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EFFECTIVENESS OF DECENTRALIZATION WITH POWER SEPARATION IN CENTRAL AUTHORITY

by

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ABSTRACT

Various real decentralized management systems are modeled in terms of linear programming decomposition with both coupling rows and columns. The proposed decentralization model is characterized by power separation within central authority. That is, the two independent organs share the central power to avoid monarchical management and each of them is competent of coordinating the activities of subsystems on distinct aspects. This biarchical control allows subsystems fuller autonomy, and in obtaining the global optimum the whole decision is now based upon more thorough agreement among the central organs and subsystems than in the price-directive or resource-directive methods of the existing hierarchical decentralization models. Thus the effectiveness of decentralization with such a structure is prescribed in the process of the redesign of real organizations.

1. PROBLEM STATEMENT

1.1 Cross-cultural and Cross-disciplinary Comparison of Decentralization

Analysis of decentralization has been done in various contexts. The variety comes not only from variety of disciplines but from that of socio-cultural background of analysts. As organization and its structure are determined by socio-cultural conditions, cross-cultural as well as cross-disciplinary comparisons may be useful in categorizing the aspects of decentralization studies done thus far.

(i) Information efficiency: In a distributed computer system information capacity is often a bottleneck and hence storage and flow of information must be reduced. Similarly in economic planning task a procedure must be established to prevent information flood in the planning offices at each level [12, 17]. (ii) Resource efficiency: In a large scale planned economy like in USSR, concern is not only with efficiency within the planning office but rather with efficiency of the whole economy for given resources. An important problem is compatibility between these two kinds of efficiency [4,5]. (iii) Response time efficiency: In a geographically dispersed service network like an American service firm an important problem is to reduce time lag between request and service supply by increasing the number of facilities [15, 16]. (iv) Human vitality stimulation: In traditional society of senior system only an elderly person can be the top manager especially in a large organization. On the other hand, in a growing society an organization needs initiative of younger middle managers for vitality. In traditional and growing society like in East Asia thus a contradiction occurs and this contradiction can be resolved by the bottom-up decision system in which the middle managers are encouraged to make decisions in an autonomous manner. Aim of decentralization is to energize a firm by spontaneous participation of subordinate units. This paper is aimed at enhancing the decentralization model from the view point of (iv) which has been relatively ignored in Western literatures.

1.2 Resource-directive vs. Price-directive Methods

Basically there are two mathematical methods in decentralization theory; resource-directive and price-directive methods. The former method has many advantages [8, 12, 17, 24] from the view point of (i), but from the view point of (iv) it has a decisive drawback that the resource center directly allocates the subordinate units the resources in the manner of rather top-down system. On the other hand the latter method provides a market in a firm wherein each subordinate unit purchases the resources spontaneously for the prices fixed by the resource center. Such a freemarket-like situation is expected quite acceptable if the free market is accepted as a typical form of freedom (this latter condition may hold in the market economy countries).

1.3 Deficiency of Price-directive Method and Its Overcome

The price-directive method also has a defect. Namely, autonomy breaks down at the final step of iteration when the resource center commands a convex combination of autonomous solutions [2]. This is a critical defect from the view point of (iv) as an imperative top-down command and is hardly interpretable as an acceptable management control. Let it be discussed in more detail. The decomposition algorithm for linear programming of angular structure which has coupling rows but has no coupling column was interpreted as hierarchical decentralized management guided by the pricing of common resources by the resource center [2, 6]. However, pricing alone fails to guide the subordinate units to the global optimum except in cases of approximation [14] and strictly concave objective function [2]. In a general case the global optimum is attained with the aid of convex combination which breaks down autonomy in an uninterpretive manner. An effort to interpret it in concordance to the acceptable management mechanism [7] still leaves some limit on autonomy.

Our price-directive decentralization model to be proposed below needs no convex combination and thereby avoids the breakdown of autonomy. This improvement results from the biangular structure of our model which has both coupling rows and columns. Although the decomposition algorithm for biangular structured linear program was once discussed in relation to decentralization [18], no difference between the decentralization of biangular structure and that of angular structure was explored then. Though a few algorithms were proposed thereafter for nonlinear cases [10, 11], these algorithmic works were not interested in characterizing the distinctive feature of the decentralization of biangular structure.

1.4 Industrial Organization Problems

Besides the theoretical interest stated above another motivation of this paper is to represent and evaluate several real management systems which are now in the process of formation or reformation.

