en concordance avec la déviation entre les estimations et les valeurs des quantités qui seront estimées au moment quand les estimation sont connues. Tant la vérification effectuée concernant les matériaux recueillis que la méthode de l'observation, la dimension de la quantité choisie, la méthode de l'estimation et les ressources etc. sont détérminants pour la qualité.

L'étude décrit un modèle de simulation qui peut se servir d'examiner l'efficacité des projets différents d'une enquête statistique. Le modèle est appliqué aux données choisies concernant 9550 entreprises de la Statistique industrielle 1962. 14 dispositions différentes sont spécifiées alternativement pour l'enquête qui seront simulées par la calculateur électronique et puis évaluées.

Le modèle de simulation présenté revéle, comme la question des moyens choisis pour améliorer la qualité est - elle compliquée. Toutefois le modèle ne doit être considéré qu'une partie d'un modèle plus général qui touche aussi tels problémes comme l'efficacité du emmagasinage systematique et l'emploi des données individuelles accumulées d'avance au cours de la procédure statistique. Afin qu'on puisse obtenir une mesure d'évaluation liée au emploi des produits statistiques, le modèle général doit encore spécifier comment le développement dans la population est influencé par des statistiques de qualité diverse.

References

(1) A.H. Browker: Tolerance Limits for Normal Distributions. Selected Techniques of Statistical Analysis, ed. by Eisenhart, Hostay and Wallis, McGraw-Hill, New York, 1947, p.p. 97-110.

(2) M.H. Hansen, W.N. Hurwitch and W.G. Madow: Sample Survey Methods and Theory, Vol. I and II, John Wiley & Sons, New York, 1953.

(3) S. Nordbotten: On the Determination of an Optimal Sample Size, Skandinavisk Aktuarietidsskrift, Uppsala 1954, p.p. 60-64.

(4) S. Nordbotten: On Errors and Optimal Allocation in a Census, Skandinavisk Aktuarietidsskrift, Uppsala 1957, p.p. 1-10.

(5) S. Nordbotten: Automatic Editing of Individual Statistical Observations, Conference of European Statisticians, Statistical Standards and Studies, No. 2, New York, 1963.

(6) L.H.C. Tippett: On Extreme Individuals and the Range of Samples Taken from a Normal Population, Biometrika, Vol. 17, 1925, p.p. 364-87.

6. Appendix

Table 1: Change impulses and effects

Change impulse	Prob. p'_m	Relative effect on a_{m2}	a_{m3}	a_{m5}	a_{m6}
1. Product price increase	0.800			0.050	
2. Product price decrease	0.100			-0.100	
3. Increase in salaries and wages	0.900	0.100			
4. Increase in cost of raw materials	0.800				0.050
5. Decrease in cost of raw material	0.100				-0.100
6. Increase in salaries and wages	0.700	0.040			
7. Decrease in salaries and wages	0.400	-0.050			
8. Increase in number of persons engaged	0.700		0.040		
9. Decrease in number of persons engaged	0.400		-0.050		
10. Increase in volum of production	0.700			0.040	
11. Decrease in volum of production	0.100			-0.020	
12. Increase in volum of raw materials	0.700				0.040
13. Decrease in volum of raw materials	0.400				-0.050
14. Unspecified impulse on salaries	0.100	-0.020			
15. Unspecified impulse on no. of persons	0.100		-0.010		
16. Unspecified impulse on cost of raw materials	0.100				-0.010
Mean effect		0.096	0.007	0.054	0.037

