ELSEVIER

European Journal of Operational Research 92 (1996) 615–627

EUROPEAN JOURNAL OF OPERATIONAL RESEARCH

Theory and Methodology

An empirical application of the information-structures model: The Postal Authority case

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Received September 1993; revised March 1995

Abstract

The information-structures model is one of the fundamental models of information economics and the theory of information systems. It provides a theoretical framework for assessing the normative value of information. This paper applies the information-structures model to quality control attribute sampling, by analyzing a real life situation in the Postal Authority. The paper demonstrates how decision makers can assess the value of information of surveys, their cost effectiveness, and the value of information of a second survey.

Keywords: Information economics; Information structures; Value of information; Orthogonal information systems; Informativeness; Quality control

1. Introduction

The information-economics approach to evaluating the value of information is based on the information-structures (IS) model developed by Marschak (1971) and Radner (1986) and later expanded by Demski (1972), Ahituv (1981), Ahituv and Ronen (1988), Ahituv and Wand (1984), Marshall and Narasimhan (1989), Stinchcombe (1990) and others. The model describes the information system as a stochastic (Markov) matrix of probabilities which transforms states of nature to signals. The decision maker must select the optimal action under given values of a priori probabilities of states of nature, and given values of payoffs. The information-economics model proposes a partial rank ordering of information structures by using Blackwell's Theorem (McGuire, 1986).

There are but few applications of information economics in general and of the information-structures model in particular. Stohr (1979) uses the information-economics approach for optimal observing of inventory levels. Information economics was used in finance (Dow and Gorton, 1993; Hindy and Huang, 1992). Some experimental studies involve the value of information and the expected utility (Schoemaker, 1991). Hilton (1990) argues about the necessary and sufficient conditions of Blackwell's Theorem. Examples of quality

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SSDI 0377-2217(95)00109-3

control (QC) problems using the information-structures model were demonstrated by Wallack and Adams (1963) and Demski (1972). Further research conducted by Moskowitz and Berry (1976) suggested a method for finding an optimal sample. Ronen (1994) applied the information-structures theory and methodology to the practical area of quality control attribute sampling. Ronen and Spector (1995) added the risk dimension to the expected utility problem.

This paper's contribution is twofold: First, it demonstrates a real life case study in the Israel Postal Authority, where information structures was applied. The Israel Postal Authority (IPA) has for several years been carrying out a survey to measure the 'regular inland letter delivery time'. The survey constitutes a quality control system of the mail delivery service offered to the Israeli public. The IPA survey will serve us in applying Radner's information-structures model (McGuire and Radner, 1986) and Ronen's (1994) analysis concerning quality control systems.

Then, it adds to the literature the only real application (as far as we know) of field results using information economics.

Section 2 reviews the information-structures model. In Section 3 we review QC attribute sampling as a special case of the information-structures model. Section 4 describes the case of the Postal Authority survey on regular inland letter delivery time where the QC methodology is applied. In Section 5 the value of information of an additional survey is investigated. In Section 6 conclusions are drawn.

2. The information-structures model: A review

This section briefly reviews the information-structures model. For further details the reader is referred to McGuire (1986) or Ahituv (1981).

Let E be a finite set of *events* (states) of nature:
$E = \{e_1, \dots, e_{n_E}\}$.
Let π be the vector of a priori probabilities associated with the events in E:

$$\pi^t = (\pi_i, \dots, \pi_{n_E}), \qquad \sum \pi_i = 1, \quad \pi_i \geqslant 0, \ i = 1, \dots, n_E,$$

where t represents the transpose operation.

Let Z be a finite set of *signals*:
$Z = \{z_1, \dots, z_{n_Z}\}$.
An information structure or information matrix, Q, is an $n_E \times n_Z$ Markov (stochastic) matrix of conditional probabilities in which signals of the set Z will be displayed at the occurrence of events in E. Thus, q_{ij} of Q is the probability that for a given event e_i, signal z_j will be displayed. (If Q contains only 1 and 0 elements, then it is a noiseless information structure.)

Let A be a finite set of feasible *actions* to be taken by the decision maker:
$A = \{a_1, \dots, a_{n_A}\}$.

A cardinal *payoff* function, U, is defined from $A \times E$ to the real numbers, $\mathbb{R}$, associating payoffs to pairs of actions and events,
$U: A \times E \to \mathbb{R}$.
The function U can be depicted by an $n_A \times n_E$ matrix, U, whose elements reflect the payoff gained under any combination of action a_i of A and event e_j of E.

