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A model is developed for a strategic plan for migrating the information processing system of a multi-regional firm from centralization to decentralization. Under the limited availability of the central computer for processing regional transactions, the objective of the plan is to minimize the global cost of processing transactions of all regions. An optimum solution to the plan is obtained by formulating the model into a dynamic program to select a particular one from a set of alternative computer systems for each region and determining the timing of its installation during a given planning period.

1. INTRODUCTION

A growing trend in information processing among multi-regional firms is to migrate from a centralized system to a decentralized one. The migration at these firms is usually carried out in steps over time. Initially, a few regional offices are selected to have own computers to process their transactions locally, while the remaining offices continue to let the central computer process their transactions by sending these transactions usually through remote-job-entry systems (RJEs). The number of regional offices with own computers increases with time until finally all the regional offices are equipped with computers. This study is to formulate a model representing a strategic plan for such a migration in information processing. The objective of the plan is to minimize the total cost of processing transactions of all regions. An optimum solution to the plan is obtained by formulating the problem into a dynamic program.

Until the mid-70s, most multi-regional firms used a centralized system to process transactions generated by regional offices. In a typical arrangement, transactions generated by the regional office were transmitted to the central computer through a RJE system; and their computed results were sent back to the originating office, where they were retained in off-line files. Since then, a number of firms have migrated their information processing from centralization to decentralization. Advantages of decentralization over centralization have been discussed by a number of authors (Streeter 1973; Appleton 1978; Ein-Dor and Seger 1978; Statland and Winski 1978; Chen and Akoka

1980; Donaldson 1980; Fried 1980). Main reasons for this migration by the firm have been an increasing cost of data transmission due to an increasing volume of transactions, and the availability of practical computer networking technology and relatively cheap micro- and mini-computers for local use. The motivation for the migration has further been strengthened by expected managerial benefits, such as local control and participation without losing advantages of centralized coordination and integration (Kaufman 1978; Kay et al. 1980). Several authors have indicated the importance of developing a strategic plan in order to successfully complete the migration (LaVoie 1977; Buchanan and Linowes 1980(a); Knotlek 1976; Ein-Dor and Seger 1978; Kay et al. 1980).

A number of authors have formulated mathematical models representing distributed information processing systems. Generally, these models are to find optimum solutions to network allocation problems, such as allocating 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 when impacts of security requirements are considered (Knotlek 1976), programs and data to nodes (Morgan and Levin 1977), files to nodes under changing conditions (Levin and Morgan 1978), various resources with non-additive costs to nodes (Ceri and Pelagatti 1982), and computers, databases, and programs to nodes, and communication lines and routing of transactions between nodes (Chen and Akoka 1980). However, there is lack of literature on models showing a strategic plan for migration from centralization to decentralization.

2. A STRATEGIC PLAN OVER A FINITE PERIOD

The subsequent formulation concerns a strategic plan for migrating the information processing of a multi-regional firm from centralization to decentralization over a planning period. Its objective is to minimize the discounted present value of the total cost of processing transactions of all regions during the planning period. Given the limited availability of the central computer in processing regional transactions, the objective is achieved by optimally determining an installation plan--a combination of a computer system and timing of its installation--for each region.

Several conditions are assumed for the formulation. Until the time of planning, all regional offices have sent their transactions to the central computer through RJEs. The existing STAR architecture connecting the central computer with the RJEs will be maintained during and after the conversion. Each region will have a known number of transactions per year that steadily increases with time.

The total processing cost of the region per period consists of the fixed and variable costs. The fixed cost covers the fixed labor, material, and rental items necessary for running a RJE system or a computer system. In addition, if the regional office uses a computer system, the fixed cost also includes an annual amortization of the initial cost of acquiring system hardware and software, developing application software, user training, etc. If a RJE system is retained, such an initial cost is not incurred.

The variable cost varies with the volume of transactions processed per period. If the regional office uses a RJE system, the variable cost covers data entry, transmission of transactions from the regional office to the central office, processes performed by the central computer, and transmission of processed results back to the regional office. If the regional office uses the computer system, the variable cost covers the data entry and processing of transactions.

