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# INFORMATION STORAGE AND ACCESS IN DECISIONMAKING ORGANIZATIONS*

by

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## ABSTRACT

Information storage and access in decisionmaking organizations is modeled using a Petri Net representation. A centralized and a decentralized database configuration are analyzed and their impacts on the decisionmakers' workload assessed. Organizational protocols are defined and their criteria of acceptability presented. Protocols' key variables, minimum allowable input interarrival time and response time, are determined for two organizational structures: parallel and hierarchical. A numerical example suggests the use of timeliness as a third organizational attribute — the first two being workload and peformance. It also demonstrates the importance of updating coordination in evaluating the organization's performance.

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# 1. INTRODUCTION

During the past decade, information theory has been applied to the analysis and evaluation of organizations. First developed by Shannon (Shannon and Weaver, 1949), information theory matured into a mathematical theory in its own right, and was applied to the study of various communications systems (Gallager, 1968). It was then used as a basic tool for modeling human decisionmaking (see Sheridan and Ferrel, 1974, and Drenick, 1975). The Partition Law of Information (Conant, 1976) provided a physical interpretation of the mathematical expressions derived by using the n-dimensional version of the theory.

A two-stage information theoretic model of the decisionmaker was introduced by Boettcher and Levis (1982). Quantitative means for measuring the human decisionmakers' workload and the organization's performance were designed under a set of restrictive assumptions. Subsequent research effort (Hall and Levis, 1984; Chyen and Levis, 1985; Tomovic and Levis, 1984) was oriented towards relaxing some of those assumptions and resolving more complex issues related to a realistic use of the decisionmaking model.

This paper addresses the issue that decisionmakers are not memoryless (an assumption in the original model) and that information storage and acccess devices are actually put to service in most modern organizations. The study of databases in acyclical organizations is approched along two directions: (a) computation of modified activity terms that represent the decisionmaker's workload and (b) consideration of time and delays in the normal functioning of an organization. The two directions are developed separately but are brought together in the illustrative example of the last section.

Figure 1 shows the Petri Net representation (Tabak and Levis, 1984) of the two-stage model of the $n^{th}$ member of an organization. His input $x^n$ is a component of a single vector source distributed by a set of partitioning matrices among all the decisionmakers (Stabile and Levis, 1984). The decisionmaker processes this input in the situation assessment ($SA^n$) stage

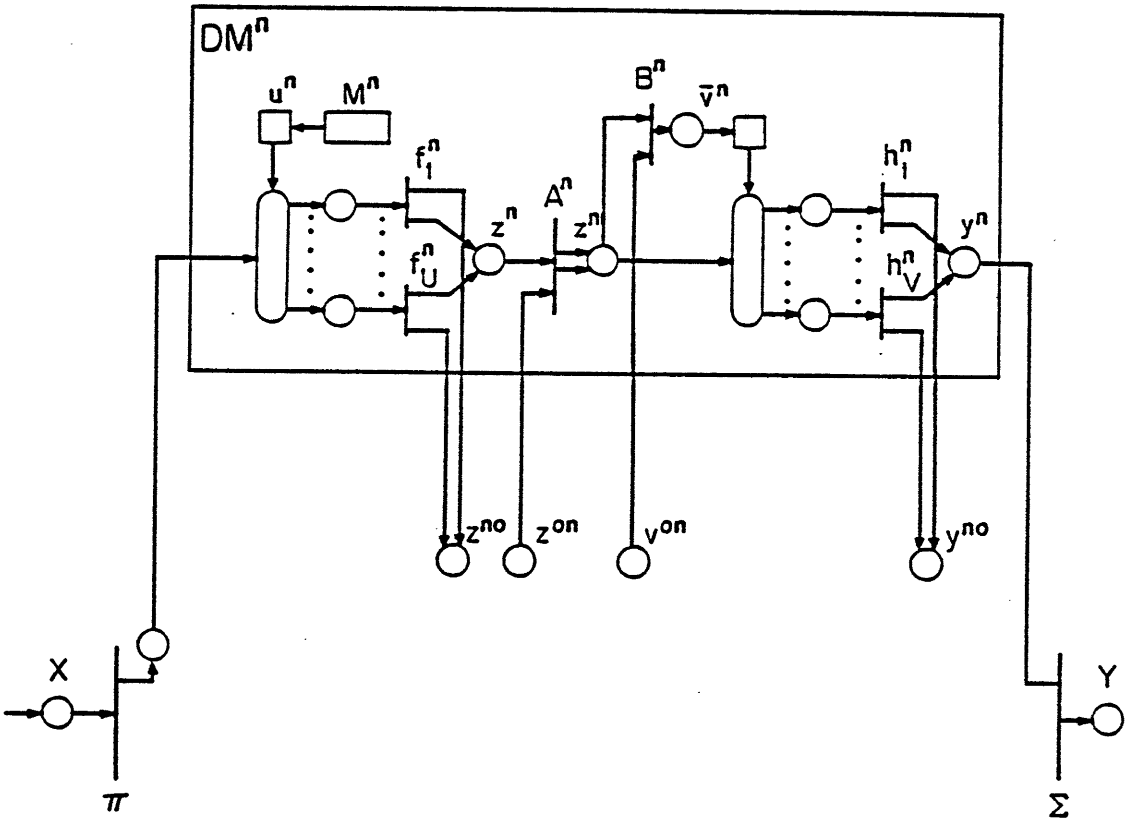

Figure 1. Petri Net Representation of the $n^{th}$ Decisionmaker of the Organization

to determine or select a particular value of the variable $z^n$ that denotes the situation. He may communicate his assessment of the situation to other members ($z^{no}$) and he may receive their assessments in return ($z^{on}$). This supplementary information may be used to modify his assessment, i.e., it may lead to a different value of $z^n$ denoted by $z^{n'}$. Possible alternatives of action are evaluated in the response selection ($RS^n$) stage. The outcome of this process is the selection of a local action or decision $y^n$ that may be communicated to other team members or may form all or part of the organization's response. A command input from other decisionmakers, $v^{on}$, may affect the selection process.

The situation assessment stage consists of U algorithms ($f_i^n$, i=1,...,U). The value taken by the variable $u^n$ determines the algorithm to be used, and is chosen according to the probability distribution $p(u^n)$. Similarly, the choice of an algorithm in the RS stage is determined by the variable $\bar{v}^n$, with probability distribution $p(\bar{v}^n|z^{n'})$.

As a response to the need for memory and information handling in today's organizations, the concept of Decision Aids first appeared a litle more than a decade ago. These devices are evolving into well-integrated Decision Support Systems (DSS) (Keen, 1981). The database is one of the three main parts of a Decision Support System. The other two are an information management program, and a machine-user interface (computer terminal) (Sprague, 1980; Sprague and Carlson, 1982). This paper will address the database and decisionmaker/machine interface issues from an information theoretic point of view. The database's storage and access procedures, and their impact on the decisionmaker's workload and performance levels, will be described.

## 2. THE GENERAL DATABASE MODEL

The database model developed in this paper conforms to the traditional definition of an information storage device: it can receive information from an external source, it stores it adequately, and it delivers this information, or part of it, whenever accessed by its users. The Petri Net model adopted here consists of two stages (see Fig. 2). The first stage, transition C, receives an input from the decisionmaker who requests access to the data. This input represents the situation in which the user is. Transition C determines then the nature of the information needed to cope with that situation, and sends a query to the next stage, D. Transition D performs the actual search, and delivers the data to the decisionmaker at a predetermined stage of his internal decisionmaking process.