The decision maker does not observe the events, but only the signals; he (she) chooses actions according to these signals. The decision maker's *strategy* can be described by an $n_Z \times n_A$ Markov matrix, D, which contains the probabilities of taking certain actions after being stimulated by certain signals. Thus, d_{ij} of D is the probability that for a given signal z_i, action a_j will be taken. (If D contains only 1 and 0 elements, then D is a pure strategy.)

Let π be a square matrix with the elements of π_i on the main diagonal, and zeros elsewhere:

$$\pi = \begin{bmatrix} \pi_1 & & 0 \\ & \ddots & \\ 0 & & \pi_{n_E} \end{bmatrix}.$$

Then, the expected payoff of the combination of an information structure Q, a decision rule (strategy) D, a payoff matrix U, and a probability vector π will be $\mathrm{tr}(QDU\pi)$, where $\mathrm{tr}(\cdot)$ represents the trace operator (McGuire, 1986). Optimization means finding a Markov matrix D^* out of all possible $n_Z \times n_A$ Markov matrices D that maximizes $\mathrm{tr}(QDU\pi)$.

Let us define

$$F(Q, U, \pi) = \max_D \{\mathrm{tr}(QDU\pi)\}.$$

Let us further define the relationship $Q_A \geqslant Q_B$ (Q_B is not better than Q_A regarding U and π) if

$$F(Q_A, U, \pi) \geqslant F(Q_B, U, \pi).$$

Q_A is regarded as 'generally more informative' than Q_B (denoted $Q_A \geqslant Q_B$) if Q_B is not better than Q_A for all payoff matrices U and all probability vectors π.

The *Blackwell Theorem* (McGuire, 1986) states that $Q_A \geqslant Q_B$ if and only if $Q_A L = Q_B$, where L is a Markov matrix with the appropriate dimensions (for an interpretation and examples the reader may refer to Ronen, 1994, or Ahituv, 1981). The ordering $Q_A \geqslant Q_B$ is only a partial ordering of the set of finite information structures Q operating on a given state-of-the-world set.

The *gross value* of information is always a relative number comparing the expected payoff gained by using different information structures. For example, assume that utility is a linear function of payoff, and that Q_B is not better than Q_A. Then the value of the information of Q_A over Q_B is $F(Q_A, U, \pi) - F(Q_B, U, \pi)$ with an appropriate calibration (see example in Ronen, 1994).

3. Quality control sampling as information structures

This section briefly reviews the application of the information-structures model to QC sampling. For further details the reader is referred to Ronen (1994).

3.1. Sample plans and information matrices

A *sample plan* is a decision rule which specifies the sample size (n) and the maximum allowable number or percentage of defectives (c) measured in the sample. A plan is therefore specified by (n, c). For example, the plan (50, 2) reads as follows. Select a random sample of 50 units and count the number of defectives. If the number of defectives is equal to or lower than 2, accept the lot; otherwise reject it. In such attribute plans, items are judged dichotomically; for example, good or bad, acceptable or rejected. Hence an attribute plan of n units can display $n + 1$ different results (or signals) which correspond to the possible numbers of defectives identified by the inspection, that is, $0, 1, 2, \ldots, n$ defectives. Thus, a QC plan can be regarded as an information structure whose domain is the real quality of a lot (i.e., the percentage of defectives), and whose range is a set of $n + 1$ signals.

An *information matrix of a sample*, M, is defined as an information matrix of a sample of size n if it is a Markov matrix as follows:

1) $M = \{m_{ij}\}$, $i = 1, \ldots, n_E$; $j = 1, \ldots, n + 1$; $\Sigma_i m_{ij} = 1$ for all j.
2) The number of rows is equal to the number of states of nature, which are the possible percentages ratios of defective items, $E = \{P_1, \ldots, P_{n_E}\}$.

3) The number of columns is equal to the number of different signals, which give the possible amounts of defective items in the sample: $y = 0, 1, \ldots, n$.
Thus M is an $n_E \times (n+1)$ matrix as follows:

$$M = \begin{matrix} P_1 \\ \vdots \\ P_{n_E} \end{matrix} \overset{y=0,\ y=1,\ldots,\ y=n}{\begin{pmatrix} & & \\ & m_{ij} & \\ & & \end{pmatrix}}.$$

4) $m_{ij} = \Pr(y = j-1 \mid P = P_i)$, $i = 1, \ldots, n_E$; $j = 1, \ldots, n+1$.

For convenience, the states of nature will be arranged in an increasing order, so that $P_1 < P_2 < \cdots < P_{n_E}$. This sorting will not change the generality of the problem (see Marschak, 1971). For examples of QC, the reader may refer to Ronen (1994).

3.2. The decision matrix of a sample

D is a decision matrix of a sample of size n if D is an $(n+1) \times 2$ Markov matrix that associates signals with decisions. The signals are the number of defectives ($y = 0$ through $y = n$), and the decisions are 'accept' or 'reject' the whole lot.