Computer systems installed after the first year may outlive the planning period, which will create the same difficulty as encountered when we try to compare alternative capital facilities having different lives. Traditionally, the difficulty with different lives is resolved by redefining planning period in one of the two methods. One method uses a planning period equal to a minimum common multiple of the lives of alternative facilities. In this case, each facility is represented by a finite chain of facilities identical to it. In the second method, each alternative facility is represented by an infinite sequence of identical facilities that is evaluated over an infinite period. In either method, the facility is normally required to produce its output at a constant rate during the planning period.

Since the output requirement is not constant in the present analysis, some other methods must be devised to evaluate competing installation plans for the region. The crux of the problem is how we should allocate the initial investment cost of the computer system to years within the planning period and to years outside, when the system outlives the planning period. A solution offered here is to allocate the initial investment to each year in proportion to the number of transactions processed during the year, with considerations given to interest.

In general, the discounted total cost of processing transactions of the region when a computer system is installed in the tth year of the n-year planning period is explained by the following descriptive formula:

$$\left[\begin{array}{l}\text{Discounted}\\ \text{Total Pro-}\\ \text{cessing Cost}\end{array}\right] = \left[\begin{array}{l}\text{Discounted Sum}\\ \text{of Processing}\\ \text{Costs in Years}\\ 1, \ldots, t-1\\ \text{when a RJE}\\ \text{is used}\end{array}\right] + \left[\begin{array}{l}\text{Discounted Sum}\\ \text{of Allocated}\\ \text{Initial Costs in}\\ \text{Years } t, \ldots, n\end{array}\right]$$

$$+ \left[\begin{array}{l}\text{Discounted Sum of}\\ \text{Processing Costs}\\ \text{in Years } t, \ldots, n\end{array}\right] \qquad (1)$$

In particular, the initial cost allocated to the mth year is explained by the following formula:

$$\left[\begin{array}{l}\text{Initial}\\ \text{Development}\\ \text{Cost}\\ \text{Allocated}\\ \text{to year } m\end{array}\right] = \left[\begin{array}{l}\text{Initial}\\ \text{Development}\\ \text{Cost}\end{array}\right] \times \left[\begin{array}{l}\text{Discounted}\\ \text{Number of}\\ \text{Transcations}\\ \text{Processed in}\\ \text{year } m\end{array}\right] \div \left[\begin{array}{l}\text{Sum of Discounted}\\ \text{Numbers of}\\ \text{Transactions}\\ \text{Processed During}\\ \text{Life of System}\end{array}\right] \qquad (2)$$

3. THE FORMULATION OF THE PLAN

The following terms and their definitions are used in the subsequent formulation:

a: number of working days per year;

c_i: cost of two-way data transmission per transaction between region i and the central office;

d_{ij}: number of transactions generated per day in region i in year j;

e_k: capacity of regional computer k in transactions per day;

f_o, f_k: annual fixed cost of using a RJE, and that of using regional computer k, respectively;

g_o, g_k: cost of data entry per transaction with a RJE, and that with regional computer k, respectively;

h_c, h_k: cost of processing a transaction by the central computer, and that by regional computer k, respectively;

i: regional office number, $i \varepsilon I = \{1,..,m\}$;

j: year in the planning period; $j = 1,...,n$;

k: alternative regional computer system, $k \varepsilon K = \{1,...,p\}$;

r: annual rate of return expected of capital projects;

q: expected life of a computer system in years;

s_k: salvage value of computer system k at the end of its life;

t: year in which a computer system is installed;

(t,k): installation plan, a combination of year t and computer system k;

u_k: cost of developing and implementing computer system k;

v_j: capacity of the central computer available for processing regional transactions per day in year j.