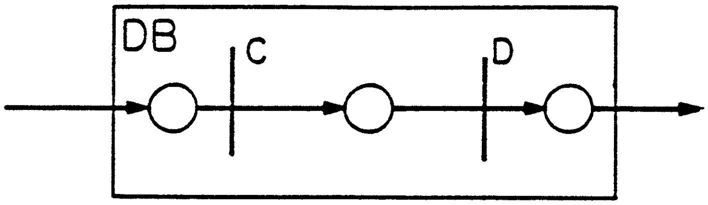

Figure 2. Petri Net Representation of the General Database Model

Databases can be used in either a centralized or a decentralized configuration. Decentralized databases are defined here as individual storage units, accessed exclusively by one decisionmaker, and holding and delivering information relevant to this decisionmaker's task only. It was proved (Bejjani, 1985) that the increase in activity due to a centralized or decentralized configuration were similar. However, there are important differences. First, the time associated with the query process is much shorter when the database is an individual one than when it is centralized. In effect, in the former case, no irrelevant information is to be scanned and then discarded, which happens in the latter case, and the system's answer to its stimuli is more timely. However, an advantage of a centralized database structure is that it allows for more convenient updating. It can be updated in one operation, providing all the decisionmakers with equally recent information, whereas decentralized databases require a much greater updating effort to obtain the same result. This paper will develop information theoretic aspects of the centralized databases and discuss the decentralized case briefly (for a comprehensive comparison of the two configurations, the reader is referred to Bejjani, 1985).

## 2.1 Centralized Databases

A centralized database is a database shared by all members of the organization. It is physically located in one place, and individual terminals allow the decisionmakers to access it independently. In the Petri Net representation, a centralized database is modeled as one unit, comprising several transition C/transition D sequences. There are two such databases, one for the SA stage, called DBSA, and one for the RS stage, DBRS. The inputs to transition $C^n$ in DBSA are the inputs to the $n^{th}$ decisionmaker, $x^n$, and the variable $u^n$ indicating the SA algorithm he is about to use (see Fig. 3). Transition $C^n$ emits then a message towards transition $D^n$ that carries a query for the information needed for $DM^n$ to process $x^n$ through the selected SA algorithm. $D^n$ in turn delivers the requested data, $d^n_{SA}$, to the decisionmaker, who receives it as an input to the algorithm he is using. The usage of DBRS follows a similar rationale applied to the RS stage.

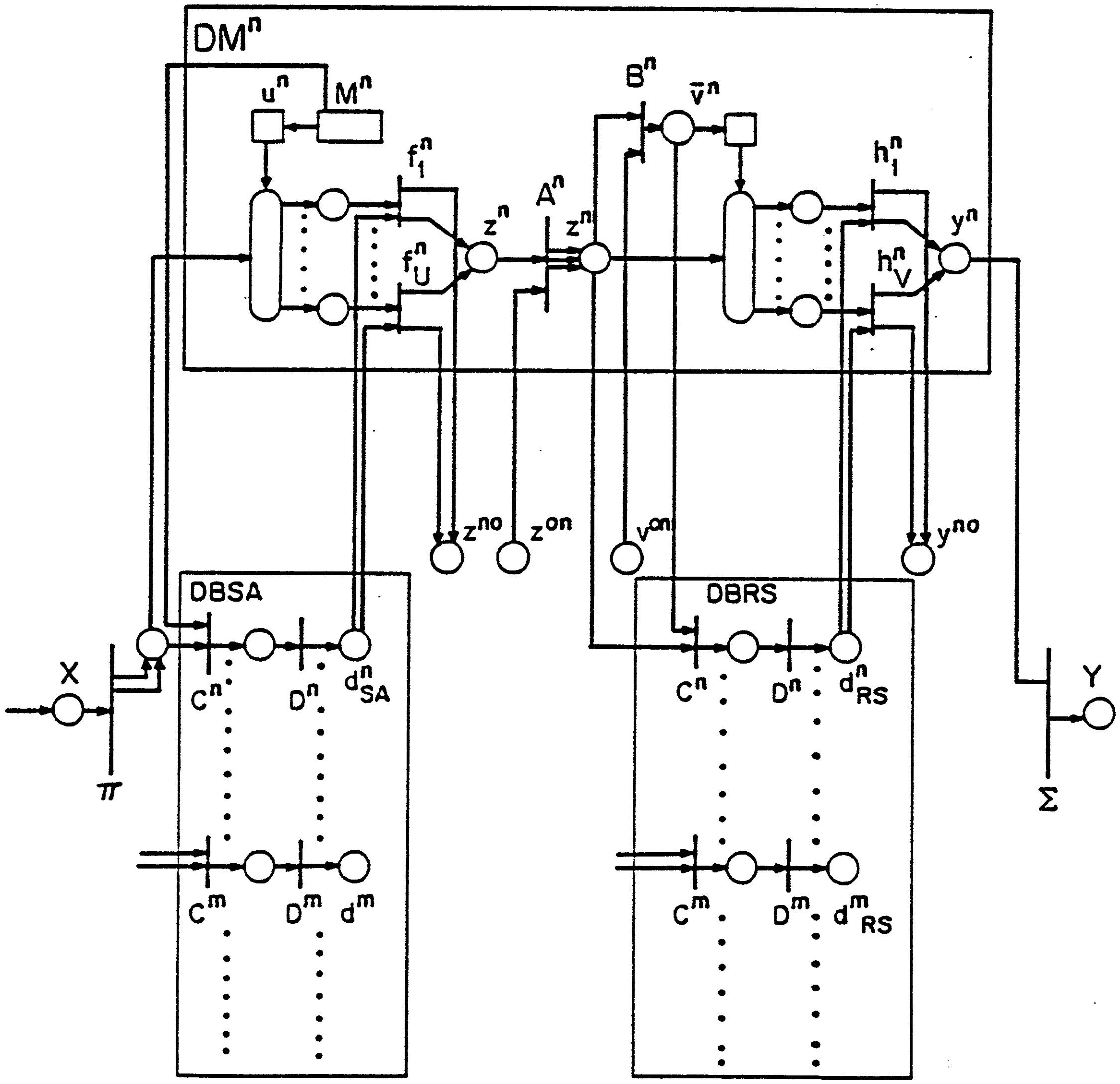

Figure 3. Petri Net Representation of DM$^n$ Using Centralized Databases

The use of databases has a significant impact on the decisionmaker's workload, as can be seen in the following development. Activity rate terms are derived by applying the Partition Law of Information Rates (Conant, 1976) to the decisionmaking model used here. For a more complete description of the calculations, the reader is referred to Bejjani (1985). The modifications to the basic model are due to the presence of two supplementary variables, $d_{SA}^n$ and $d_{RS}^n$, and to their relationship with the existing structure. For simplicity, the superscript n will be omitted in the following equations whenever confusion may not arise.

Throughput Rate:

$$F_t = \bar{T}(x,d_{SA},z^{on},v^{on},d_{RS}:u,z^{no},\bar{z},\bar{v},y^{no},y) \tag{1}$$

Blockage Rate:

$$F_b = \bar{H}(x,d_{SA},z^{on},v^{on},d_{RS}) - F_t \tag{2}$$

Noise Rate:

$$F_n = \bar{H}(u) + \bar{H}_{\bar{z}}(v) \tag{3}$$

Coordination Rate:

$$\begin{aligned}
F_c = {} & \sum_{i=1}^{U} \left(\bar{g}_c^{i}\ (p(x,d_{SA})) + \frac{\alpha_i}{\tau_{SA}} H(p_i)\right) + \bar{H}(z) \\
& + \bar{g}_c^{A}\ (p(z,z^{on})) + \bar{g}_c^{B}\ (p(\bar{z},v^{on})) \\
& + \sum_{j=1}^{V} \left(\bar{g}_c^{U+j}\ (p(\bar{z},d_{RS})) + \frac{\alpha_{U+j}}{\tau_{RS}} H(p_j)\right) + \bar{H}(y) \\
& + \bar{H}(z) + \bar{H}(\bar{z}) + \bar{H}(\bar{z},\bar{v}) + \bar{T}_z(x,d_{SA}:z^{on}) + \bar{T}_{\bar{z}}(x,d_{SA},z^{on}:v^{on}) \\
& + \bar{T}_{\bar{z},\bar{v}}(x,d_{SA},z^{on},v^{on}:d_{RS})
\end{aligned} \tag{4}$$

where

$$p_i = p(u=i) \quad ; \quad p_j = p(v=j) \tag{5}$$

$$H(p) = p\log_2 p + (1-p)\log_2(1-p) \qquad (6)$$

and $\alpha_i$ is the number of variables of the algorithm i that are reinitialized at each iteration. The symbol $\tau_{SA}$ designates the mean interarrival time of the input to the SA stage. $\tau_{RS}$ has an equivalent meaning with respect to the RS stage. The mean input interarrival time can be used in the equations, if the interarrival time is not constant, by regulating the source (Hall, 1982). The functions $\bar{g}_c^i$, $\bar{g}_c^{U+j}$, $\bar{g}_c^A$ and $\bar{g}_c^B$ are the individual coordination rate functions of the SA, A, B, and RS algorithms, and are of the following form:

$$\bar{g}_c^i = \sum_{j=1}^{\alpha_i} \bar{H}_u\,(w_j^i) - \bar{H}_u(W^i) \qquad (7)$$