Table 2: Error impulses and effects

Error impulses	Prob. p_r	Relative effect on a_{r2}	a_{r3}	a_{r5}	a_{r6}
Class 1 and 2:					
1. Owner's income included in salaries	0.050	0.100			
2. Working owners excluded from persons engaged	0.050		-0.020		
3. Homeworkers included	0.010	0.100	0.100		
4. Raw materials for contract work included	0.010			0.050	0.050
5. Taxes included in cost of raw materials	0.010				0.050
6. Subsidies excluded from cost of raw materials	0.010				-0.050
Mean effect for class 1 and 2 impulses		0.0060	-0.0000	0.0005	0.0005
Class 3:					
7. Observation dublicated	0.001	1.000	1.000	1.000	1.000
8. Positive } decimal point shift in	0.001	9.000	9.000	9.000	9.000
9. Negative } all variables	0.001	-0.900	-0.900	-0.900	-0.900
10. Positive } decimal point shift in	0.005	9.000			
11. Negative } salaries and wages	0.005	-0.900			
12. Positive } decimal point shift in	0.005		9.000		
13. Negative } no. of persons engaged	0.005		-0.900		
14. Positive } decimal point shift in	0.005			9.000	
15. Negative } gross value of production	0.005			-0.9000	
16. Positive } decimal point shift in	0.005				9.000
17. Negative } cost of raw materials	0.005				-0.900
Mean effect for class 3 impulses		0.0496	0.0496	0.0496	0.0496
Class 4:					
18. Production in other establishments with higher productivity included	0.050	0.250	0.250	0.500	0.400
19. Production in other establishments with lower productivity included	0.050	0.500	0.500	0.250	0.200
20. Complete non-response	0.030	-1.000	-1.000	-1.000	-1.000
21. No response for salaries and wages	0.060	-1.000			
22. No response for persons engaged	0.030		-1.000		
23. No response for gross value of prod.	0.010			-1.000	
24. No response for cost of raw materials	0.100				-1.000
Mean effect for class 4 impulses		-0.0525	-0.0225	-0.0025	-0.1000
25. Unspecified impulses	0.050	-0.038	-0.014	-0.012	-0.038
Mean effect for all impulses		0.0012	0.0264	0.0470	-0.0518

Table 3: Decision Table A for automatic control

	Statement	Decision columns						
	IG = Y(1)							
	IG = ITAB(IG)							
	Y(2) . GT . 0	N						Y
	Y(3) . GT . 0		N					Y
	Y(5) . GT . 0			N				Y
	(Y(2)+Y(3).LE.G(1,IG)).AND				N			Y
1	(Y(2)/Y(3).GE.G(2,IG))							
	(Y(5)-Y(6))/Y(3).LE.G(3,IG)).AND					N		Y
1	(Y(5)-Y(6)/Y(3).GE.G(4,IG))							
	(Y(6)/Y(5).LE.G(5,IG)).AND.						N	Y
1	(Y(6)/Y(5).GE.G(6,IG))							
	DO 1 I = 1,6	X	X	X	X	X	X	
1	Y (I) = X (I)							
	IE = IE + 1							
	WRITE (10,900)(Y(I),I=1,6)[1)]	X	X	X	X	X	X	X
	IN = IN + 1							
	IF (IN - 9550) 2, 3, 3							
3	WRITE (20,901) IE							
2	CONTINUE							

1) Y(I) is here equivalent Z(I)