The following $A_i(t,k)$ represents the discounted cost of processing transactions of regional office i where plan (t,k) is executed as previously explained by formula (2):

$$A_i(t,k) = \sum_{j=1}^{t-1} \{f_o + a(g_o+c_i+h_c)d_{ij}\}/(1+r)^j$$

$$+ [\{u_k - s_k/(1+r)^q\}/(1+r)^{t-1}]\{\sum_{j=t}^{n} d_{ij}/(1+r)^j\}/\{\sum_{j=t}^{t+q-1} d_{ij}/(1+r)^j\}$$

$$+ \sum_{j=t}^{n} (f_k + ah_k d_{ij})/(1+r)^j$$

$$i \in I;\ t = 1, \ldots, n;\ k \in K, \qquad (3)$$

where the capacity of the regional computer, e_k, should be big enough to process all transactions in region i during its serivce as follows:

$$d_{ij} \leq e_k \qquad j = t, \ldots, t + q - 1 \qquad (4)$$

Let x_{itk} be decision variables having a value of 1 or 0 depending on whether or not plan (t,k) is executed in region i. Since the objective of the global plan is to select a particular installation plan for each region so that the sum of the costs of processing transactions of all regions is minimized, it is given by the following Z:

$$Z = \min_{x_{itk}} \sum_i \sum_t \sum_k x_{itk} A_i(t,k) \qquad (5)$$

where

$$x_{itk} = 0 \text{ or } 1 \qquad i \in I;\ t = 1, \ldots, n;\ k \in K \qquad (6)$$

Since only one plan will be executed in each region, we have

$$\sum_t \sum_k x_{itk} = 1 \qquad i \in I \qquad (7)$$

The system thus selected must satisfy the capacity requirement in (4), that is written as follows:

$$d_{ij} x_{itk} \leq e_k \qquad i \in I;\ t = 1, \ldots, n;\ j = t, \ldots, t + q - 1 \qquad (8)$$

Further, the available capacity of the central computer should be able to process the transactions of regions without computer system, that is written as follows:

$$\sum_{i} \sum_{t=j+1}^{n} \sum_{k} d_{ij} x_{itk} \leq v_j \qquad j = 1, \ldots, n \qquad (9)$$

The determination of the values of x_{itk} is done by a subsequent dynamic program. Before formulating this program, preliminary steps are taken to reduce the number of alternative installation plans in each region. This will simplify the computational procedure, although the steps can be embeded in the dynamic program.

(1) Reducing the number of alternative systems in each year:

Alternative computer systems considered for installation in region i in year t must satisfy the capacity constraint in (4). Among them, find a computer system, k_i', giving the minimum cost and write its function as follows:

$$A_i(t,k_i') = \min_k A_i(t,k) \qquad i \in I;\ t = 1, \ldots, n \qquad (10)$$

If there are p feasible systems to install in each region in each year, there will be a total of np global plans to be evaluated for the region. The selection of k_i' will reduce the number from np to n.

(2) Reducing the number of alternative years for installation:

Of the n minimum cost plans for region i represented by $A_i(1,k_i')$, ..., $A_i(n,k_i')$ as obtained above, find a plan giving the smallest cost, and let its year and the cost function be represented by t_i' and $A_i(t_i',k_i')$, respectively:

$$A_i(t_i',k_i') = \min_t A_i(t,k_i') \qquad i \in I \tag{11}$$

As far as region i is concerned, the plan with the cost $A_i(t_i',k_i')$ is the best one among the plans satisfying the capacity requirement in (8).

The installation of a computer system in year t_i' means all transactions of the region must be processed by the central computer in years prior to t_i'. In some of these years, the central computer might become overloaded and fail to satisfy the constraint in (8), which would force the firm to install a computer system in the region prior to t_i'. Thus, it is necessary to evaluate not only the installation plan installed in t_i' but also the best plan in each of years 1, ..., t_i' - 1, represented by the cost functions $A_i(1,k_i')$, ..., $A_i(t_i'-1,k_i')$. If it is allowed to make the strong assumption that each of years 1, ..., n has an equal chance to be t_i', the number of possible plans to evaluate for the region will be (1+n)/2. Thus, the number of global plans to be evaluated is reduced from np to n(1+n)/2 by this step.