3.3. The prior probability vector and the payoff matrix

The *prior probability vector* is a vector $\pi = \{\pi_1, \ldots, \pi_{n_E}\}$ whose elements are the prior probabilities of the n_E states of nature, $P_1, \ldots, P_{n_E}$ (where $P_1 < P_2 < \cdots < P_{n_E}$). Note that π is defined for both the plan and the sample matrices.

The *payoff matrix U* is a $2 \times n_E$ matrix in which each element u_{ki} displays the payoff related to a decision k ('accept' or 'reject') and to the occurrence of the state of nature i.

4. The survey on 'regular inland letter delivery time'

The Israel Postal Authority (IPA) delivers about 1.5 million miscellaneous postal articles daily (letters, postcards and printed matter) in, to and from Israel. The operating process of regular mail delivery begins when postal articles are deposited (through mailboxes, post offices or directly at the sorting center). These articles are then collected and delivered to the sender's local sorting station, where they are sealed and sorted by place of destination. After being sorted, the articles are sent to the place of destination. There they undergo primary sorting by delivery area; subsequently they are passed on to the mailman's table, who sorts his articles by address and according to his usual route.

The survey on 'regular inland letter delivery time' is carried out by sending 'experimental letters', which go through the entire operating process previously described, and help measure the time taken up by the process, from the sender's mailbox to the addressee's home or P.O. Box. Addressees are picked at random from population registers and from lists of P.O. Box holders. Each letter includes a stub, and the addressee is asked to fill in data about the date and time of the letter's arrival. The answers are entered into a computer and processed to yield statistical results which include the average delivery time of a regular inland letter, the distribution of letters according to their delivery time, the average delivery time of a letter within city limits, the average delivery time of letters sent to a certain district, etc.

4.1. The survey as an IS

In order to define a system as an information system, we must describe the matrices U, D, P and π, defined in Section 3.

The prior vector P

To check the quality of inland letter delivery services, the IPA sends 21 000 experimental letters monthly all over Israel. In this paper the analysis will be carried out on the *intra-Tel-Aviv* part of the survey, i.e. only letters that are both sent from and addressed to Tel-Aviv. We will now adapt the QC methodology to this special case.

The sample matrix M

The *states of nature* correspond to the possible proportions of defective 'items' $(P_1, \dots, P_{n_E})$, i.e. the proportions of 'defective letters'; define a 'defective letter' as a letter whose delivery time exceeds 1.2 days. The signals are defined as the number of possible defects in the sample, $Y = 0, 1, \dots, n$.

Mailboxes across town are emptied 3 to 4 times daily. Sorting of all postal articles collected during the day takes place the night following. In Tel-Aviv their delivery is carried out by mailmen the morning after. In addition, problems can come up which are almost inevitable in a system which delivers 1.5 million postal articles daily: sorting errors, mailbag routing errors, vehicle routing errors, vehicle breakdowns, etc. Therefore a quality service marker was set, consisting of 1.2 days from the mailbox drop until home delivery.

The number of rows in the information matrix M equals the number of states of nature (n_E); the number of columns equals the number of signal possibilities $(n + 1)$; see the equation in Section 3.1. In our case M is of size $n_E \times 201$ since 200 'experimental letters' are sent within Tel-Aviv (21 000 letters are sent all over Israel; see Section 4.1). Its elements are the binomial probabilities

$$m_{ij} = \binom{201}{j} P_i^j (1 - P_i)^{201-j}.$$

States of nature

The probabilities of the states of nature, according to past experience, are as follows: $P_1 = 0.05$, $P_2 = 0.07$, $P_3 = 0.08$, $P_4 = 0.09$, $P_5 = 0.10$, $P_6 = 0.11$, $P_7 = 0.12$, $P_8 = 0.13$, $P_9 = 0.14$, $P_{10} = 0.15$, $P_{11} = 0.16$, $P_{12} = 0.17$, $P_{13} = 0.20$, where P_i is the percentage of 'defective letters' whose delivery time exceeds 1.2 days. In this case, matrix M will look as follows:

$$M = \begin{array}{c} \\ 0.05 \\ 0.07 \\ 0.08 \\ 0.09 \\ 0.10 \\ 0.11 \\ 0.12 \\ 0.13 \\ 0.14 \\ 0.15 \\ 0.16 \\ 0.17 \\ 0.20 \end{array} \!\!\! \begin{array}{c} 0, 1, 2, 3, \dots, 200 \\ \left[\begin{array}{c} \quad \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \quad \end{array} \right] \end{array},$$

where, e.g.