The terms $\bar{H}(z)$, $\bar{H}(\bar{z})$, $\bar{H}(\bar{z},\bar{v})$ in (4) can be interpreted to represent the direct coordination rate between subsystems, through the fact that one subsystem's output is another's input. However, indirect coordination between the subsystems is accounted for by the transmission rate terms. $\bar{T}_z(x,d_{SA}:z^{on})$ represents the coordination rate that is due to the relationship between x and $d_{SA}$, and $z^{on}$. Indeed, if the inputs to $DM^n$ and those to the rest of the organization (RO) are related, or if $d_{SA}^n$ and $d_{SA}^m$, $m \neq n$, are not totally independent, due to the structure of the storage or the updating process in the centralized database, then $z^{on}$ can bring to $S^A$ information about the inputs to the system that is not contained in z. Similar interpretations hold for the other two transmission rate terms. The term $\bar{T}_{\bar{z},\bar{v}}(x,z^{on},d_{SA},v^{on}:d_{RS})$ raises the question of the relationship between $d_{SA}$ and $d_{RS}$, i.e., whether the situation assessment database (DBSA) and the response selection one (DBRS) are related.

## 2.2 Decentralized Databases

A decentralized database structure is shown in Figure 4. The only difference with respect to Figure 3 is the presence of only one transition $C^n$/transition $D^n$ sequence per database, which models the exclusive use of

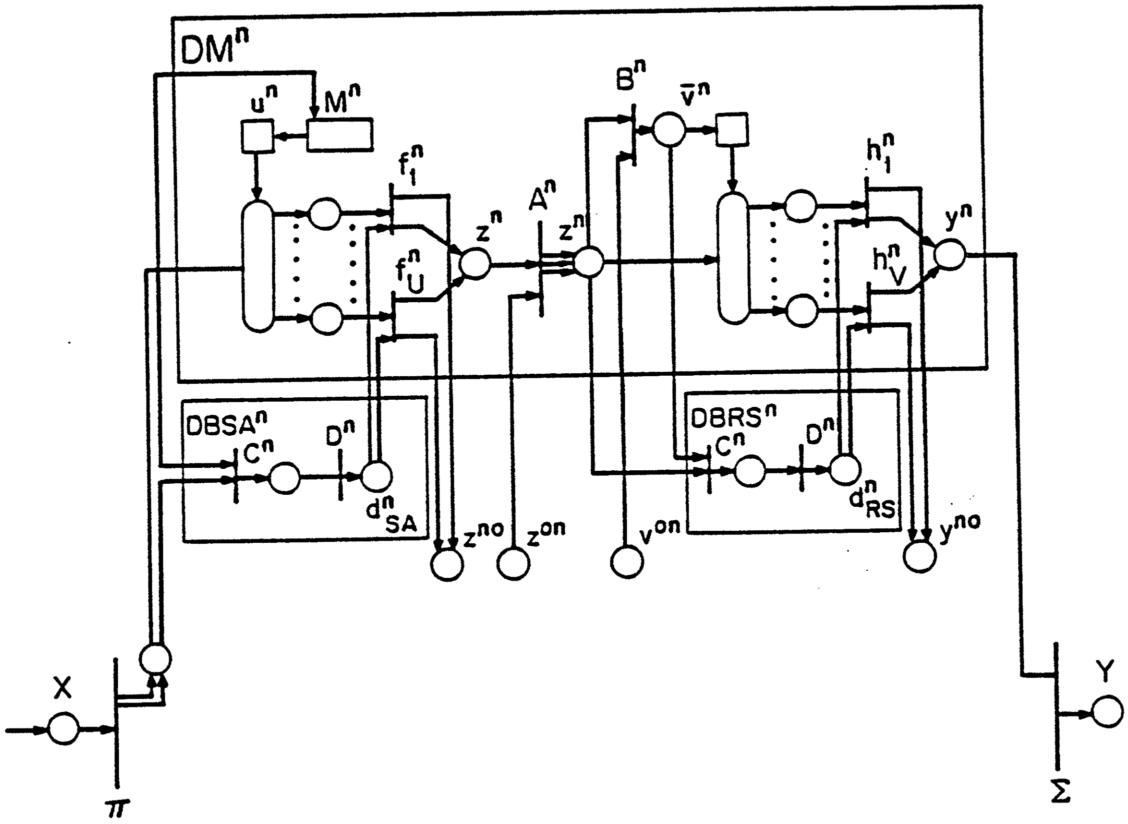

Figure 4. Petri Net Representation of DM$^n$ Using Decentralized Databases

each database by a single decisionmaker. Apart from that, decentralized databases are assumed to function in exactly the same manner as centralized ones.

### 2.3 Fixed Databases and the Memoryless Model

The results in section 2.1 were derived assuming the data $d_{SA}$ and $d_{RS}$ to be variable quantities. However, it might very well be the case that $d_{SA}$ and $d_{RS}$ are fixed, either because the databases are never updated or because the values taken by $d_{SA}$ and $d_{RS}$ remain valid during a very long time, compared to the mean input interarrival time. In this simple case, the database's direct contribution to the decisionmaker's activity rate is null, and the expressions developed above become similar to those derived in the basic memoryless decisionmaker case. They are derived by simply eliminating the variables $d_{SA}$ and $d_{RS}$ and the input variables to the databases from the equations, which shows that the reduction from the database-equipped model to the memoryless one is consistent.

# 3. PROTOCOLS AND THEIR APPLICATION TO ORGANIZATIONAL STRUCTURES

## 3.1 Definition of Protocols and Determination of Their Key Variables

A protocol is the description of the chronological order in which elementary tasks have to be performed within one decisionmaker as well as between two or more of them. Determination of procotols is a fundamental design problem for organizations in general, and of updatable database-equipped ones in particular. Indeed, if the sequences of operations for each decisionmaker are not clearly defined, and if the updating tempo of the database does not take these sequences into account, chaos can result. In brief, the situation could arise where different decisionmakers would be accessing different databases at different times, with different levels of accuracy and relevance of the data, in order to process the same input.

Since the Petri Net representation (Tabak and Levis, 1984) clearly illustrates the organization's protocol as defined above and since a key notion in the definition of a protocol is the amount of time involved at each step of the decisionmaking process, an acceptable protocol for a given organization will consist of its Petri Net representation supplemented with the allocation of a processing time to each transition. The processing time in fact represents the maximum allowable duration of a transition for the organization to function in an orderly fashion, following its operating protocol.

Assumptions: In devising an acceptable protocol for the kind of organizations dealt with here, the following assumptions are made:

(1) - the source emits the input X with a constant interarrival time

(2) - the various transitions have constant processing times.

(3) - communication between transitions is instantaneous.

(4) - any transition can process an incoming input as soon as it has finished processing the previous one, and no sooner.

(5) - no queueing is allowed at any stage of the process.

Assumptions (1) and (2) are a corollary of the broader assumptions that the whole system operates in steady state. Assumption (3) states in fact that all the decisionmaking occurs within the transitions, and that no processing time is allocated to places. Assumption (4) is putting the "pipe-line effect" into words; this assures that the information flow through the system is continuous. Assumption (5) is a prerequisite to the application of Petri Net theory to the study of information theoretic decisionmaking models: in effect, when queueing takes place, two or more different tokens can coexist in the same place. Since transitions do not have any means of recognizing priorities in choosing one token as an input out of the same place, the queue cannot be managed, and the organization's protocol is transgressed. (For a relaxation of this assumption, see Jin, 1985).