4. THE DYNAMIC PROGRAM

The two steps discussed above will substantially reduce the number of alternative installation plans, or system-year combinations, for each region. Using cost functions $A_i(t,k_i')$ for $t = 1,\ldots,t_i'$, representing the feasible plans, the global objective function in (5) is rewritten in terms of variables t_i representing installation years for region i, instead of χ_{itk} as follows:

$$Z = \min_{t_i,\ldots,t_m} \sum_i A_i(t_i,k_i') \qquad i\varepsilon I;\ t_i = 1,\ldots,t_i' \tag{12}$$

First, for the computational purpose, let

$$C_m(v_1,\ldots,v_n) = \min_{t_1,\ldots,t_m} \sum_i A_i(t_i,k_i') \qquad i\varepsilon I;\ t_i = 1,\ldots,t_i' \tag{13}$$

subject to the following constraint on v_j, the central computer's available capacity in year j, previously given in (9):

$$\sum_{i=1}^{m} d_{ij}w_{ij}(t_i) \leq v_j \qquad j = 1, \ldots, n \tag{14}$$

where

$$w_{ij}(t_i) = \begin{cases} 1 & \text{if } j < t_i \\ 0 & \text{if } j \geq t_i \end{cases}$$

First, select a value of t_m for region m from 1, ..., t_m' and compute

$$\min_{t_1,\ldots,t_{m-1}} \sum_{i=1}^{m} A_i(t_i,k_i') = A_m(t_m,k_m') + \min_{t_1,\ldots,t_{m-1}} \sum_{i=1}^{m-1} A_i(t_i,k_i') \tag{15}$$

Once t_m is selected, t_1, ..., t_{m-1} must be restricted to integer values satisfying

$$\sum_{i=1}^{m-1} d_{ij}w_{ij}(t_i) \leq v_j - d_{mj}w_{mj}(t_m)$$

Since the minimization of the second term on the right-hand side of (15) depends on $v_j - d_{mj}w_{mj}(t_m)$, we may write

$$C_{m-1}(v_1-d_{m1}w_{m1}(t_m),\ldots,v_n-d_{mn}w(t_m)) = \min_{t_1,\ldots,t_{m-1}} \sum_{i=1}^{m-1} A_i(t_i,k_i')$$

In the second step, we have

$$C_{m-2}(v_1-d_{m-11}w_{m-11}(t_{m-1})-d_{m1}w_{m1}(t_m),\ldots,v_n-d_{m-1n}w_{m-1n}(t_{m-1})-d_{mn}w_{mn}(t_m))$$

$$= \min_{t_1,\ldots,t_{m-2}} \sum_{i=1}^{m-2} A_i(t_i,k_i')$$

By continuing this process, we finally get to region 1:

$$C_1(v_1-\sum_{i=2}^{m} d_{i1}w_{i1}(t_i),\ldots,v_n-\sum_{i=2}^{m} d_{in}w_{in}(t_i)) = A_1(t_1,k_1')$$

where t_1 should be selected from 1, ..., t_1' so that it should satisfy

$$d_{1j}w_{1j}(t_1) \leq v_j - \sum_{i=2}^{m} d_{ij}w_{ij}(t_i) \quad j = 1, \ldots, n$$

To summarize, the above computational steps are rewritten to the following dynamic program in recursive form:

$$C_m(v_1,\ldots,v_n) = \min_{t_m} \{A_m(t_m,k_m') + C_{m-1}(v_1-d_{m1}w_{m1}(t_m),\ldots,v_n-d_{mn}w_{mn}(t_m))\} \quad (16)$$

The actual computation starts with

$$C_1(v_1-\sum_{i=2}^{m} m_{i1}w_{i1}(t_i),\ldots,v_n-\sum_{i=2}^{m} m_{in}w_{in}(t_i)) = \min_{t_1} A_1(t_1,k_1')$$

and determine $A_1(t_1,k_1')$ for each of the feasible values of t_1. Next, determine $A_2(t_2,k_2')$ in the same manner. Repeat this computational step to finally determine the objective function in (12):

$$Z = C_m(v_1,\ldots,v_n)$$

5. A NUMERICAL EXAMPLE

The recursive formulation in (16) is used to obtain an optimum global plan for a problem with five regions, four alternative computer systems, and a planning period of five years. Various conditions used in the example are shown in Table 1. The programming logic used for the computation is shown in Appendix I.

The total numbers of feasible installation plans in regions 1, 2, 3, 4, and 5 that satisfy capacity constraints in (8) are 20, 8, 12, 19, and 6, respectively, as shown in Table 2. If the method of complete enumeration were used, it would require the evaluation of 20x8x12x19x6 or 218,880 global plans. This number is reduced to 5^5 or 3125 by the first step of preliminary reduction. In the second reduction step, the minimum cost systems for regions 1,...,5 have been found in years 5, 4, 4, 1, and 3, respectively, that further reduces the number of global plans to be evaluated to 5x4x4x1x3 or 240. Of the 240 global plans, the dynamic program has evaluated 220 plans as feasible and rejected 20 plans as not meeting the central computer's capacity limitation. Table 3 shows the number of global plans to be evaluated at each step in the reduction procedure.