Table 4: Decision Table B for automatic control and correction

	Statements	Decision columns																						
	IG=Y(1)																							
	IG=ITAB(IG)																							
5	Y(2).GT.0	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y									
	Y(3).GT.0	N	N	N	N	Y	Y	Y	Y	N	N	N	N	Y	Y									
	Y(5).GT.0	N	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N									
	Y(6).GT.0	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y									
	(Y(2)/Y(3).LE.G(1,IG)).AND															N	N	N	N	Y	Y	Y	Y	
1	(Y(2)/Y(3).GE.G(2,IG))																							
	((Y(5)-Y(6))/Y(3).LE.G(3,IG)).AND.															N	N	Y	Y	N	N	Y	Y	
1	((Y(5)-Y(6))/Y(3).GE.G(4,IG))																							
	(Y(6)/Y(5).LE.G(5,IG)).AND.															N	Y	N	Y	N	Y	N	Y	
1	(Y(6)/Y(5).GE.G(6,IG))																							
	K.EQ.5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N		Y
	IF(K)3,4,3																						X	
4	DO 1 I=1,6																							
1	HD(I,IG)=Y(I) [1]																							
3	CONTINUE																							
	DO 2 I=1,6	X																						X
2	Y(I)=HD(I,IG)																							
	Y(5)=Y(6)*HD(5,IG)/HD(6,IG)		X																					
	Y(3)=Y(5)*HD(3,IG)/HD(5,IG)	X	X																					
	Y(3)=(Y(5)-Y(6)) HD(3,IG)/			X									X				X							
1	(HD(5,IG)-HD(6,IG))																							
	Y(3)=Y(2)*HD(3,IG)/HD(2,IG)									X	X	X												
	Y(2)=Y(3)*HD(2,IG)/HD(3,IG)		X	X	X	X	X	X	X							X		X	X					
	Y(5)=Y(3)*HD(5,IG)/HD(3,IG)					X				X	X			X										
	Y(5)=Y(6)+(HD(5,IG)-HD(6,IG)						X								X									
1	*Y(3)/HD(3,IG)																							
	Y(6)=Y(5)*HD(6,IG)/HD(5,IG)			X		X				X		X		X										
	Y(6)=Y(5)-(HD(5,IG)-HD(6,IG))							X								X		X		X	X	X		
	*Y(3)/HD(3,IG)																							
	K=K+1			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	GOTO 5																							
	K=0																						X	X
	WRITE (10,900)(Y(I),I=1,12) [2]																							

1) HD(I,IG) denotes the store&'hot deck value for variable I in industri group IG.
2) Y(I) is here equivalent to Z(I).

Table 5: Initial hot deck values

Industry ISIC	Variable Z_{i2}	Z_{i3}	Z_{i5}	Z_{i6}	No of establ. in sample
11, 12, 14, 15, 19	180	11	692	9	2
20	231	17	2112	1589	89
21, 22	1464	92	9270	816	3
23	367	30	1578	778	9
24	246	22	958	507	26
25	225	15	1159	625	27
26	260	20	830	347	30
27	1073	66	5623	2926	9
28	1137	59	3414	1269	32
29	387	32	1725	1083	6
30	127	6	360	190	1
31	1100	60	5720	1452	11
32	148	10	659	355	1
33	241	16	507	112	11
34	183	11	2567	1969	3
35	532	31	1533	650	26
36	562	35	2009	889	27
37	205	12	496	178	4
38	1765	98	6196	4022	31
39	124	11	329	97	2

Table 6: Tolerance interval limits

Industry ISIC	Y_{i2} / Y_{i3}		$(Y_{15} - Y_{i6})/Y_{i3}$		Y_{i6} / Y_{i5}	
	$\bar{G}$	$\underline{G}$	$\bar{G}$	$\underline{G}$	$\bar{G}$	$\underline{G}$
11[1]	0.00	0.00	0.00	0.00	0.00	0.00
12[1]	0.00	0.00	0.00	0.00	0.00	0.00
14[1]	18.66	16.00	63.94	50.66	0.01	0.00
15[1]	0.00	0.00	0.00	0.00	0.00	0.00
19[1]	0.00	0.00	0.00	0.00	0.00	0.00
20	25.23	3.00	92.41	46.81	1.49	0.44
21[2]	16.94	15.04	96.73	84.39	0.09	0.07
22[2]	0.00	0.00	0.00	0.00	0.00	0.00
23	18.33	8.57	179.77	11.57	0.68	0.26
24	15.09	12.42	44.00	6.00	0.73	0.25
25	20.90	4.00	47.82	7.25	0.80	0.34
26	19.41	8.00	37.28	14.37	0.70	0.25
27	19.37	12.34	60.84	23.28	0.62	0.25
28	22.95	3.66	81.88	14.55	0.63	0.00
29	14.59	8.35	34.40	12.00	0.68	0.57
30[2]	21.16	21.16	28.33	28.33	0.52	0.52
31[3]	20.31	6.00	106.88	7.00	0.75	0.19
32[3]	14.80	14.80	30.40	30.40	0.53	0.53
33	18.12	5.50	40.00	12.33	0.51	0.00
34	17.47	11.83	64.47	26.20	0.79	0.18
35	20.30	6.33	43.05	10.37	0.55	0.20
36	21.93	8.60	45.16	2.80	0.91	0.09
37	21.50	9.20	27.77	24.25	0.44	0.33
38	23.33	8.42	40.80	13.14	0.71	0.04
39	12.85	8.50	24.57	14.87	0.32	0.18

