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TIMELINESS OF INFORMATION: A BASIC MODEL

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ABSTRACT

The recency of information is determined by the factors: update processing delay (turnaround time), update interval, retrieval delay (response delay), and decision delay. The effects of these factors are different in scheduled as opposed to triggered decision-making. Costs and benefits of more recent information are tentatively modeled.

Keywords: timeliness, response time, delay, model, framework, costs, benefits.

1. INTRODUCTION

In this paper we shall examine the timeliness of information, also known under such headings as recency, currency, delay, response time, age. We limit ourselves to the role of information in managerial decision-making. We concentrate on the management information system (MIS), as far as it is so much formalized that it can be computerized. We use the following framework. Let an event - often called a transaction in data processing (DP) terminology - occur at the point of time t_0. Then this event leads to the creation of a data image (one or more records) - or to the change of existing records - at a time t_1 with $t_1 \geq t_0$. In on-line data-capture systems $t_1 \downarrow t_0$ where the symbol $\downarrow$ means that t_1 approaches t_0 "from above". These data - together with other data - influence a decision made at time t_2 with $t_2 \geq t_1$. In real-time systems it is possible that $t_2 \neq t_1$. The decision - together with non-controllable (environmental) variables - changes the real world including the own organization, at a time t_3 with $t_3 \geq t_2$. The inertia of technology creates this delay; van Aken (1978, p. 160). The lag $t_3 - t_2$ depends primarily on the characteristics of the real-world system, not on the data processing system. Nevertheless relations with the DP system are possible. For instance, in inventory systems the delivery (lead) time is reduced when the buyer's DP system is connected to the supplier's DP system; likewise machine switchovers may take less time with numerically controlled equipment. The state of the real-world system at a time t_4 ($t_4 \geq t_3$) depends on the history (time path) of decisions and environmental variables up to t_4. (In Markov systems the state at time t_4 depends only on the state at a single prior point of time .)

We shall distinguish between decision-making <u>triggered</u> by some external event like the arrival of a customer, and decision-making scheduled at fixed points of time. Unscheduled decisions occur at stochastic (probabilistic) points of time. According to Blumenthal (1969) middle-management makes primarily periodic decisions, top-management makes irregular decisions, and lower management is involved in real-time decision-making.

Our discussion of the timeliness of information is related to, yet different from, Emery (1971, pp. 33-37), Gregory & Atwater (1957) and Gregory & van Horn (1963, pp. 576-580). The most detailed discussion can be found in Gregory & Atwater (1957) which, however, is completely batch-oriented. Delays are also discussed by Knutsen & Nolan (1974, p. 34) and Strassmann(1970). Braat (1973) studies the effects of control frequency on DP costs and operating costs. Several additional references can be found in Bonney (1969, p. 122).

2. UNSCHEDULED DECISIONS

Let us consider the various elements affecting the recency of information. In arbitrary order we distinguish:
(i) Update processing delay P: When data are submitted to the computer, it requires P time units to process them. We decided to include in this delay the input time needed by human operators such as key-punch typists. In batch systems P is certainly not negligible, and is known as turnaround time. In on-line systems individual transactions can be processed, in which case P is small: $P \downarrow 0$.
(ii) Update interval I: Data can be collected over I time units before being submitted for processing. In on-line data-capture systems - such as point-of-sale (POS) systems - this interval is virtually zero since individual transactions are processed. In batch systems, by definition, I is certainly not negligible. In an organisation the magnitude of I is often based on tradition.
(iii) Retrieval delay R: If the decision maker asks information at time t, the information comes available at time $t + R$. This is known as response time in real-time systems. As we mentioned under (i), the turnaround time in batch systems is associated with the processing time P. If in a batch system an ad-hoc question arises then a special program might be submitted, and the time it takes to obtain the answer might be denoted by R rather than P. In the normal batch situation, however, R corresponds to the time it takes to retrieve the desired data manually in the output that was produced in P time units. Observe that a system may have on-line retrieval (R small), combined with periodic (say weekly) batch updating of the data base: I = 1 week, P not small.
(iv) Decision delay D: When the information is available, the decision maker needs time to reach a decision. An additional component is the time it takes to affect the physical system itself, after the decision has been made. For instance, in production scheduling this time component comprises machine

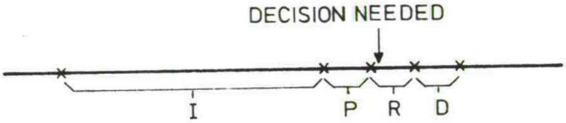

Figure 1: MINIMUM TOTAL DELAY

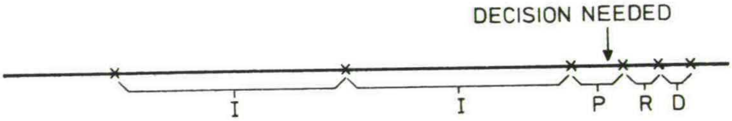

Figure 2: MAXIMUM TOTAL DELAY

set-up times; in inventory control the delivery or lead time is such a time lag; see the time lag $t_3 - t_2$ in section 1. In our approach we have included this reaction delay within D.
Note that the above classification differs from the classical categorization in EDP, where one distinguishes data collection, recording, transmission, processing, storage, retrieval and display.