$$m_{5,0} = \Pr(Y = 0 \mid P = P_5 = 0.10) = \binom{201}{0} \cdot 0.1^0 \cdot 0.9^{201} = 6.35 \cdot 10^{-10},$$

$$m_{5,1} = \Pr(Y = 1 \mid P = P_5 = 0.1) = \binom{201}{1} \cdot 0.1^1 \cdot 0.9^{200} = 1.42 \cdot 10^{-8},$$

$$m_{5,10} = \Pr(Y = 10 \mid P = P_5 = 0.1) = \binom{201}{10} \cdot 0.1^{10} \cdot 0.9^{191} = 4.3 \cdot 10^{-3}.$$

The QC plan matrix

In our case we determine the acceptance number at 10% of the survey: $C = 20$ (see Section 3.1). This choice was based on cost and risk considerations (see Ronen and Spector, 1995). Hence the resulting matrix Q (see Section 2) will be as follows:

$$Q = \begin{array}{c} \\ 0.05 \\ 0.07 \\ 0.08 \\ 0.09 \\ 0.10 \\ 0.11 \\ 0.12 \\ 0.13 \\ 0.14 \\ 0.15 \\ 0.16 \\ 0.17 \\ 0.20 \end{array} \begin{array}{c} \begin{array}{cc} Y \leqslant 20 & Y > 20 \end{array} \\ \left[\begin{array}{cc} 0.999 & 0.001 \\ 0.959 & 0.044 \\ 0.873 & 0.127 \\ 0.731 & 0.269 \\ 0.550 & 0.450 \\ 0.368 & 0.632 \\ 0.219 & 0.781 \\ 0.116 & 0.884 \\ 0.055 & 0.945 \\ 0.024 & 0.976 \\ 0.009 & 0.991 \\ 0.003 & 0.997 \\ 0.000 & 1.000 \end{array} \right] \end{array}.$$

q_{12}, for example, is the summation of $m_{1,0}$ to $m_{1,20}$ as calculated in the previous matrix.

The a-priori probability vector π

Based on past experience, we take in our case

$$\pi^t = [0.069, 0.034, 0.034, 0.138, 0.207, 0.034, 0.138, 0.069, 0.103, 0.034, 0.069, 0.034, 0.034].$$

The same probability vector is used both with the sample information matrix M, and with the plan information matrix Q.

The payoff matrix U

In our case (in thousands of dollars) we take

$$U = \begin{array}{c} \\ \text{'no'} \\ \text{'0'} \end{array} \begin{array}{c} \begin{array}{ccccccccccccc} 0.05 & 0.07 & 0.08 & 0.09 & 0.10 & 0.11 & 0.12 & 0.13 & 0.14 & 0.15 & 0.16 & 0.17 & 0.20 \end{array} \\ \left(\begin{array}{ccccccccccccc} 0 & 0 & 0 & 0 & 0 & -30 & -40 & -50 & -60 & -70 & -80 & -90 & -100 \\ -9 & -8 & -7 & -6 & -5 & 21 & 31 & 41 & 51 & 61 & 71 & 81 & 91 \end{array} \right) \end{array}.$$

We assume that service quality influences only one percent of total stamp sales within Tel-Aviv.

According to *IPA management*, a 'very good lot' is one that contains less than 10% defectives. A 'good lot' is one that contains between 10% and 20% defectives, and a bad one contains 20% defectives.

1. Whenever 'the lot is not good', i.e. $P_{11} = 0.2$, and 'nothing is done' to remedy the situation, the IPA loses one percent of sales. In other words, the IPA loses customers and income it would have received, had it taken remedial steps.
2. The 'better' the lot, i.e. $P_i < 0.2$, the less the IPA loses if it 'does not do anything' to remedy the situation, until the proportion of defectives reaches 10%, which is a 'good lot'.
3. Whenever $P_{i\nu} \leqslant 0.1$, the IPA does not win or lose anything by choosing 'not to do anything', since these proportions of defectives are 'good' and no remedial steps are needed.
4. Whenever 'the lot isn't good', i.e. $P_{13} = 0.2$, and the IPA decides to 'do', i.e. to remedy the situation, it stands to win over potential customers and get back one percent of sales it lost as a result of poor service quality. But we must subtract the cost of the remedial steps; for example, the purchase of a new machine, the hiring of an additional employee. (This is a rigorous assumption since in most cases, service quality can be improved at no extra cost.)

