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Abstract

Since the mid-70s, some multi-regional firms have adopted decentralization in information processing, influenced mainly by an increasing cost of data transmission and the availability of low-cost mini- or micro-computers and computer-networking technology. Given computer and communications technologies, an economic decision on whether or not a regional office should have an own computing facility depends mainly on the distance between the regional and central offices and the volume of data to be processed. Transition from centralization to decentralization often advocates a mixed system in which some regional offices use the central facility while others use local facilities. In this study, we formulate an integer-linear programming model representing such a system and then apply the model to a numerical example.

KEYWORDS: Information Systems; Decentralized Information Processing; Computer Networks; Integer-Linear Programming

1. Introduction

Decentralization in information processing has been adopted by large firms having operations in many regions. Before adopting complete decentralization, these firms have often gone through an interim stage in which some of the regional offices use the computer at the central office while others use computers in their own offices. This study is to formulate a model representing the interim system as an integer-linear program.

Until the mid-70s, most multi-regional firms used a central computer facility to serve the information processing needs of regional offices. In the centralized system, transactions generated in the regional office were usually put into a remote-job-entry system and transmitted to the central computer, and their processed results were sent back to the original office, printed out, and maintained in manual files (Infosystems (a) and (b) 1980). One of the basic reasons for using the centralized system is economies of scale available to large computers. To explain such economies, economists, following Chenery (1952), have used the following power function for the relationship between the capacity P and the investment cost C of a capital facility:

$$C = \alpha P^{\beta}$$

where α and β are parameters to be determined empirically; α represents the investment cost of a facility with unit capacity, and β is the scale factor. Economies of scale exist if β is less than unity, whereas diseconomies of scale exist if β is greater than unity. For computers, β is estimated to be around 0.5 (Knight 1963; Arbuckle 1966; Solomon 1966; Oldehoeft and Halstead 1972).

From the economic point of view, economies available with large computers tend to favor centralized processing, while an increasing cost of data communications due to an increasing volume of transactions tends to work against the centralization. From the viewpoint of management, decentralized processing offers the benefits of local control and participation without losing advantages of centralized coordination and integration (Kaufman 1978; Kay et al. 1980). Multiregional firms sooner or later may have to resolve the issue of centralization or decentralization in information processing by weighing advantages and disadvantages associated with each mode of processing.

A number of authors have examined the issue and indicated the economic and non-economic advantages of centralization and decentralization as follows (Streeter 1973; Appleton 1978; Ein-Dor and Seger 1978; Kaufman 1978; Statland and Winski 1978; Chen and Akoka 1980; Donaldson 1980; Fried 1980; Kay et al. 1980):

(1) Advantages of centralization:

- Possible economies of scale in processing a greater volume of transactions.
- Economies achieved through reductions in duplication of record storage, and program preparation and maintenance.
- Economies in preparation and protection of a fewer sites.
- Fuller utilization of processor capacity by assigning priorities over a larger and more diverse population of applications.

- More effective use of programming and technical skills concentrated at a central site.
- Ability to absorb local temporary overloads that might give pressure to upgrade decentralized processors.
- Consolidation of administrative technical functions otherwise duplicated.
- Managerial advantages achieved by centralization of a company's data base.

(2) Advantages of decentralization

- Production of information better suited to local needs because of the familiarity of systems personnel with local problems.
- Faster and more flexible adjustments of systems to cope with changes in local requirements.
- Ability to meet special local requirements.
- Stronger and happier relationship between the local EDP personnel and the local organizational unit.
- Reduced data communications costs.
- Maintenance of higher I/O quality.
- Better control over the infusion of technology such as the use of low cost micro- and mini-computers.
- Stronger responsibility felt by local managers for controlling the total cost of EDP in decentralized environment than in centralized environment.