In the following discussion the reader may look ahead at Table 1. In a batch system the minimum total delay occurs if the decision happens to be required, immediately after the information has been updated and processed; see Fig. 1 (none of the following figures are supposed to have a correct scale). Hence, at the moment the physical system changes, the decision is based on information of age P + R + D. This minimum age holds if the information reflects the status of a variable like inventory, not if the information reflects individual events such as orders over the update interval I. The status variable is important in, say, ordering new stock. The individual events may be of interest in finding out the maximum size of an individual order. In banking individual events may be relevant because of a rule like "If the maximum account withdrawal is larger than x, then do immediately ... ". For individual events the minimum age is P + R + D, the same as for status information. The maximum age is I units higher, assuming that at an update point all previous events are available in an appropriate summarized form, say a frequency diagram. Hence, if events occur at a constant rate, the average or expected age is I/2 + P + R + D.

The maximum total delay occurs if the decision is triggered immediately before new information has been processed; see Fig. 2. Hence, we add an extra I time units to all corresponding entries in Table 1. If the probability of triggered decisions is constant over time, then the expected delay is the average of the corresponding minimum and maximum total delays; see the last row of Table 1. Observe that in general the component I will be large relative to the other components.

Table 1

Recency of information
(Unscheduled decisions, batch processing)

	Information on	
	Status	Events
Decision just after processing ends (Minimum age)	P + R + D	P + R + D (minimum) P + R + D + I (maximum) P + R + D + 1/2 I (average)
Decision just before processing ends (Maximum age)	P + R + D + I	P + R + D + I (minimum) P + R + D + 2 I (maximum P + R + D + 3/2 I (average)
Average age	P + R + D + 1/2 I	P + R + D + I

In <u>on-line</u> systems individual events can be immediately processed so that the update and processing times become virtually zero: $I \downarrow 0$, $P \downarrow 0$. Hence, Table 1 reduces to a simple relation, namely, the age of the information is approximately $R + D$. In on-line systems attention is concentrated on the retrieval delay R. In some systems such as airline reservation systems, the decision-making delay D is indeed negligible since the decision is simple. In other systems the situation may be so complicated that the decision maker can benefit very much from the assistance of a computer, to arrive at a decision: D can be reduced by computerized decision-models, report mode (e.g. queries), format (graphics) etc. An example is given by Morton (1971) who describes a system where D was reduced from 6 days to ½ day by means of a graphic decision-making system.

Observe that some questions may need, not the most recent information, but information concerning a specific, historic point of time: "What did Mr. John Smith order on September 7, 1956?" For such a query only R + D matters. Other queries of this type are library searches: "List all publications on computer storage techniques published before 1955".

From Table 1 it follows that in order to realize a desired total delay, one or more components P, R, D, I may be changed. The effect of changing one of the components P, R, or D is the same in this simplified model, but the effect of I varies: the weight of I may be 0, 1/2, 1, 3/2 or 2. While the effect of the various components may be the same, their technical realization is different and hence implies different economic costs. The update interval I may be eliminated through the introduction of an on-line data-capture system. In an on-line system, the processing time P for a single event is small compared to processing a batch which reflects events over a whole period I. In an on-line retrieval system, R will be smaller than in a batch system. D may be thought of as independent of the computer system in certain situations. As we observed, however, the computer may assist in arriving at a decision so that D decreases. Given a specific computer system operating in batch mode, the organization can still choose among several values for the update interval I. Let us next look at the economic costs and benefits of changing the values of the age components. In this paper we will limit ourselves to a rather qualitative discussion. More exact models and technique are presented in Kleijnen (1979): Information Economics, simulation, etc.

Fig. 3 is a crude picture illustrating possible relationships between the timeliness of information and its costs.