5. As lots get 'better', i.e. $P_i < 0.2$, the IPA continues to receive what it would have lost as a result of poor service quality (for each P_i separately), minus the remedial costs.
6. When $P_i = 0.05$, the IPA loses the remedial costs if it chooses to take unnecessary corrective measures, which have no additional benefits.
7. Whenever $0.05 < P_i < 0.11$, the IPA loses the remedial costs if it chooses to take corrective measures, but it earns a marginal sum stemming from an additional improvement in the quality of service, from 'good' to 'very good'.

Attributes of the quality control payoff matrix

In any quality control matrix U of one-time acceptance control by attributes, only one of the following three situations can take place:

(a) 'acceptance preference': $U_{1,i} \geqslant U_{2,i}$ for all i.
(b) 'rejection preference': $U_{1,i} \leqslant U_{2,i}$ for all i.
(c) 'selective preference': there is an i^* such that

$$U_{1,i}\begin{cases} \geqslant U_{2,i}, & i \leqslant i^*, \\ \leqslant U_{2,i} & i \geqslant i^*. \end{cases}$$

In situations of 'acceptance preference' or 'rejection preference' the value of information is zero, and there is no need to carry out acceptance control, since lots will always be accepted or reject regardless of test results. In other words, there exists a decision rule (a certain decision matrix) preferable to any other decision rule, independent of the received signal and of the a-priori probabilities. Looking at the nature of the payoff matrix U, we can see that our case is in a 'selective preference' situation, with $i^* = 5$.

Theorem (Ronen, 1994). *Let Q be a quality control plan matrix with elements q_{ij}, where $i = 1, \ldots, n_E$, $j = 1, 2$. Let U be the payoff matrix with elements U_{ij}, where $i = 1, 2$ and $j = 1, \ldots, n_E$. Then*

$$\sum_{i=1}^{n_E} \pi_i(q_{i1} - q_{i2})(U_{1i} - U_{2i}) \geqslant 0$$

is a necessary condition for the positive gross benefits of quality control sampling.

In our case we get

$$\sum_{i=1}^{1i} \pi_i(q_{i1} - q_{i2})(U_{1i} - U_{2i}) = 49{,}238 > 0.$$

Hence it in worthwhile to carry out quality control.

The decision matrix D

We distinguish between a sample decision matrix and a plan decision matrix.

(a) *Sample decision matrix.* In the case of our survey, the decision alternatives are:

1) 'Do nothing', i.e. 'accept lot'. The survey indicates that the mail delivery process within Tel-Aviv (for example) meets management's demands. Hence there is no need for corrective measures.
2) 'Take corrective measures', i.e. 'reject lot'. The survey indicates that something in the process is amiss and there is a need for corrective measures to remedy the situation. This decision may be split into several sub-decisions in accordance with the remedial steps required. For example, if the problem is known to be in the sorting stage of the process, decisions can be taken along the lines of hiring additional sorters, replacing existing sorters, purchasing an automatic sorting machine, and the like.

Nevertheless, the survey's purpose is firstly to determine whether there is or is not a problem in a given route od mail delivery, and only after determining which route is in fact responsible, do we study it in detail in order to decide which remedial steps ought to be taken.

The decision matrix D looks like this:

$$\begin{array}{c} \\ Y=0 \\ Y=1 \\ \vdots \\ Y=200 \end{array} \begin{array}{c} \text{'do nothing'} \quad \text{'do'} \\ \left[\begin{array}{cc} & \\ & \\ & \\ & \end{array} \right] \end{array}$$

(b) *QC plan decision matrix*. In our case the decision matrix will look like this:

$$\begin{array}{c} \text{signal} \\ Y \leqslant 20 \\ Y > 20 \end{array} \begin{array}{c} \text{decision} \\ \text{'do nothing'} \quad \text{'do'} \\ \left(\quad d_{ij} \quad \right) \end{array}$$

Strategies are pure if the elements of D are all 0's and 1's; they are mixed if at least two elements are fractions. D is obtained after solving a linear programming problem, as we shall see next.

Decision matrix and expected payoff

As stated above, D will be obtained by solving the following linear programming problem:

$$F(Q, U, \pi) = \underset{D}{\text{Max}} \ \{\text{tr}(QDU\pi)\}.$$

It can be seen that $D^* = I$, the unit matrix, is the optimal decision matrix for the information system Q:

$$\begin{array}{c} \\ Y \leqslant 20 \\ Y > 20 \end{array} \begin{array}{c} \text{'do nothing'} \quad \text{'do'} \\ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \end{array}.$$

The expected income in this case is $F = \text{tr}(QDU\pi) = \$20\,804$. Suppose there were no information system, i.e.

$$Q_1 = \begin{pmatrix} 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{pmatrix}^{t}.$$

The expected income would then be $F = \text{tr}(Q_1 DU\pi) = -\$3.815$. In other words, the information system yields a net expected information value of $F_{\text{net}} = 20\,804 - (-3.815) = \$24\,619$. As stated before, the above sum is the monthly benefit for the intra-Tel-Aviv part of the survey. The yearly expected information in this part alone is worth about \$300 000. Consequently, the expected information value for the state of Israel is 2 million US dollars a year (postal articles within Tel-Aviv constitute about 40% of all postal articles sent from Tel-Aviv, and articles sent from Tel-Aviv constitute about 46% of articles sent throughout Israel). It should be noted that the IPA's Economic Department carries out various surveys, in addition to the one on regular inland letter delivery. These surveys concern deliveries of parcels, registered letters, large envelopes, express mail and so on.