The division system which has been considered as a typical example of hierarchical decentralization management connecting the autonomous divisions via common resources was quite common among firms. This fact gave the decentralization theory some reality, and reciprocally the effectiveness of the division system was supported by this theory. However, the recent trend is that many big firms slightly reform the division system by adding a trans-divisional bureau off the existing hierarchical line. The activity of this bureau is to integrate, with its high technology, various machines produced by respective divisions into a complex system because the integrated system is today more profitable than the straight sum of the components. This reformation is acceptable to the firms because it is so slight that it disturbs no running operation of the firms. However, it breaks the hierarchical structure which was considered the essential feature of decentralization. Now a question arises as to the effectiveness of such a redesigned nonhierarchical division system. This question is urgent in the organizational redesign process. Our model will represent this reformed division system and provide its theoretical foundation.

Another example of the price-directive decentralization is an intercorporate system under the leadership of a bank. This is quite common in a developing economy where the most scarce resource is the capital which is held by a bank. Here a bank guides the member companies through the management of capital. However, a nonhierarchical form of intercorporate system is emerging in this decade in Japan. That is, a trading company which has no particular resource shares the leadership with a bank and integrates various machines produced by the member companies into a complex system for higher profitability. Now a similar question arises as to its effectiveness in intercorporate system design.

A third example of the price-directive decentralization is the semi-developed national or regional economy where each sector acts autonomously under the leadership of the national bank or government. A problem is that the distribution sector (whole sale and retail) which produces nothing and the public sector which manages no scarce resource do not appear in the existing model of decentralization despite their important impact on the production sectors. The distribution sector and the public sector are extremely big in the traditional Asian economy and the semi-socialized economy respectively. Our model will include the distribution sector or the public sector explicitly in the model and will thereby evaluate their effective contribution to guiding the whole system to the global optimum.

2. PROBLEM FORMULATION

2.1 Modeling of Transdivisional Integration Activity

A transdivisional integration bureau in a big firm "produces" and sells a complex system through integration of various machines which are produced by the respective divisions (Fig. 1). It gathers the component machines as a rule from within the same firm. Hence its activity consumes the divisional resources and increases the divisional demands. Thus the k-th divisional activity is now constrained as follows.

$$A_{kk}\, x_k \leqq b_k - A_{k0}\, x_0 \qquad (1)$$

A_{kk}: $m_k \times n_k$ - matrix of technology coefficient,

x_k : n_k - column vector of the k-th divisional activity level,

b_k : m_k - column vector of the k-th divisional resource and demand level,

A_{k0}: $m_k \times n_0$ - matrix of effect coefficient of the activity of the transdivisional integration bureau on the k-th divisional resource and demand,

x_0 : n_0 - column vector of the activity level of the transdivisional integration bureau.

The conventional division system allows a division of assembled machinery to purchase the component from the market outside the firm if a division of the component machines within the firm supplies a more expensive one. This situation can mathematically be modeled in such a way that every component is once sold to the market and is purchased back therefrom by the division of assembled machinery, yielding the following constraint.

$$A_{kk}\, x_k \leqq b_k \qquad (1')$$

The difference between (1) and (1') comes from the difference between the purposes of these two corporate systems. The conventional division system seeks tactical efficiency, specifically cost reduction, through competition with the market. On the other hand the transdivisional integration bureau is set up to seek strategic efficiency, specifically higher profitability, through integration of the existing product lineup of the firm. The bureau may adapt its design of a system to availability of component machines by substitution between machines through its proper change of design. Accordingly the last term of the right hand side in (1) also denotes substitution between divisions, and therefore the vector x_0 is common for all $k = 1, \ldots, N$. As a common activity it forms the coupling columns, yielding the biangular structured model which has coupling columns as well as coupling rows. Its nonzero coefficient submatrices are depicted in Fig. 2.

Fig. 2

2.2 Modeling of Intercorporate System

Several firms form a cooperative group under the joint leadership of a bank and a trading company. The latter takes up an order for a big project from the market and then gives orders for component machines, materials and services to the member firms in the group. This relation can also be depicted by Fig. 1 and leads again to the constraint (1) and the biangular structured model (Fig. 2) where indices 0 and k ($k = 1, \ldots, N$) denote the trading company and the member firms respectively.