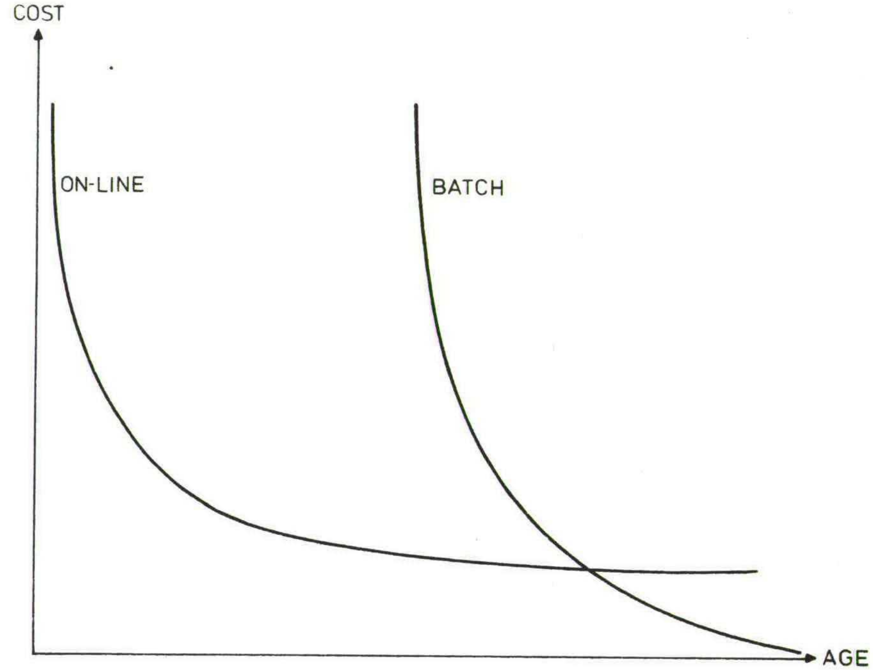

Figure 3: COST - AGE RELATIONS

In on-line systems delays can technically be reduced to zero (or better, to the decision delay D). However, queuing theory shows that reducing waiting times (involved in the response time R) towards zero, requires exponentially increasing computer capacity. In the batch mode the recency can be drastically improved by decreasing the update interval I. In that case the number of batch runs per year increases, and hence we are confronted with increased costs fixed per run (e.g. mounting a disk pack) accumulated per year. The number of transactions affects the update processing delay P. Apart from this effect, P can be reduced by a more powerful computer which involves higher cost. Economies of scale would make the cost increase less than proportional, contradicting the shape of the curve in Fig. 3. So it is difficult to specify the exact shape of the curves. The literature on cost curves is very scarce. In an old batch oriented article, Gregory & Atwater (1957) proposed cost curves U-shaped relative to the update interval I, and with drastic increases relative to the processing delay P. Brenner (1965) also claimed that cost is a U-shaped function of age since very old, off-line information requires long searches; Gregory & Van Horn (1963, pp. 586-588) proposed such a U-shape since keeping old information increases the data base size. However, these arguments concern the "retention period" of data: how long to keep data within the data base; see Kleijnen (1979). More study is needed to determine whether general relations can be postulated between the cost and timeliness of information, or whether we have to resort to case-studies.

Several authors have suggested hill-shaped curves for the relationship between the <u>value</u> and the recency of information; Brenner (1965), Gregory & Atwater (1957, p. 64). We would maintain, that more recent data cannot be less valuable than older data, provided the user knows how to use the data in an optimal, or at least a satisfactory, way. Without such knowledge there is indeed the possibility of overreaction, i.e. too frequent decision-making may destabilize a system. So we assume that the user is capable to determine that, say, monthly decisions on production are better than weekly decisions. Then it is still possible to aggregate weekly data, say, on sales and inventory into monthly data (and to ignore weekly data of the current, incomplete month). Consequently, more timely information has no negative gross value. Besides adequate decision rules, adequate forecasting routines are needed. For example, weekly data may show a more erratic pattern than monthly data. Hence the user should be capable to determine an optimal or satisfactory update interval I, or an adequate value for the smoothing constant α in exponential smoothing. In Information Economics it has been proven mathematically that information cannot have negative gross value; Marschak (1971, pp. 201-202). Information Economics assumes that the user has perfect knowledge about his system, and acts in an optimal way. A theoretical discussion on the optimal control of systems can be found in the literature on control engineering; Gupta & Hasdorff (1970). Of course, in practice managers may deviate from a theoretically optimal policy. Note that a hill-shaped curve may very well hold for the marginal increase of value, or for the net value.