In our case, the maximal information value occurs when the information system is *perfect*:

$$Q_2 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}^{t}.$$

Then $F = \text{tr}(Q_2 DU\pi) = 25\,895$. Hence the net value of perfect information is $F_{\text{perfect information}} = 25\,895 - (-3.815) = \$29\,710$. Even if it were technically possible to 'track' each and every letter going through the system, it would not be economically worthwhile since such 'tracking' would (obviously) cost more than the value of perfect information.

The normative, perceived and realistic values of information

We will now compare the normative, perceived and realistic values of information obtained in this case.

The normative value. The normative value is the value of information measured by a quantitative analytic model of the link between the organization's performance and information (Ahituv, 1980).

The task of a quality control system is to ensure that products or services meet a given standard. The process of quality control is paramount in a service organization such as the IPA, since good service is a central aim and can influence many of the organization's performance indicators facets, such as income, reputation and sales. For example, an information control system for errors in the sorting and channelling of postal articles and parcels may save unnecessary investment of resources on delivery of the postal article through the system up to its correct destination. The QC system's task is to discover errors which repeat themselves, and to treat their causes. Quality control is mainly based on the statistical analysis of surveys, and the correction of the entire 'population', based on the survey's results. According to the information-structures model, when measuring the normative value of information in a quality control system, the quality control system is 'translated' into a Markovian matrix, as explained above. The analysis of the 'regular inland letter' survey's normative value appears above.

The perceived value. The perceived value of information is the information's subjective value, as seen by the decision maker. The importance of the survey's information may be estimated by the number of phone calls reaching the IPA's Statistics Department; these calls are from districts managers and others in the IPA, asking to know the survey's results before their release. This information also serves as evidence in the meetings which take place at IPA management (attended by the IPA's Director General and its department and districts managers), on details of the survey's results. The importance attributed to the survey's results by the Director General largely influences the perceived value in the eyes of other decision makers. If the Director General appreciates the survey as a good and effective management tool and uses its results for decision making purposes, other managers and IPA workers will appreciate the survey accordingly. The above analysis is true for any organization, not just the IPA. The value of information is not always measured in money terms. Nevertheless, in order to compare the normative, perceived, and real values of the survey, we asked a number of IPA decision makers what value they place on the survey: How much would they be willing to pay for it to be carried out? The average answer was $18 000 a month, which translates to $220 000 a year.

The realistic value. The realistic value of information is measured as the actual marginal improvement in the managing system's performance as a result of the introduction of the information system, i.e. the difference between system performance with and without the information. This value is difficult to measure or estimate, since it is difficult to divorce the information system's influence from other environmental influences.

In our estimate, system performance improved by about $21 000 a month as a result of the quality of service survey. This estimate is based on a comparison of system performance (stamp sales) before and after the survey's introduction. In order to neutralize environmental influences on system performance, the following components were taken into account: rate hikes, natural economic growth, the consumer price index, and growth in population and in the gross national product. After accounting for the above factors, we obtained a real growth of about $250 000 a year in system performance. This translates to $21 000 monthly.

Comparison of normative, perceived and real values of the 'regular inland letter delivery time survey'

As stated above, we obtained:

Normative value: $300 000.
Perceived value: $220 000.
Realistic value: $250 000.

It can be seen that decision makers greatly appreciate the survey as a valuable tool which assists them in decision making. However, they do not appreciate its full normative value, probably because they are not aware of its full significance and influence on system income and profitability. The above data also show that the survey is economically worthwhile, since the utility it brings is greater than its cost (which is about $36 000 a year). It should be pointed out that the above values of an information system can change with time. The normative value can change as a result of changes in the payoff matrix or in the a-priori probability vector; the perceived value can change for example as a result of shifts in management policy; and the real value can change as a result of changes in the managing system's performance.