1) Considered as one group in the scheme with automatic correction
2) " " " " " " " " " "
3) " " " " " " " " " "

Table 7: Production time and quality indicators and ranking

Design alternatives	Actual production time	Indicators					Ranking				
		Q(2)	Q(3)	Q(5)	Q(6)	Q	V(2)	V(3)	V(5)	V(6)	V
1. Unintensive, automatic control, limited specification	$1<T<2$	$.49x10^{11}$	$.12x10^{9}$	$.18x10^{13}$	$.51x10^{12}$	$.24x10^{13}$	7	7	6	5	5
2. Unintensive, automatic control, full specification	$1<T<2$	$.93x10^{10}$	$.10x10^{8}$	$.24x10^{12}$	$.15x10^{11}$	$.26x10^{12}$	2	3	1	1	1
3. Unintensive, automatic control and correction, limited specification	$T<1$	$.73x10^{11}$	$.22x10^{9}$	$.31x10^{13}$	$.97x10^{12}$	$.41x10^{13}$	10	11	10	10	10
4. Unintensive, automatic control and correction, full specification	$T<1$	$.31x10^{11}$	$.10x10^{9}$	$.22x10^{13}$	$.77x10^{12}$	$.31x10^{13}$	4	5	9	9	9
5. Intensive, automatic control, limited specification	$1<T<2$	$.49x10^{11}$	$.12x10^{9}$	$.18x10^{13}$	$.51x10^{12}$	$.24x10^{13}$	8	7	8	8	8
6. Intensive, automatic control, full specification	$1<T<2$	$.10x10^{11}$	$.97x10^{7}$	$.25x10^{12}$	$.16x10^{11}$	$.28x10^{12}$	3	2	2	2	2
7. Intensive automatic control and correction, limited specification	$T<1$	$.89x10^{11}$	$.29x10^{9}$	$.15x10^{14}$	$.93x10^{13}$	$.25x10^{14}$	12	12	14	14	14
8. Intensive automatic control and correction, full specification	$T<1$	$.66x10^{11}$	$.21x10^{9}$	$.13x10^{14}$	$.75x10^{13}$	$.21x10^{14}$	9	10	12	13	13
9. Accurate observation of a sample, limited specification	$T<1$	$.47x10^{12}$	$.15x10^{10}$	$.11x10^{14}$	$.37x10^{13}$	$.15x10^{14}$	13	13	11	11	11
10. Accurate observation of a sample, full specification	$T<1$	$.68x10^{12}$	$.21x10^{10}$	$.14x10^{14}$	$.45x10^{13}$	$.20x10^{14}$	14	14	13	12	12
11. Complete, unintensive observation, limited specification	$T<1$	$.36x10^{11}$	$.13x10^{9}$	$.15x10^{13}$	$.48x10^{12}$	$.21x10^{13}$	6	9	5	6	5
12. Complete, unintensive observation, full specification	$T<1$	$.70x10^{10}$	$.23x10^{8}$	$.33x10^{12}$	$.96x10^{11}$	$.44x10^{12}$	1	4	4	4	4
13. Complete, accurate observation, limited specification	$2<T<3$	$.75x10^{11}$	$.11x10^{9}$	$.17x10^{13}$	$.48x10^{12}$	$.23x10^{13}$	11	6	7	6	7
14. Complete, accurate observation, full specification	$2<T<3$	$.34x10^{11}$	$.83x10^{6}$	$.27x10^{12}$	$.37x10^{12}$	$.34x10^{12}$	5	1	3	3	3