A different situation exists if in an on-line retrieval system the emphasis is not on the recency of the information in the data base, but on the response time of the computer system once a query has been started. In that case the user may want fast response time in order to give a fast answer to his customers, whereas the data retrieved from the data base does not have to be completely up-to-date. Note that psychologically, an instantaneous response time is not desirable since the operator gets confused if he cannot see a (small) pause between his question and the computer's answer. Another practical point is that the value of the turnaround time may depend on the time of day the job is submitted for processing. For instance, if the job is submitted at the end of the working day, say at 5 P.M., then it does not matter whether the job is completed at 1 A.M. or 2 A.M. the next morning.

In general, the value-age relationship depends on the use of the information in the management of the organization, and not on the DP subsystem itself. In environments where important changes occur frequently, the value of recent information is high. For instance, in air navigation it is of ultimate importance. In such systems as inventory control systems, more recent information may or may not be worth its cost. In tactical or strategic decisions the planning period is so long that the recency of information has less effect on the accuracy of the forecasts needed for these decisions: In decision-making historical data are useful only as a means to forecast the future. The predictability of the future is affected by the following factors:

(i) the recency of the input data

(ii) the accuracy of the input data

(iii) the appropriateness of the forecasting model (transformation). Various degrees of sophistication are made possible by computers

(iv) the planning horizon: The accuracy of predictions decreases as we have to forecast a variable's value for a point of time further in the future[1).]

3. SCHEDULED DECISIONS

The optimal frequency of decision-making is studied in control theory. In practice it is traditional to adhere to a rhythm of daily, weekly, monthly, yearly decision-making. If we assume, as a conceptual framework, that all information is generated by the computer only, then it makes no sense to revise decisions before new updated information comes available. Hence the decision interval, say T, should satisfy the condition $T \geq I$. If we would allow for unexpected information from outside the computer system, then this new information might trigger the need for a new interpretation of the computer output. Such triggered decisions, however, would take us back to section 2 on unscheduled decisions. It does make sense to have more frequent updating than decision-making ($T > I$) since more frequent computer runs (small I) may be made for other purposes, such as decisions at lower levels, and administrative applications like payroll and invoicing. For the periodic decisions themselves it is most efficient to have $T = I$.

Compared to non-periodic decisions, the retrieval time R vanishes since we can schdule computer operations such that the information is available at the time of the periodic decision-making; see Fig. 4. Comparison with Table 2 shows that now decisions are scheduled to be made immediately after processing ends; see P + R + D in the upper-left corner of Table 1; R vanishes in the present case. This yields Table 2.

Table 2

Recency of information (scheduled decisions)

Information on		
Status	Events	
P + D	P + D	(minimum)
	P + D + T	(maximum)
	P + D + 1/2 T	(average)

Let us consider information on <u>events</u> in Table 2. We assume that in periodic decision-making decisions are far apart, so that D is small compared to T. Likewise, P is small compared to T. So <u>the</u> way to decrease the average delay of

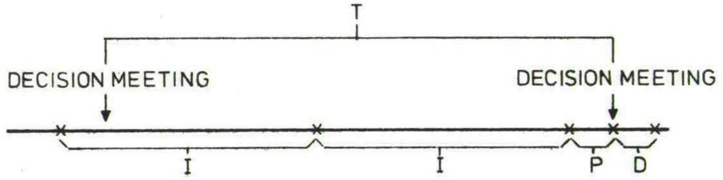

Figure 4: THE COMPONENTS DETERMINING THE AGE OF INFORMATION

information is more frequent decision-making. On-line data capture is wasteful in this respect, since the data are not used until the next decision-making session. On-line computer systems can be useful for reducing the decision delay time D: fast ad-hoc data retrieval, interactive modeling. Table 2 shows that the timeliness of information on status variables is not affected by the decision interval T. However, reactions to changes in the value of a status variable are possible only with intervals of length T. So in periodic decision-making the most important variable is T. The magnitude of T depends on the organization, not on the computer.

Let us consider whether it makes sense to have a situation where contrary to the above assumption, we have $P > T$. For instance, every day we update our market survey, but it takes 14 days to process all the data; decisions are made daily: $I = 1$, $P = 14$, $T = 1$. The fact that we take frequent observations ($I = 1$) suggests that the environment changes frequently. Old information ($P = 14$), however, does not permit good control over such an environment. Obviously we have to decrease the lag P drastically. If this cannot be done, we may still maintain the frequency of decision-making, since the decision itself may be not to change previous decisions.

It is well-known form Industrial Dynamics studies that delayed information can create business cycles. Delays can be shortened not only by faster computers and more frequent decision-making, but also by changing the information flows within the company; van Aken (1978). In our analysis we did not investigate the effects of having more than one decision-maker; see Kleijnen (1979). Observe that periodic decision-making is analogous to "sampled data control systems" in control theory, i.e., systems observed only at regular points of time.