Proposition: Under assumptions (1) to (5), two necessary conditions for an organization's protocol to be acceptable are:

- every transition in the system must have a processing time smaller than or equal to the mean input interarrival time.
- the total amount of time spent by a token in one place cannot exceed the mean input interarrival time.

Both necessary conditions provide a symmetric analytical tool. Indeed, if the processing times of the transitions in the system are fixed, then the minimum admissible input interarrival time for the organization can be determined: it is equal to the greater of two quantities: the maximum processing time present on the Petri net diagram of that organization, and the maximum time any token spends in any place. Determining this minimum interarrival time is a very useful way of comparing the effectiveness of different organizational structures in a given context.

The second necessary condition applies in cases of organizational interactions where one decisionmaker sends some information to another and cannot proceed before receiving a message back. Thus, the proposition provides a way of determining the upper limit of the response time of this other decisionmaker, everything else being fixed. This will be made clearer in the next section.

As a last comment, one should realize that the use of the proposition is not restricted to decisionmaking organizations. In fact, its arguments are relevant to any acyclical information processing structure where Assumptions (1) to (5) are satisfied.

## 3.2 Construction of Protocols for the Centralized Case

In this section, the proposition will be used to develop protocols for two particular organizations using a centralized database configuration. The basic quântity for each organization is $\tau$, the processing time of any SA or RS transition. It is assumed to be identical for all such transitions in both organizations, and it will be the unit used for all quantities computed here. Furthermore, $\tau$ is assumed to be greater than the processing time of other types of transitions, on the grounds that more decisionmaking takes place in SA and RS transitions than in the others. The database's response time is assumed to be $\tau$ as well.

### Parallel Organizational Structure

In a parallel organizational structure, decisionmakers are linked by somewhat symmetrical relationships: they do not formally issue commands to each other, and they can share information at all stages according to pre-established operating procedures. The parallel structure considered in this work is a three-person organization, (Fig. 5) called "Organization P" from here on. $DM^1$ and $DM^3$ use only one SA algorithm and two RS algorithms each, and $DM^2$ has the choice between two SA algorithms, whose output can be processed by only one RS algorithm. The command input $v^{on}$ is absent from the model, due to the non-hierarchical structure; the decisionmakers do however share information about their situation assessments.

Organization P uses two centralized databases, DBSA and DBRS; An acceptable protocol for this organization has been derived and is given in Figure 5. Its main characteristics are the minimum interarrival time (IT) it allows, $\tau$, and the organization's total response time (RT), the time interval between the arrival of the input and the generation of a corresponding response, which is equal to $19\tau/3$.

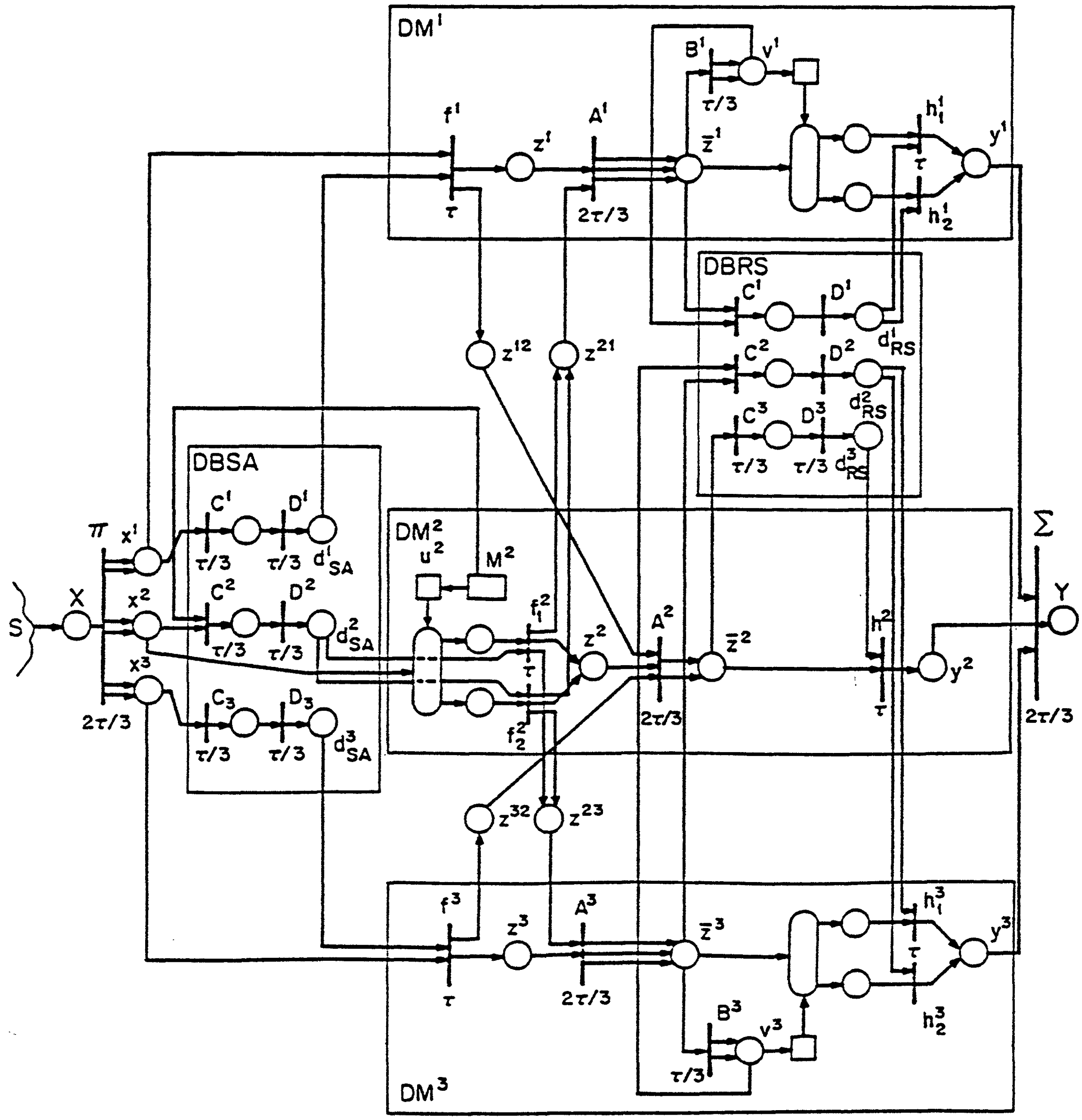

Figure 5. Protocol of Organization P Using Centralized Databases

## Hierarchical Organization Structure

A hierarchical organizational structure allows decisionmakers to have an influence on each other's response selection. This influence can be represented by a command input, $v^{on}$. The hierarchical structure analyzed here is a three-person organization, known as organization H, equipped with centralized databases as shown in Figure 6.