Various suggestions have been made on the methodology of developing a decentralized system (LaVoie 1977; Buchanan and Linowes 1980(a) and (b)). Mathematical models representing decentralized processing have been formulated by some authors. Many of them are to obtain optimum solutions to problems of allocating information processing resources, such as workloads between the centralized and decentralized computers (Mitrani and Sevcik 1979), files to nodes and capacities to communication links (Mahamond and Riordon 1976), files to nodes by taking into consideration impacts of security requirements (Knotlek 1976), programs and data to nodes (Morgan and Levin 1977), files to nodes under changing conditions (Levin and Morgan 1978), a variety of resources with non-additive costs (Ceri and Pelagatti 1982), and computers, databases, and programs to nodes, and communication lines and routing of transactions between nodes (Chen and Akoka 1980). Other models are simulation models to compare the performances of centralized and decentralized systems (for example, Lientz and Weiss 1978).

The present study is to formulate a mixed centralized and decentralized system that differs from most existing models in a few aspects. First, it takes into consideration the problem of migration from centralization to decentralization implicit in the planning suggested by (Knotlek 1976; Ein-Dor and Seger 1978; Buchanan and Linowes 1980 (a); Kay et al. 1980). Second, it divides applications into two groups, critical and non-critical, according to their needs for prompt processing, and makes it mandatory to have all transactions beloning to the critical group processed by the local computer, if it is available. Third, it assumes both the fixed and variable costs of processing transactions, while most existing decentralization models assume only the variable cost.

2. Transitional Systems and Critical Transactions

A migration from centralization to decentralization in information processing is usually carried out over a period of time during which some regional offices use local facilities while others continued to use the central facility. The implementation of a local computer in a regional office in the early stage of migration may not be warranted if the office does not generate a big enough volume of transactions or is not located far enough from the main office. Avoiding a direct change from centralization to decentralization may be justified by other practical reasons such as limitations on funds, skilled regional personnel, and central training facilities and personnel.

In the decentralized system the regional computer is usually connected directly with the central computer by maintaining the same STAR architecture used previously in the decentralized system. This architecture permits the regional office to process its transactions without interruption by transactions of other offices.

Applications may be classified according to whether the timely processing of their transactions is critical or not. For example, a large corporate data center in a Fortune 500 company used such classification to divide its applications into five groups. In this classification, 49 percent of the total applications was regarded as critical and the rest as non-critical (Myers 1986). Most of the critical applications are directly related with daily operations as the following list indicates:

(1) Critical-1: Accounts Receivable, Accounts Payable, General Ledger, Inventory Control, Payroll, Pricing and Billing, and Customer Order Processing.

(2) Critical-2: Advertising, Fixed Assets, Manufacturing Control, Product Distribution, Purchasing, and Warehouse Scheduling.

(3) Critical-3: Cash Management, Distribution Order Entry, Freight Bill Auditing, Mail Order, and Product Entry.

Non-critical ones are either applications that generate summary reports of daily operations or applications not directly related with the operations. If a local computer exists, it would be natural for the regional office to process all critical transactions locally, whereas the local processing of non-critical transactions would not be essential.

3. Formulation

The subsequent formulation concerns a multi-regional firm in transition from centralization to decentralization in information processing. Each of its regional offices can have a remote-job-entry system or one of several alternative computer systems which will be directly connected with the central computer. Transactions generated at the regional office are divided into two types, critical and non-critical, following the previous argument. A regional computer system should at least have a capacity to process all critical transactions generated in the region each day. Non-critical transactions may be processed by the regional or central computer, depending on the availability of its capacity and the costs of processing and transmitting a transaction.

Under the above conditions, a computer network with a given host computer at the central office is formulated as an integer-linear program in order to find a minimum cost system. The formulation assumes a set of deterministic conditions including the volumes of critical and non-critical transactions generated at each regional office, the fixed periodic cost of each alternative system and the variable costs of processing critical and non-critical transactions by the system.

The fixed cost consists of the one-time cost allocated to each period over an expected life of the system and the recurring fixed cost. The one-time cost covers such items as the initial purchase of hardware and software, system development and implementation, site preparation, and user training. The recurring fixed cost covers the lease of hardware and software, rental of space, and overhead labor. The variable cost depends on the type of transaction processed and is a product of unit cost and volume of transactions. It covers such items as data preparation and entry, processing by a particular regional computer or by the central computer, data transmission for sending a transaction from a particular regional office to the central office and sending it processed result back to the regional office.