2.3 Modeling of Function of Distribution Sector

The distribution sector processes market information and distributes market demand to relevant sectors. The distribution activity includes the substitution activity which satisfies demand for a commodity with another commodity. Such a demand reorganization activity differs the function of the distribution sectior from that of the transportation (or physical distribution) sector. In this way it affects the demand of each sector and couples each other. Hence it can be expressed by the last term of the constraint (1) in biangular structured model. The coefficient matrix A_{k0} may typically consist of 1, 0, and -1 according to out-, no- and inflow. Production sectors are denoted by k (k = 1, ..., N).

2.4 Modeling of Function of Public Activity

The government makes public expenditure or provides public commodities. Economists have tried to define them in terms of their properties [19, 22]. However, commodities with the same property often compete each other, one as a public and the other as a private commodity. The most typical examples of the public commodities may be a park and a city bus, but a commercial park and a bus managed by a private company may exist in the same city in competition with the public ones. A typical example of public expenditure is a subsidy for agricultural products, but subsidized domestic grains compete with unsubsidized imported grains.

The public commodity and public expenditure may generically be termed the public activity in context of activity analysis. Its realistic definition may be that it is the activity managed by the government. Interpretation of the last term of the constraint (1) is now as follows:

A_{k0}: the matrix of effect coefficient of public activity upon the demand and resource of private sector k.

x_0 : the vector of level of public activity.

The same public activity impacts each private sector in a different manner. Hence the coefficient A_{k0} depends on k.

2.5 Global Model

Replacing the constraint (1') with (1) in the conventional decentralization model of the Dantzig-Wolfe type [6] leads to the following model which is to be called the global problem and whose coefficient matrix is depicted by Fig. 2. Herein the row indexed by 0 denotes the constraint on the common resource.

$$\left.\begin{array}{ll} \text{maximize} & w = \sum_{k=0}^{N} c_k\, x_k \\ \text{subject to} & \sum_{k=0}^{N} A_{0k}\, x_k \leqq b_0 \\ & A_{k0}\, x_0 + A_{kk}\, x_k \leqq b_k,\ k = 1, 2, \ldots, N \\ & x_k \geqq 0,\ k = 0, 1, 2, \ldots, N \end{array}\right\} \quad (G)$$

Its dual solution is denoted below by $(p_0; p_1; \ldots; p_N)$ with each component of $1 \times m_k$, $k = 0, 1, 2, \ldots, N$. To avoid triviality we assume that the both of its primal and dual optimal solutions exist.

3. DECOMPOSITION PROCEDURE AND SOLUTION METHOD

3.1 Primal Decomposition

Applying the conventional decomposition rule to the global problem (G) yields the master problem (C_P^ℓ) and subproblem (S_P^ℓ) for iteration ℓ as follows.

$$\left.\begin{array}{lll} \text{maximize} & w_P = \sum_{k=0}^{N} c_k \sum_{i=0}^{\ell-1} x_k^i\, g_k^i & (2) \\ \text{subject to} & \sum_{k=0}^{N} A_{0k} \sum_{i=0}^{\ell-1} x_k^i\, g_k^i \leqq b_0 & (3) \\ & \sum_{i=0}^{\ell-1} g_k^i = 1,\ k = 0, 1, \ldots, N & (4) \\ & g_k^i \geqq 0,\ k = 0, \ldots, N; & \\ & \qquad i = 0, 1, \ldots, \ell-1 & (5) \end{array}\right\} \quad (C_P^\ell)$$

where g_k^i is a scalar variable for all k and ℓ, and x_k^i denotes the given scalar fixed as the solution of (S_P^i) at iteration i.

$$\left.\begin{array}{ll} \text{maximize} & w_P^S = \sum_{k=0}^{N} (c_k - p_0^\ell A_{0k})\, x_k \\ \text{subject to} & A_{k0}\, x_0 + A_{kk}\, x_k \leqq b_k,\ k = 1, \ldots, N \\ & x_k \geqq 0,\ k = 0, 1, \ldots, N \end{array}\right\} \quad (S_P^\ell)$$

where p_0^ℓ denotes the given vector fixed as the dual solution associated with (3) in (C_P^ℓ).