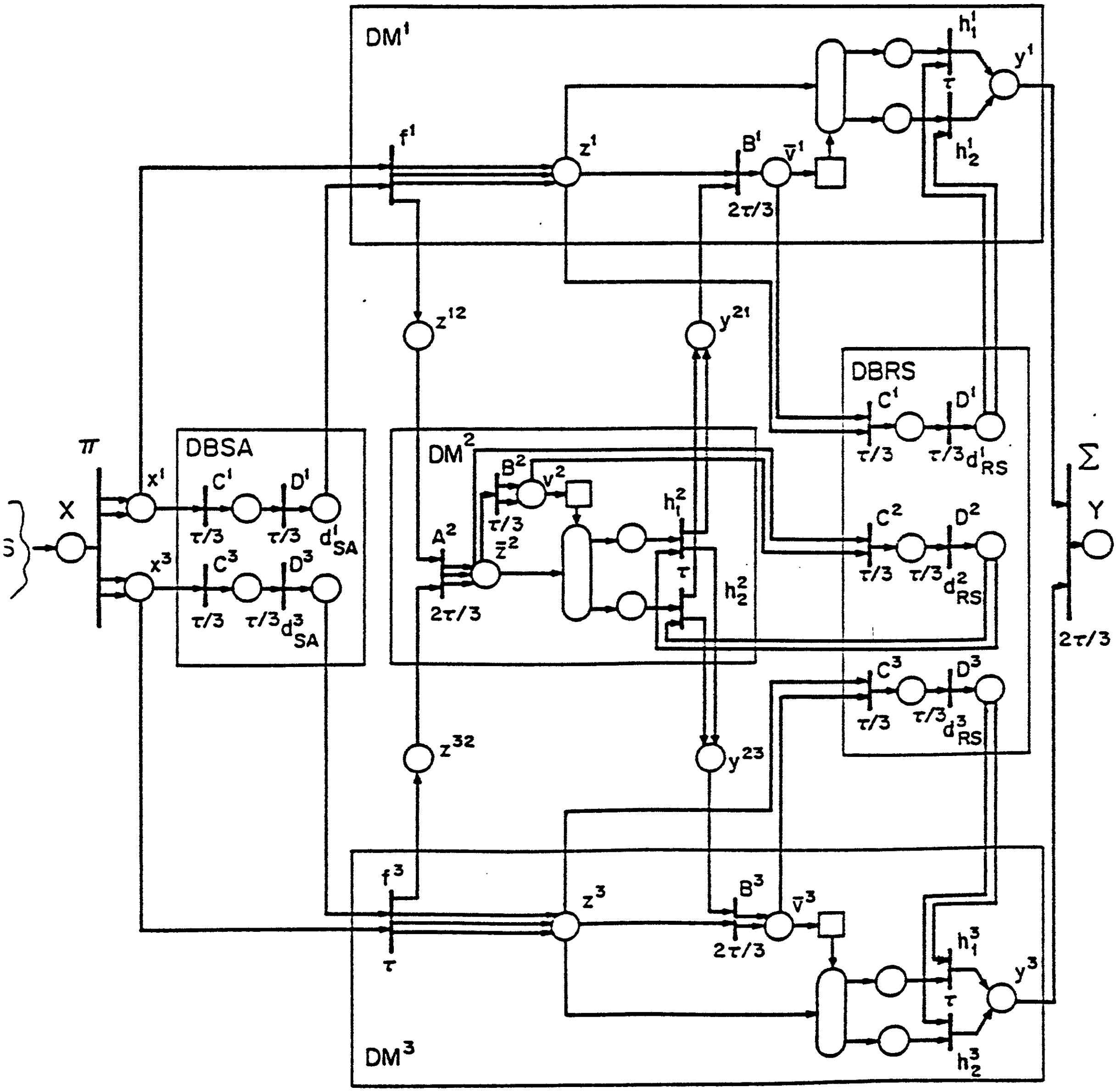

Figure 6. Protocol of Organization H Using Centralized Databases

Organization H consists of two decisionmakers who actually contribute to its output, $DM^1$ and $DM^3$, and one coordinating decisionmaker, $DM^2$, who analyzes $DM^1$'s and $DM^2$'s situation assessments in order to issue a command to them that carries his instructions about the way the organization's response should be constructed. $DM^2$ is not in contact with the environment, therefore he does not need an SA stage, neither do $DM^1$ and $DM^3$ need an information fusion transition, A. The three decisionmakers in organization H have each two RS algorithms.

One acceptable protocol for organization H is that represented in Figure 6. The minimum interarrival time, $11\tau/3$, is much greater than for organization P. This is due to the relationship between transition $f_1^1$ and $DM^2$, where the information coming out of $f_1^1$ has to be processed by all $DM^2$'s transitions before transition $B^1$ can be fired and the last token leaves the place $z^1$. Application of the symmetric argument of the proposition's necessary conditions determined the mean interarrival time as $11\tau/3$. The organization's response time is calculated quite simply in this case, by adding all processing times along the path followed by the original input and is $8\tau$. For more complex organizations, the System Array approach is preferable for computing time delays (Tabak and Levis, 1984; Jin, 1985).

## 3.3 Construction of Protocols for Decentralized Case

It was pointed out in section 2.2 that the only salient differences between a centralized and a decentralized structure as defined here pertain to transition D's processing time and the establishment of satisfactory updating. In this section, transition D is assumed to require a total time of $\tau/3$, which is half what was needed in the centralized configuration. Again, this number depends greatly on the nature of the organization's decision support system.

Acceptable protocols for organizations P and H with decentralized databases are given in Figures 7 and 8, respectively. The minimun interarrival time IT and the response time RT for each organization are $\tau$ and

$12\tau/3$ for the parallel one and $10\tau/3$ and $7\tau$ for the hierarchical one.

The reduction in the IT and RT, when compared to the centralized cases, is due entirely to the shorter response time of the database.