4. CONCLUSION

We have distinguished a number of components determining "the" recency of information, namely, update processing delay P, update interval I, retrieval delay R, decision delay D, and - in periodic decisions - decision interval T. Costs and benefits were characterized roughly.

The resulting framework is useful when evaluating other theories and techniques for the quantification of financial benefits of information. For instance, the role of T can be investigated by *simulating* systems, using different values of T; see Kleijnen (1979).[2] It does not seem interesting to simulate periodic decisions based on information with varying processing delays P since - for any computer system - P is much smaller than T. For example, in many business games T equals one quarter. Nevertheless, Boyd & Krasnow (1963, p. 13) simulated a system with P *not* much smaller than T! Instead of simulation, we may use *Information Economics* and *Industrial Dynamics* models. These models are usually limited to periodic decision-making; the components P, I, R and D are not explicitly modelled.

In Kleijnen (1979) we survey several other attributes of information such as accuracy, aggregation, privacy, recovery, etc. That publication also includes an evaluation of various theories and techniques to quantify the economic consequences of these attributes: Information Economics, Industrial Dynamics, simulation and gaming, etc.

NOTES

1) $\mathrm{var}(\hat{x}\ |t=n+1)=\sigma_u^2\ \{1/n+(n+1-\bar{t})^2 / \sum_{t=1}^{n}(t-\bar{t})^2\}$. Smallest $\mathrm{var}(\hat{x}\ |t)$ if $t=\bar{t}$. See any book on regression analysis.

2. In such a simulation the state of the system that is to be

controlled, may be determined by difference equations with time lags much smaller than T. However, only every T time units decisions for the next T time units can be made.

REFERENCES

1. BLUMENTHAL, S.C., MANAGEMENT INFORMATION SYSTEMS; A FRAMEWORK FOR PLANNING AND DEVELOPMENT. Prentice-Hall, Inc., Englewood Cliffs, 1969.

2. BONNEY, M.C., Some considerations of the cost and value of information. THE COMPUTER JOURNAL, 12, 1969, pp. 118-123.

3. BOYD, D.F., and H.S. KRASNOW, Economic evaluation of management information systems. IBM SYSTEMS JOURNAL, 2, March 1963, pp.2-23.

4. BRAAT, J.J.M., The I.P.S.O. control system. INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH, 11, no.4, 1973, pp.417-436.

5. BRENNER, J.R., Toward a value theory of information. In: ECONOMICS OF AUTOMATIC DATA PROCESSING, edited by A.B. FRIELINK, North-Holland Publishing Company, Amsterdam, 1965.

6. EMERY, J.C., COST-BENEFIT ANALYSIS OF INFORMATION SYSTEMS. SMIS Workshop Report No. 1, The Society for Management Information Systems, 1971. (second printing March 1973).

7. GREGORY, R.H. and T.V.V. ATWATER, Cost and value of management information as functions of age. ACCOUNTING RESEARCH, 8, no.1, Jan 1957, pp.42-70.

8. GREGORY, R.H. and R.L. VAN HORN, AUTOMATIC DATA-PROCESSING SYSTEMS. Wadsworth Publishing Company, Inc., Belmont, second edition, 1963.

9. GUPTA, S.C., and L. HASDORFF, FUNDAMENTALS OF AUTOMATIC CONTROL. John Wiley & Sons, Inc., New York, 1970.

10. KLEIJNEN, J.P.C., COMPUTERS AND PROFITS, QUANTIFYING FINANCIAL BENEFITS OF INFORMATION. Addison-Wesley Publishing Company, Reading, 1979.

11. KNUTSEN, K.E. and R.L. NOLAN, Assessing computer costs and benefits. JOURNAL SYSTEMS MANAGEMENT, Feb. 1974, pp. 28-34.

12. MARSCHAK, J., Economics of information systems. JOURNAL AMERICAN STATISTICAL ASSOCIATION, 66, no.333, March 1971, pp. 192-219.

13. STRASSMANN, P.A., Forecasting considerations in design of management information systems. In: INFORMATION FOR DECISIONMAKING; QUANTITATIVE AND BEHAVIORAL DIMENSIONS, edited by A. RAPPAPORT, Prentice-Hall, Englewood-Cliffs, New Jersey, 1970

14. VAN AKEN, J.E., ON THE CONTROL OF COMPLEX INDUSTRIAL ORGANIZATIONS. Martinus Nijhoff Social Sciences Division, Leiden (Neth.), 1978.