5. The value of an additional survey

In addition to its regular survey, which measures letter delivery time, the IPA commissions additional surveys to be carried out by external, independent firms. One example is the 'complementary survey'. The purpose of the 'complementary survey' was to get complementary information on letter delivery times at the different stages of the mail delivery process; these stages are not detailed in the 'regular inland letter delivery time' survey. The 'complementary survey' sampled 'live' letters within the system (as opposed to 'planted' experimental letters in the regular survey), at different stages of their delivery process:

- from the time they are collected and until completion at the following stations:
  - sorting;
  - internal mailmen;
  - mailman's table;
- from the mailman's table to their destination, through telephone polls among addressees whose letters were in the mailman's table before he set out on his route.

The 'complementary survey's' information matrix R is defined over the same set of states of nature as the regular inland letter delivery time survey's information matrix P. Let the matrix R be the information matrix of plan (500, 55) of the 'complementary survey'. This definition enables us to obtain a more informative system than the P matrix of the regular survey, since the 'complementary survey' offers more detailed information as to the different stages in the operational process.

$R =$

	$Y \leq 55$	$Y > 55$
0.05	1.000	0.000
0.07	1.000	0.000
0.08	0.993	0.007
0.09	0.945	0.055
0.10	0.791	0.209
0.11	0.530	0.470
0.12	0.266	0.734
0.13	0.098	0.902
0.14	0.027	0.973
0.15	0.005	0.995
0.16	0.001	0.999
0.17	0.000	1.000
0.20	0.000	1.000

R's expected income, when π, U and D are identical to those of P, is
$F_R = \text{tr}(RDU\pi) = \$21\,149$.

Hence, R is more informative than P: $F_R - F_P = 21\,149 - 20\,804 = \$345$.
The expected gross benefit of using information system R (the complementary survey) is \$345 a month greater than the expected benefit of using information system P (the regular survey), when each system is used separately.

Systems P and R are independent and thus mutually orthogonal (see Ahituv and Ronen, 1988).

The inclusive information system S

An inclusive information system is one which is composed of two or more orthogonal information systems; see Ronen (1994) for more details.

S will be calculated by the orthogonal product $S = P@R$ or

$$S = \begin{pmatrix} 0.999 & 0.001 \\ 0.956 & 0.044 \\ 0.873 & 0.127 \\ 0.731 & 0.269 \\ 0.550 & 0.450 \\ 0.368 & 0.632 \\ 0.219 & 0.781 \\ 0.116 & 0.884 \\ 0.055 & 0.945 \\ 0.024 & 0.976 \\ 0.009 & 0.991 \\ 0.003 & 0.997 \\ 0.000 & 1.000 \end{pmatrix} @ \begin{pmatrix} 1.000 & 0.000 \\ 1.000 & 0.000 \\ 0.993 & 0.007 \\ 0.945 & 0.055 \\ 0.791 & 0.209 \\ 0.530 & 0.470 \\ 0.266 & 0.734 \\ 0.098 & 0.902 \\ 0.027 & 0.973 \\ 0.005 & 0.995 \\ 0.001 & 0.999 \\ 0.000 & 1.000 \\ 0.000 & 1.000 \end{pmatrix} = \begin{pmatrix} 0.999 & 0.000 & 0.001 & 0.000 \\ 0.956 & 0.000 & 0.044 & 0.000 \\ 0.867 & 0.006 & 0.126 & 0.001 \\ 0.691 & 0.040 & 0.254 & 0.015 \\ 0.435 & 0.115 & 0.356 & 0.094 \\ 0.195 & 0.173 & 0.335 & 0.297 \\ 0.058 & 0.161 & 0.208 & 0.573 \\ 0.011 & 0.105 & 0.087 & 0.797 \\ 0.001 & 0.054 & 0.026 & 0.919 \\ 0.000 & 0.024 & 0.005 & 0.971 \\ 0.000 & 0.009 & 0.001 & 0.990 \\ 0.000 & 0.003 & 0.000 & 0.997 \\ 0.000 & 0.000 & 0.000 & 1.000 \end{pmatrix},$$

where:

$S_{11} = P_{11} \times R_{11} = 0.999 \times 1 = 0.999,$

$S_{12} = P_{11} \times R_{12} = 0.999 \times 0 = 0.000,$

$S_{13} = P_{12} \times R_{11} = 0.001 \times 1 = 0.001,$

and so on.

The optimal decision matrix is obtained by solving the following linear programming problem:

$$F(S, D^*, U, \pi) = \operatorname*{Max}_D \{\text{tr}(SDU\pi)\}.$$

It is easily seen that the optimal decision matrix is

$$D^* = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \end{pmatrix}^t,$$

and S's expected income is $F_s = \text{tr}\{SD^*U\pi\} = \$24012$.