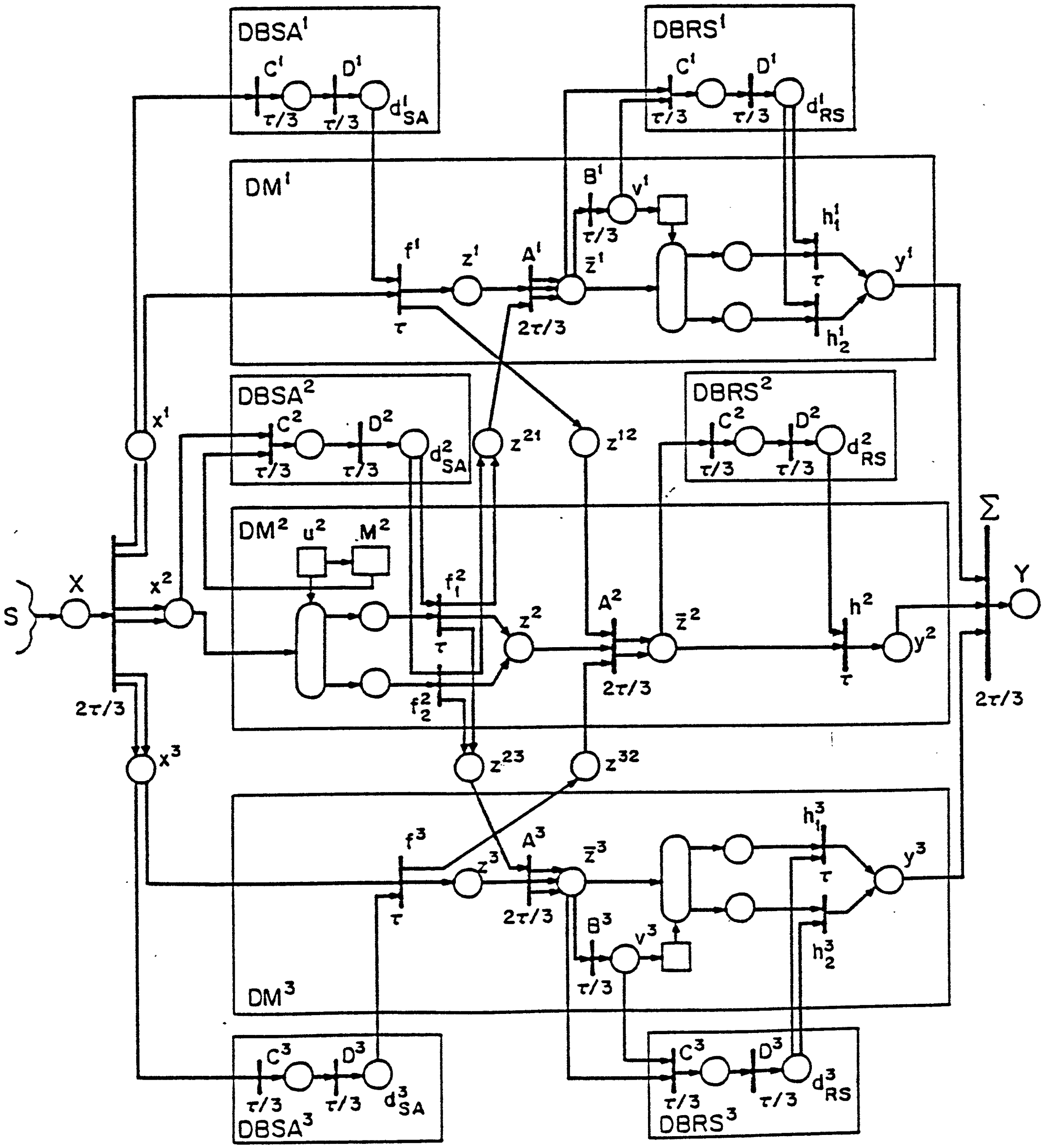

Figure 7. Protocol of Organization P Using Decentralized Databases

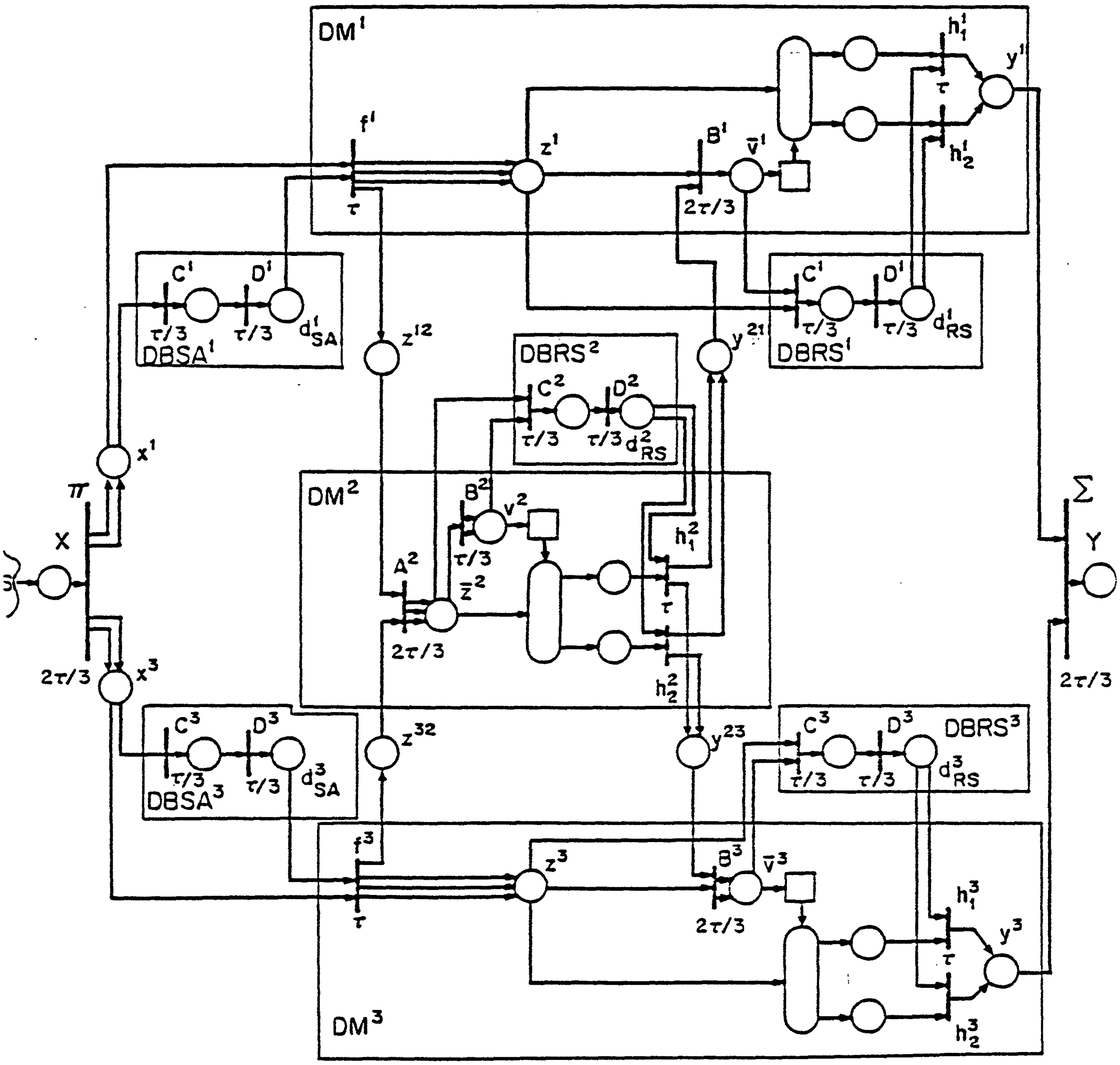

Figure 8. Protocol of Organization H Using Decentralized Databases

## 3.4 Remarks

Each protocol in the previous sections has been derived under some very specific conditions, in order to make different organizations and different database structures comparable along the same criteria. These results are contingent upon using similar transition processing times for both organizational structures.

The minimum allowable input interarrival time is much greater for a hierarchical organization than for a parallel one. This follows from the more complex sequences of tasks that have to be performed in a hierarchical organization before a new input can be handled. The total response time is also greater for organization H than for organization P, and the difference is due again to the increased complexity.

The second observation is that, whatever the organization, a decentralized database structure leads to improved performance with respect to time. In organization P, the decentralized structure leads to an 11% improvement in the response time over the corresponding centralized one, while in organization H its leads to improvements in both IT and RT of 9% and 13% respectively. These results are due to the basic premise that decentralized databases takes less time to perform the data query process than centralized ones do. (The numerical results of the above two paragraphs are summarized in Table 1).

TABLE 1. TIME CHARACTERISTICS OF ORGANIZATIONS P AND H

| | Centralized DB | Decentralized DB |
|---|---|---|
| IT(P) | $\tau$ | $\tau$ |
| IT(H) | $11\tau/3$ | $10\tau/3$ |
| RT(P) | $19\tau/3$ | $17\tau/3$ |
| RT(H) | $8\tau$ | $7\tau$ |

IT = Minimum Allowable Interarrival Time; RT = Response Time

# 4. AN ILLUSTRATIVE EXAMPLE

## 4.1 Description of the Organizations Used

In this section, tactical organizations, one parallel and one hierarchical, are used to address the issues that arise in the qualitative evaluation of organizations, the problems raised by a lack of coordination between several individual databases, and the trade-off between performance and timeliness. (The example is developed in its entirety in Bejjani, 1985).

The first organization is the parallel one (Organization P) in Figure 5. It consists of three naval battle groups defending a maritime front. The first group, $DM^1$, holds one extremity of the front, $DM^2$ holds the center, and $DM^3$ the other end. The inputs received by the organization are signals emitted by unidentified platforms (submarines, surface ships, planes). The different decisionmakers' tasks are to attempt to identify the source of these signals (enemy or friends) in the SA stage, and to select the appropriate response (fire, request identification, or take all measures required to face an attack) in the RS stage.

The SA database provides information, obtained from intelligence sources, that describes the codes the enemy could use when emitting the kind of signals received by organization P. This information will be compared to the actual input to determine the latter's identity. The RS database, DBRS, informs the decisionmakers about the level of alert present in their area at each iteration.

The second organization is the hierarchical one (Organization H) shown in Figure 6. The context is the same as for organization P, but here only $DM^1$ and $DM^3$ actually receive any external signals or select an active response. $DM^2$ is a coordinator who, based upon the situation assessments received from $DM^1$ and $DM^3$, gives instructions about what RS algorithm should be selected by either of them. The organization's overall mission is the one defined for organization P.

## 4.2 Results

A primary feature of the example is its numerical simplicity: all the variables of the system are determined using binary logic based on the comparison of quantities; there are no actual computations. Detailed definition of the variables and the algorithms for the case of a single decisionmaker has already been presented (Boettcher, 1981). The basic step in the computation of the performance-workload pair (J,G) is determining the pure strategies present in the organization (Levis and Boettcher, 1983). In the cases at hand, each DM has two pure strategies, each obtained by the exclusive use of one algorithm (no decisionmaker here has, in any stage, more than two algorithms from which to choose). Activity rates are a better measure of the decisionmakers' workload than absolute activity, because of the time constraints present in real-world situations. The following equation applies here:

$$F^i = \bar{G}^i = \frac{G^i}{\tau} \qquad i = 1,2,3 \tag{8}$$

for either organization. The performance measure J is the expected value of the cost the organization incurs when it does not produce the correct response for a given input. The workloads $\bar{G}^i$ determined by each pure strategy and the corresponding performance level J are plotted in the $(J, \bar{G}^1, \bar{G}^2, \bar{G}^3)$ space. Then, the performance-workload (P-W) locus for each DM is constructed where all possible mixed strategies are considered as linear combinations of the pure ones. The graphs thus obtained are the projections of the overall (P-W) locus of the organization on each of three planes: $(\bar{G}^1,J)$, $\bar{G}^2,J)$, $(\bar{G}^3,J)$. Because the input is perfectly symmetric, as well as $DM^1$'s and $DM^3$'s roles in each organization, only the projections for $DM^1$ and $DM^2$ are shown.