3.2 Dual Decomposition

Applying the same decomposition rule to the dual problem of (G) yields the dual master problem (C_D^ℓ) and subproblem (S_D^ℓ) for iteration ℓ as follows.

$$\left.\begin{array}{lll} \text{minimize} & w_D = \sum_{k=0}^{N} \sum_{j=0}^{\ell-1} p_k^j\, b_k\, h_k^j & (6) \\ \text{subject to} & \sum_{k=0}^{N} \sum_{j=0}^{\ell-1} p_k^j\, A_{k0}\, h_k^j \geqq c_0 & (7) \\ & \sum_{j=0}^{\ell-1} h_k^j = 1,\ k = 0, 1, \ldots, N & (8) \\ & h_k^j \geqq 0,\ k = 0, 1, \ldots, N; \quad j = 0, 1, \ldots, \ell-1 & (9) \end{array}\right\} \quad (C_D^\ell)$$

where h_k^j is a scalar variable for all k and j, and p_k^j denotes the given scalar fixed as the solution of (S_D^j) at iteration j.

$$\left.\begin{array}{ll} \text{minimize} & w_D^S = \sum_{k=0}^{N} p_k \, (b_k - A_{k0} \, x_0^\ell) \\ \text{subject to} & p_0 \, A_{0k} + p_k \, A_{kk} \geqq c_k, \; k = 1, \ldots, N \\ & p_K \geqq 0, \; k = 0, 1, \ldots, N \end{array}\right\} \quad (S_D^\ell)$$

where x_0^ℓ denotes the dual solution associated with (7) in (C_D^ℓ).

The decomposition done so far [18] stopped here, but we can proceed further for the purpose of full autonomy.

3.3 Separation of Subproblems

Since p_0^ℓ and x_0^ℓ are fixed in (S_P^ℓ) and (S_D^ℓ) as the dual solutions of (C_P^ℓ) and (C_D^ℓ) respectively, problems (S_P^ℓ) and (S_D^ℓ) are separable in variables. Furthermore, fixing x_0 in (S_P^ℓ) as $x_0 = x_0^\ell$ and p_0 in (S_D^ℓ) as $p_0 = p_0^\ell$, we can decompose (S_P^ℓ) and (S_D^ℓ) into N independent problems respectively. Thus (S_P^ℓ) reduces to the divisional problems (D_K^ℓ), k = 1, 2, ..., N as follows.

$$\left.\begin{array}{ll} \text{maximize} & w_P^k = (c_k - p_0^\ell \, A_{0k}) \, x_k \\ \text{subject to} & A_{kk} \, x_k \leqq b_k - A_{k0} \, x_0^\ell \\ & x_k \geqq 0 \end{array}\right\} \quad (D_k^\ell)$$

It can be seen that (S_D^ℓ) reduces to the dual problems of (D_k^ℓ), k = 1, 2, ..., N. Hence $x_1^\ell, \ldots, x_N^\ell$ are the primal solutions of (D_k^ℓ) and $p_1^\ell, \ldots, p_N^\ell$ are the dual solutions of (D_k^ℓ), k = 1, ..., N.

3.4 Attainability of Global Optimum

As was already stated, the primal master problem (C_P^{ℓ}) and the dual master problem (C_D^{ℓ}) are connected through (D_K^{ℓ}), $k = 1, \ldots, N$. Hence a primal-dual algorithm is applied to solving the problem. Its stopping criterion of iterations is the equality between the primal and dual objectives, i.e., $w_P = w_D$. (Fig. 3)

Lemma 1: The algorithm described in Fig. 3 attains the global optimum.

Proof. The algorithm in Fig. 3 is different from that of [18] only in that (S_P^{ℓ}) is divided into (D_k^{ℓ}), $k = 1, \ldots, N$. Hence the validity of the latter algorithm implies that of the former.

Q.E.D.

Lemma 2: [18] Let x_k^* and p_k^* denote the optimal primal and dual solutions of (G) respectively for $k = 0, 1, \ldots, N$. Then

$$x_k^* = \sum_{i=0}^{\ell-1} g_{k\ell}^{i}\, x_k^{i}, \quad k = 0, 1, \ldots, N$$

$$p_k^* = \sum_{j=0}^{\ell-1} h_{k\ell}^{j}\, p_k^{j}, \quad k = 0, 1, \ldots, N$$

where ℓ denotes the final iteration and $g_{k\ell}^{i}$ and $h_{k\ell}^{j}$ denote the optimal values of g_k^i and h_k^j at iteration ℓ.

4. FULL AUTONOMY AND INTELLIGIBILITY

4.1 Intelligible Interpretability

The problem (C_P^{ℓ}) represents the authority of the resource center which manages the common resources and decides its price p_0^{ℓ}. In short it is competent of price-directive control as in [6].

The problem (C_D^ℓ) represents the common activity of the trans-divisional integration bureau which affects the demands and resources of all the divisions. In short it is competent of resource-directive control as in [8, 17]. Finally the problems (D_k^ℓ) represent the divisional activities, $k = 1, \ldots, N$. Thus every action is intelligibly interpreted.