We see that the value of information resulting from the use of the inclusive information system is higher than the value of information resulting from the separate use of each system:

$F_P = \$20804$; $F_R = \$21149$; $F_S = \$24012$.

So the addition of the 'complementary survey' system to the regular survey increased the value of information by

$F_S - F_P = 24012 - 20804 = \$3208$

per month, which is about $40000 a year.

We may now perform a cost-effectiveness check on the 'complementary survey'. We know the complementary survey costs the IPA about $10000 a month. Optimal use of the survey's result by combining it with the regular survey (i.e. an inclusive system) will increase the IPA's expected income by $3208 per month. Hence we might conclude that the 'complementary survey' is *not* worthwhile. We must bear in mind, though, that the expected income in question deals only with 'do'/'do nothing' decisions, whereas the 'complementary survey' helps us decide, in the case of a 'do' decision, 'where' and 'what' to do. This additional utility is not included in the above analysis, so the 'complementary survey' creates an additional information system whose states of nature are: 'sorting problem', 'delivery problem', etc. The signals received by the decision maker guide him towards the location of the problem. The information system will look as follows:

$Q =$		sorting problem	delivery problem
	sorting problem		
	delivery problem		

In addition, decisions taken by the decision maker will relate to a specific problem, as opposed to general problems. For example, let us assume the 'complementary survey' gives us perfect information:

$$Q = \begin{array}{r} \\ \text{sorting problem} \\ \text{delivery problem} \end{array} \begin{array}{c} \begin{array}{cc} \text{sorting problem} & \text{delivery problem} \end{array} \\ \begin{pmatrix} 1 & \quad\quad 0 \\ 0 & \quad\quad 1 \end{pmatrix} \end{array}.$$

Further we assume

$$U = \begin{array}{r} \\ \text{replace sorter} \\ \text{replace mailman} \end{array} \begin{array}{c} \begin{array}{cc} \text{sorting problem} & \text{delivery problem} \end{array} \\ \begin{pmatrix} 40\,000 & -3\,000 \\ -5\,000 & 30\,000 \end{pmatrix} \end{array}.$$

From past experience we know that 80% of the cases are sorting problems and 20% are delivery problems. The linear programming solution yields

$$D^* = \begin{array}{r} \\ \text{sorting problem} \\ \text{delivery problem} \end{array} \begin{array}{c} \begin{array}{cc} \text{replace sorter} & \text{replace mailman} \end{array} \\ \begin{pmatrix} 1 & \quad\quad 0 \\ 0 & \quad\quad 1 \end{pmatrix} \end{array}.$$

and the expected income is

$$F = \operatorname{tr}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \times \begin{pmatrix} 40\,000 & -3\,000 \\ -5\,000 & 30\,000 \end{pmatrix} \times \begin{pmatrix} 0.8 & 0 \\ 0 & 0.2 \end{pmatrix} = \$38\,000.$$

In other words, there is an added expected utility of \$38 000 in addition to the \$3208 utility resulting from use of the orthogonal system.

As mentioned before, the purpose of the complementary survey was to improve the existing system's informativeness with respect to the different stages of the operational process. In retrospect it turned out that the complementary survey's results, insofar as they concerned the entire process (from the time the letter is mailed till its final delivery), were very similar to those of the regular survey. In other words, the complementary survey served to control the existing information system (the regular survey), and to confirm its results.

6. Conclusion

Information systems are important decision making tools. The information provided by these systems is used by decision makers as 'signals' which refer to various 'states of nature'.

Nowadays there exist many organizational information systems. The organizations' decision makers intuitively value these systems, although they find it difficult to quantify their value and to check them as to their cost-effectiveness.

The Israel Postal Authority (IPA) is an organization with many information systems. One of these systems is the 'regular inland letter delivery time survey', which was analyzed in this paper as a service quality control system. The main conclusions stemming from our analysis are:

1) The survey is a valuable decision support system, assisting decision makers in taking the right decisions as to improvements and corrective steps needed in the mail delivery operational process. The survey's utility exceeds its costs; hence it is an economically worthwhile survey to carry out.
2) Occasional 'complementary surveys' are also recommended. These surveys are 'orthogonal' to the existing information system, improve its informativeness, and guide decision makers to present-state optimal decisions. In addition, they constitute a control system on the existing system.

The above analysis of the specific IPA survey can be carried out for any organization's information system. Analyzing an information system according to the normative model will first and foremost 'order' one's thinking and decision-making processes, directing one to the system's main factors. In addition, analyses like the one presented herein enable us to carry out cost effectiveness tests, check the usefulness of creating and operating information systems, and check the usefulness of creating and operating orthogonal information systems.

Acknowledgement

The authors wish to thank an anonymous referee for his/her enlightening comments and efforts.

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