The dynamic program has produced an optimum plan requiring a total processing cost of $16,394,863. This plan consists of the following installation plans for individual regions:

Region i	Computer System k	Installation year t
1	2	5
2	5	4
3	5	4
4	2	1
5	5	2

6. CONCLUSION

A strategic plan has been formulated to migrate the information processing of a multi-regional firm from centralization to decentralization. Under a constraint on the availability of the central computer, the objective of the plan is to minimize the discounted total cost of processing transactions of all regions during the period. An optimum solution to the plan is obtained through a dynamic program that specifies a particular computer system to be installed in each regional office and the timing of its installation.

The information processing system in the STAR architecture has been analyzed in this paper. Another common form of the decentralized system for a multi-regional firm is the TREE architecture, in which individual regional offices are connected with the central computer through regional computer centers. As an extension of the present study, it would be worthwhile to investigate a strategic plan for developing such a network.

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Table 1 Conditions Used in Example

Number of Transactions Per Day, R_{ij}

Region i	Year j: 1	2	3	4	5	Annual Rate of Increase After Year 5
1	150	195	254	330	428	20%
2	320	448	627	878	1229	10
3	440	528	634	760	912	15
4	520	572	629	692	761	8
5	700	840	1008	1210	1452	5

Costs and Capacity of Computer Systems

Computer System, k	Initial Investment	Capacity in Transactions Per day e_k	Annual Fixed Cost f_k	Processing Cost Per Transaction H_k
0 (RJE)	--	--	$10,000	
1	$200,000	1,000	20,000	$5.2
2	300,000	1,200	30,000	5.1
3	400,000	1,500	40,000	4.9
4	500,000	1,900	50,000	4.7
Central Computer	--	v_j = 1,800 for all j	--	h_c = $3.4

Rate of discount = 10%

Number of working days per year, a = 250

Life of a computer system = 5 years

Table 2

Number of Feasible Computer Systems for Each Region

Region	Year 1	Year 2	Year 3	Year 4	Year 5	Total Feasible Plans
1	4	4	4	4	4	20
2	2	2	2	1	1	8
3	4	3	2	2	1	12
4	4	4	4	4	3	19
5	2	1	1	1	1	6

Table 3

Reduction in Total Number of Global Plans

	At each Reduction Procedure	Global Plans to be Evaluated
	Total enumeration	218,880
1.	After the first reduction step	3,125
2.	After the second reduction step	240
3.	By the dynamic program	220

Appendix I

Dynamic Program

Set the minimum cost C^* = arbitrary large value

Do for each $t_m = 1$ to t_m'

  If $D_{mj} = d_{mj} w_{mj} \leq v_j$ for all $j = 1$ to n where $w_{mj} = 1$ for $j < t_m$ or otherwise $w_{mj} = 0$, then

    Do for each $t_{m-1} = 1$ to t_{m-1}'

      If $D_{m-1j} = D_{mj} + d_{m-1j} w_{m-1j} \leq v_j$ for all $j = 1$ to n where $w_{m-1j} = 1$ for $j < t_{m-1}$ or otherwise $w_{m-1j} = 0$, then

        - - -

          Do for each $t_1 = 1$ to t_1'

            If $D_{1j} = D_{2j} + d_{1j} w_{1j} \leq v_j$ for all $j = 1$ to n where $w_{1j} = 1$ for $j < t_1$ or otherwise $w_{1j} = 0$, then compute $C = \sum_i A_i(t_i, k_i')$

              If $C^* > C$, then

                Set $C^* = C$, $J_i^* = t_i$, and $k_i^* = k_i'$ for all $i = 1$ to m

              Else, go to next t_1

              End if

            Else, stop t_1

            End if

          End do

        - - -

```
            Else, stop t_{m-1}
            End if
        End do
    Else, stop t_m
    End if
End do.
```