The capacity of a central or regional computer system is represented by throughput in critical or non-critical transactions processed per day. It covers not only the CPU but also the memory space and peripherals required for processing the indicated number and type of transactions, and maintaining the database required for the processing.

The total cost of the network consists of the comprehensive costs of processing transactions of all regions. The cost of each region takes one of the following two forms depending on whether the region has a computer system and whether the computer processes non-critical transactions as well as critical transactions:

(1) If a remote-job-entry (RJE) system is used,

Total cost = (Fixed cost of keeping the RJE system) + (Variable cost of data preparation and entry, data transmission, and processing done by the central computer for all transactions)

(2) If a regional computer system is used,

Total cost = (Fixed cost of keeping the computer system) + (Variable cost of data preparation and entry of all transactions) + (Variable cost of processing all critical transactions and some non-critical transactions by the regional computer) + (Variable cost of transmitting the remaining non-critical transactions and their processing done by the central computer).

The following set of terms will be used in the formulation:

h : Subscript representing the type of transaction involved, $h \in H = \{1,2\}$ where 1 or 2 represents a critical or non-critical transaction.

j : Subscript representing the region involved, $j \in J = \{1,\ldots,M\}$.

k : Subscript representing the regional system; $k \varepsilon K = \{0,1,...,N\}$ where 0 means a remote-job-entry system; and $k \varepsilon K' = \{1,...,N\}$ when only computer systems are considered.

B_h : Capacity of the central computer available for processing regional transactions, type-h transactions processed per day.

C_h : Unit cost of processing a type-h transaction by the central computer system.

N_{hj} : Number of type-h transactions generated in region j per day.

D_{hj} : Unit cost of transmitting a type-h transaction from region j to the central office, processing it by the central computer, and transmitting the result back to region j.

E_k : Fixed overhead cost of keeping regional computer system k and maintaining its connection with the central computer system per day.

F_{hk} : Capacity of regional computer k in type-h transactions processed per day. As an exception, the remote-job-entry system (k=0) has no limit on data entry capacity.

G_{hk} : Unit cost of entering a type-h transaction into regional computer system k.

H_{hk} : Unit cost of processing a type-h transaction by regional computer system k.

Further, the following decision variables are used in the formulation:

(1) x_{jk} is a binary integer taking a value of 1 or 0 depending on whether system k is implemented in region j.

(2) y_{jkp} is a non-negative variable representing the number of non-critical transactions processed by computer p when region j has regional computer k, $p \varepsilon P = \{1,2\}$; p = 1 means the regional computer, and p = 2 means the central computer. No variable is necessary to represent the number of critical transactions processed by the regional computer, since if the computer exists, it must process all of the transactions.

Thus, the objective of the model is to minimize the following total cost by determining proper values for x_{jk} and y_{jkp}:

$$\text{Obj. } Z = \min_{x_{jk}, y_{jkp}} \; + \sum_j x_{j0}\{E_0 + \sum_h N_{hj}(G_{h0} + D_{hj} + C_h)\}$$

$$+ \sum_j \sum_{k'} [x_{jk'}\{E_{k'} + N_{1j}(G_{1k'} + H_{1k'}) + N_{2j}G_{2k'}\}$$

$$+ y_{jk'1}H_{2k'} + y_{jk'2}(D_{2j} + C_2)]$$

$$h \varepsilon H, \; j \varepsilon J, \; k \varepsilon K, \; k' \varepsilon K', \; p \varepsilon P \qquad (1)$$

subject to

$$x_{jk} = 1 \text{ or } 0 \qquad \forall \; j \varepsilon J, \; k \varepsilon K$$

$$y_{jkp} \geq 0 \qquad \forall \; j \varepsilon J, \; k \varepsilon K', \; p \varepsilon P \qquad (2)$$

Further, x_{jk} and y_{jkp} must satisfy the following set of constraints:

(1) Only one system is implemented in each region:

$$\sum_k x_{jk} = 1 \qquad \forall \; j \varepsilon J, \; k \varepsilon K \qquad (3)$$

(2) The capacity of the central computer cannot be exceeded by workload:

$$\sum_j (N_{1j}/B_1 + N_{2j}/B_2)x_{j0} + \sum_j \sum_k (1/B_2)y_{jk2} \leq 1 \quad j \in J,\ k \in K' \qquad (4)$$