TABLE 1

4.2 Full Autonomy of Each Division

Convex combination which was commanded by the resource center without the consent of divisions is replaced here by the full agreement among the two central organs and divisions.

Lemma 3. (i) $$p_0^\ell = \sum_{j=0}^{\ell-1} h_{0\ell}^j \, p_0^j \tag{10}$$

(ii) $$x_0^\ell = \sum_{i=0}^{\ell-1} g_{0\ell}^i \, x_0^i \tag{11}$$

Proof. (i) It was shown [7, 25] that the convex combination on the dual solutions obtained so far forms the final dual solution in the Dantzig-Wolfe type decomposition, and (C_P^ℓ) is of this type. Hence (10) holds. (ii) (C_P^ℓ) and (C_D^ℓ) are of the same structure, and hence the argument of (i) holds also for the dual solution of (C_D^ℓ). Q.E.D.

Theorem 1: $x_k^\ell = x_k^*$ and $p_k^\ell = p_k^*$ for $k = 0, 1, \ldots, N$

Proof. (i) $x_0^\ell = x_0^*$ by Lemma 2 and 3.

(ii) $p_0^\ell = p_0^*$ by the parallel argument.

(iii) We will show that $x_k^\ell = x_k^*$ for $k = 1, \ldots, N$. Indeed, note that $x_0^\ell = x_0^*$ and $p_0^\ell = p_0^*$ are fixed and given to (D_k^ℓ) before calculating x_k. Then by the partitioning theorem of Benders [3 (Theorem 3.1), also 1, 9, 21], $x_k^\ell = x_k^*$ in (D_k^ℓ) for $k = 1, \ldots, N$.

(iv) $p_k^{\ell} = p_k^*$. Indeed, the argument of (iii) holds for the dual problem of (D_k^{ℓ}), also for the dual solution Q.E.D.

Theorem 1 is interpreted so that each divisional solution obtained in an autonomous manner immediately forms the associated component of the global solution, i.e., that there is no need to take a convex combination to reform the divisional solutions obtained. Hence all divisions enjoy full autonomy under the price guide p_0 and the common activity x_0 by the two central organs. At the same time each central organ also enjoys full autonomy as in the conventional decentralization.

Full autonomy was not attained in the conventional decentralization model where the global optimum often did not lie on an extreme point of the feasible region of divisional problem. Full autonomy is attained in our model where the global optimum can lie practically on an extreme point of the feasible region of divisional problem which practically contracts or expands as the effect of the common activity of a central organ (Fig. 4).

Fig. 4

4.3 Operation Procedure of System

The iteration of decomposition algorithm is often considered to represent the coordination process in decentralized management [7, 20, 23, 24]. In an extreme case their correspondence is considered as being almost one-to-one, and this idea leads to the view that the convergence speed of algorithm is a critical criteria for applicability of decentralization model [23, 24]. It may be so from the view point of (i) stated in §1.1 where the purpose is to find the optimum while preventing information overflow. From the view point of (iv), however, the purpose is to encourage the spontaneous decision of divisions while keeping the global optimum. It deserves noting that a firm often knows the near-optimal values of managerial parameters from its past experience or from some information of its competitors and resource market. In such a situation just a few iterations of coordination brings these values nearer the optimum.

Suppose the two central organs know the near-optimal values of x_0^* and p_0^* and act according to these values. Then, following our proposed model, each division is expected to act autonomously also in the near-optimal way.

The directors of these two central organs and of the divisions are under the personnel management of the top decision maker and their promotion to the top executives is also determined by the top. Hence they are expected to act honestly to the whole firm. Hence the competence of the top is to set the objectives and to manage a personnel promotion of the directors at middle level though such an immaterial activity of the top does not explicitly appear in our model.

4.4 Acceptability

The coordination in our model consists of the freemarket-like price-direction and of the free competition between the trans-divisional and divisional activities. The central authority has a power separation system between two organs. Under this system full autonomy is allowed. In such a value system that free economy, power separation and autonomy are highly evaluated, the proposed system is expected highly acceptable to its members.