The use of activity rates in this instance has the effect of illustrating very clearly the tradeoff between timeliness and workload (Figs. 9 and 10). The performance of organization P is better than that of H; the performance index for P takes values between 0 and 0.9 for P but between 1.2 and 4.5 for H. However, the workload of the members of P is much higher than that of H, namely, it varies between 8.1 bits/sec and 11.6 for P, while it is only 1.2 and 2.7 for H. Measuring workload in terms of activity rates gives organization H a significant advantage as far as keeping the decisionmakers' workload below a given maximum (the bounded rationality constraint) is concerned. However, another tradeoff appears here that involves the notion of timeliness. In effect, since in this example workload is a decreasing function of the mean interarrival time, Eq. (8), low workload levels are obtained by allowing a high IT, which penalizes the organization in terms of its timeliness. Thus, workload is reduced in H, but timeliness is sacrificed.

Another consideration of interest is the effect of poor updating coordination on the organization's performance when decentralized databases are used (e.g., Figures 7 and 8). The impact of two different updating sequences on performance is reflected on the (P-W) loci. In the first scheme, $DM^2$'s and $DM^3$'s RS databases are assumed to be updated, at $\tau + 0$, in coordination with the input arrival. $DM^1$'s DBRS, however, is updated at $\tau + \tau$, with a delay of $\tau$ over the input to which the data correspond. New performance levels for each pure organization strategy were derived and a performance-workload locus was drawn (see Fig. 11(a)). The main effects are the upward movement of the original locus, and a degradation in performance: the range of J is from 0.35 to 1.0 as opposed to 0 to 0.9 for the perfectly coordinated (or the centralized) database case; this represents a drop of 29% in the average performance of the organization.

A second scheme exhibits a less coordinated updating sequence: $DBRS^2$ is updated at $\tau + 0$, $DBRS^1$ at $\tau + \tau$, and $DBRS^3$ at $\tau + 2\tau$. $DM^1$ and $DM^3$ both now have a greater propensity to make the wrong decision, and the resulting (P-W) locus is presented in Fig. 11(b). The best performance (lowest J) is now 0.8, which is very close to what the worst performance was in the coordinated case, and the worst performance level is 1.2. The range of possible performance levels has shrunk further, and the drop in average performance with respect to the original case is 68%.