(3) The capacity of the regional computer cannot be exceeded by workload:

$$(N_{1j}/F_{1k})x_{jk} + (1/F_{2k})y_{jk1} \leq 1 \qquad \forall\ j \in J,\ k \in K' \qquad (5)$$

(4) If computer k is used in region j, the sum of y_{jk1} and y_{jk2} should equal N_{2j}; if not, the sum should be zero.

$$y_{jk1} + y_{jk2} = N_{2j}x_{jk} \qquad \forall\ j \in J,\ k \in K' \qquad (6)$$

With the objective function in (2) and constraints in (2)-(6), an integer-linear program for the mixed centralized and decentralized system has been formulated.

4. Numerical Example

The model developed above is now applied to a case involving five regional offices, a remote-job-entry system or four alternative computers available to each of the offices, and a given computer to be used at the central office. Tables 1 and 2 show the details of the regional transactions, and the central computer and alternative regional computers.

An optimum solution with a total cost of $47,987 per day is obtained by the program package LINDO after 36 iterations. The details of the solution are listed in Table 3. They may be summarized as follows:

Region 1: Retain the remote-job-entry system and send all transactions to the central computer.

Region 2: Install computer 4 and process all transactions locally.

Region 3: Retain the remote-job-entry system and send all transactions to the central computer.

Region 4: Install computer 3 and process all transactions locally.

Region 5: Install computer 2, process critical transactions locally, and send non-critical transactions to the central computer.

4. Conclusion

Multi-regional firms have been implementing a decentralized system for information processing because of the availability of low-cost but powerful minicomputers and computer-networking technology, and an increasing cost of data transmission with an increasing volume of transactions generated by regional offices. Transition from centralization to decentralization in information processing typically goes through an intermediate stage in which some of the regional offices use their own computers while others continue to use the central computer. In this study, we have formulated an integer-linear program for a network model representing the intermediate stage. The use of the model has been illustrated through a numerical example. As a sequel to this one-period analysis, a useful future research study would be the formulation of a dynamic program representing a staged conversion plan from a centralized system to a decentralized system.

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Table 1

Details of Regional Transactions

Region j	Number of Transactions Per Day		Data Transmissions Cost Between Region and Central Office per Transaction	
	Critical N_{1j}	Non-critical N_{2j}	Critical D_{1j}	Non-critical D_{2j}
1	150	270	$ .8	$ .7
2	700	1170	1.3	1.1
3	320	500	1.2	1.0
4	520	880	1.6	1.4
5	440	760	1.3	1.1

Table 2

Details of Central and Regional Computers

Computer	Fixed Cost Per Day E_k	Data Preparation and Entry Cost per Transaction		Unit Cost of Processing a Transaction		Capacity in Transactions Processed Per Day*	
		Critical G_{1k}	Non-critical G_{2k}	Critical H_{1k}	Non-critical H_{2k}	Critical F_{1k}	Non-critical F_{2k}
Central Computer	--	--	--	$3.4	$2.8	2600**	3600**
Regional Computer:							
k = 0***	$120	$5.0	$4.0	--	--	--	--
k = 1	400	4.6	3.7	$5.2	$4.2	600	960
k = 2	500	4.3	3.4	5.1	4.1	780	1250
k = 3	760	4.1	3.3	4.9	3.9	1100	1800
k = 4	1060	4.0	3.2	4.8	3.8	1500	2400

*Capacity when applied to a specific type of transaction.
**Capacity available to the processing of regional transactions.
***Remote-job-entry system.

Table 3

Optimum Network

Region j	Computer Selected k	Critical Transactions: Total N_{1j}	Critical Transactions: Regionally Processed	Critical Transactions: Centrally Processed	Non-critical Transactions: Total N_{2j}	Non-critical Transactions: Regionally Processed Y_{jk1}	Non-critical Transactions: Centrally Processed Y_{jk2}
1	0	150	0	150	270	0	270
2	4	700	700	0	1170	1170	0
3	0	320	0	320	500	0	320
4	3	520	520	0	880	880	0
5	2	440	440	0	760	0	760