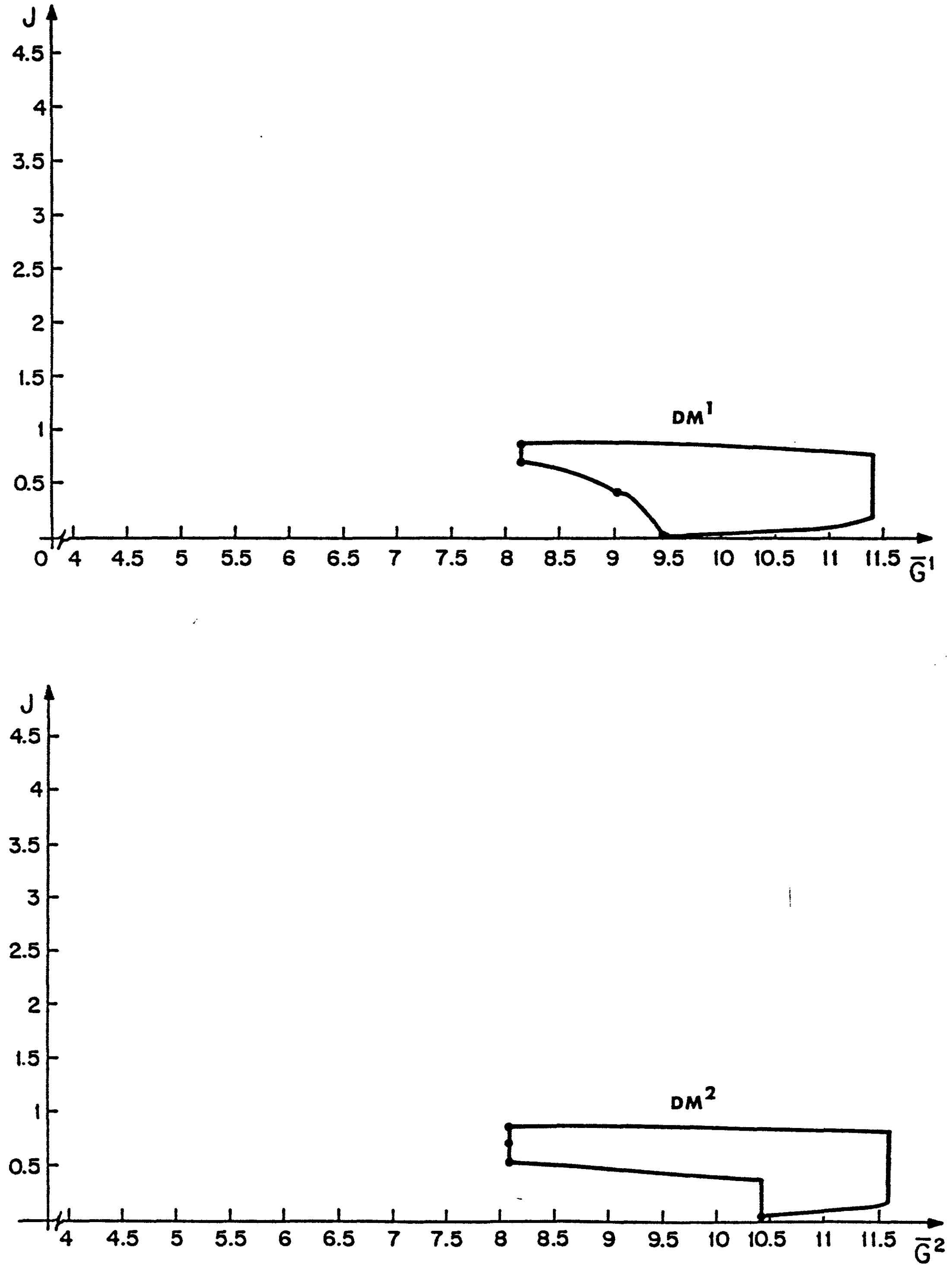

Figure 9. (P-W) Loci for P Using Activity Rates

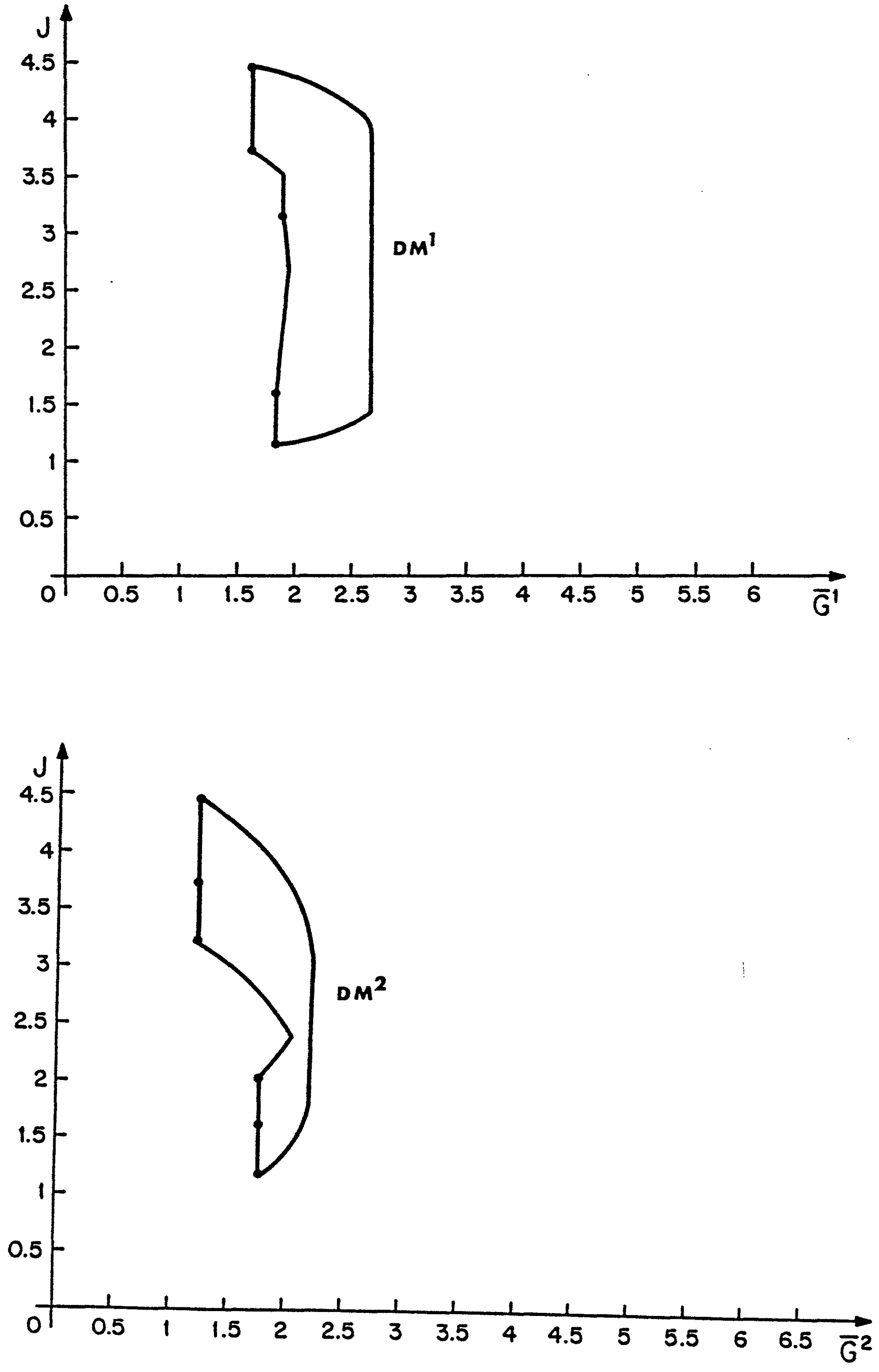

Figure 10. (P-W) Loci for H Using Activity Rates

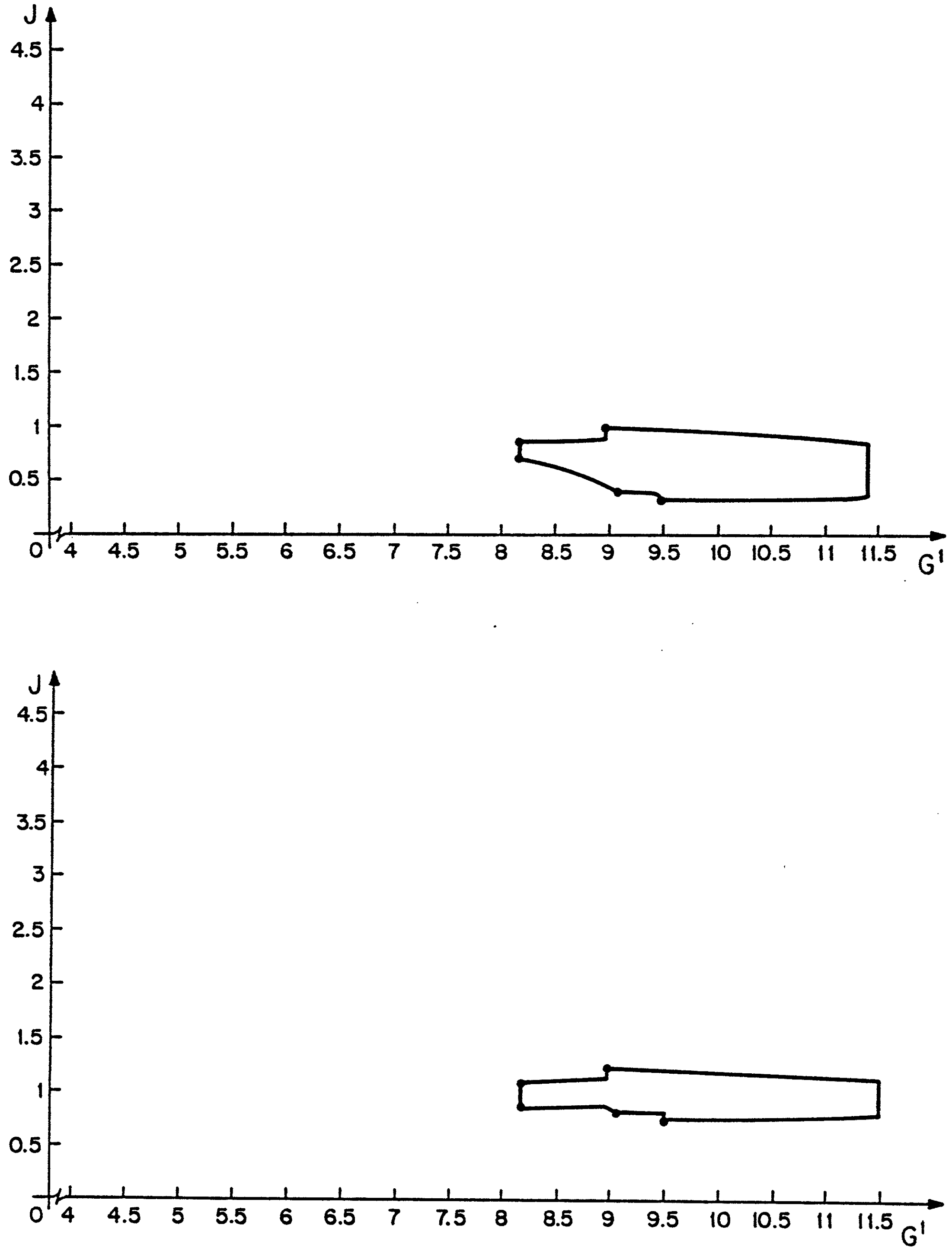

Figure 11. (P-W) Loci for $DM^1$ in P with Uncoordinated Databases

Let the transition processing time be equal to $\tau$ seconds. Then IT(P) will be $\tau$ seconds as well, and IT(H) $11\tau/3$ seconds (or $10\tau/3$ sec., depending on the database configuration). In any event, IT(H) is much greater than IT(P) and may handicap organization H if it has to respond to threats arriving at a high rate. As an example, consider a wave of enemy planes attacking the battlegroup: If no defense can be initiated without processing every input through the SA stage, then the anti-aircraft batteries cannot shoot at a rate higher than one missile every $3.6\tau$ sec. If a new threat arrives once every $\tau$ seconds, then P is an adequate structure, while H is far from being one. An additional disadvantage of organization H appears when response times are taken into account: the battlegroup will need $8\tau$ seconds to fire on a threat after it is detected; this might be too long if the threat is very close to the battlegroup when its presence is detected.

When the platforms that the organization has to deal with are slower units, like submarines or surface ships, organization H's timeliness disadvantage is less critical, because of the longer time available for constructing an adequate response and because of the smaller threat arrival rate. In fact, the latter can be so small as to make any difference between IT(P) and IT(H) seem irrelevant. Since the organizations designed in this example have to deal with both slow and fast threats, one has to consider the relative probability of being attacked by fast or slow threats, and weigh it by the expected costs in each alternative during the evaluation of the two organizational structures.

## 5. CONCLUSION

In this paper, the use of database networks was introduced into the organization, in two alternative configurations: centralized, and decentralized. Information theoretic aspects of data storage devices were analyzed. Time-related consideration were presented and used to create new criteria for the evaluation of the organization. The example illustrated the major theoretical results.

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