5. CONCLUSION

Various decentralized systems in the real world are modeled here in terms of biangular structured linear programming and its decomposition. This normative model is shown to remove the major deficiency of the existing decentralization models of price-directive type, to make the whole process interpretive in an intelligible manner and to make every decision based upon the unanimous agreement among the central organs and divisions. In this way the effectiveness of these real systems is theoretically proved for the purpose of systems assessment. Specifically the following advice may be implied by this normative model; to augment the existing division system with a transdivisional bureau competent of integrating the products in a corporate system and to admit joint leadership of a trading company with a bank in an intercorporate cooperation system.

The nonlinear biangular model wherein so many parameters are exchanged among the two master problems and the subproblems [10, 11] is left uninterpreted because some parameters are hardly interpretable in an intelligible manner. Even a nonlinear angular model [13] remains uninterpreted.

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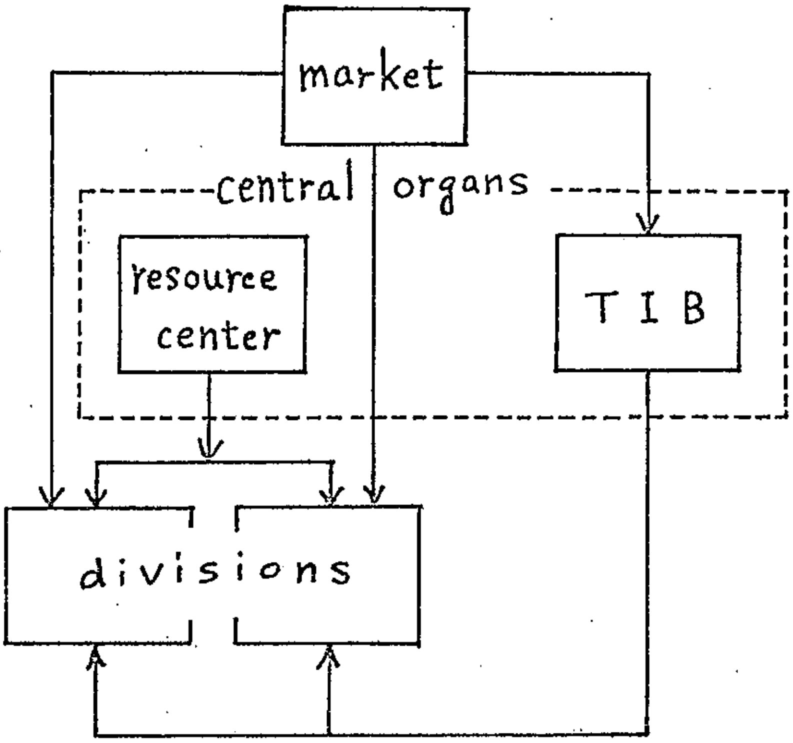

Fig. 1

Structure of Corporate System

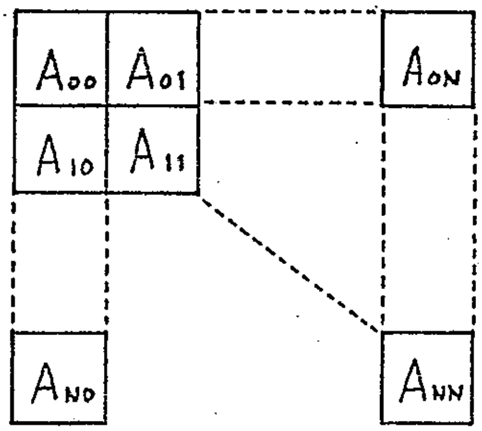

Fig. 2

Structure of Nonzero Submatrices

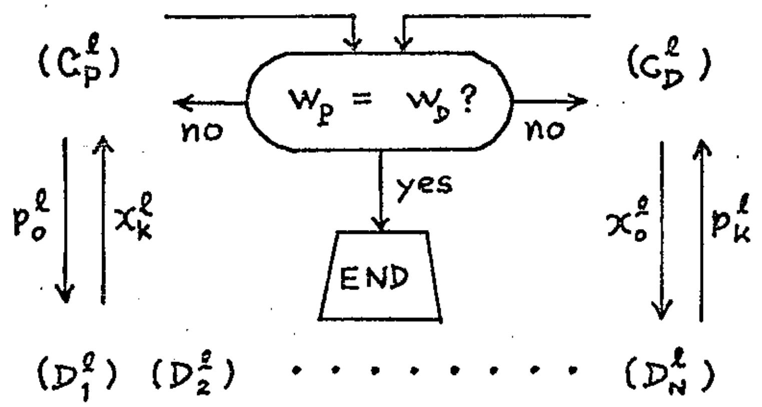

Fig. 3

Flow of Algorithm

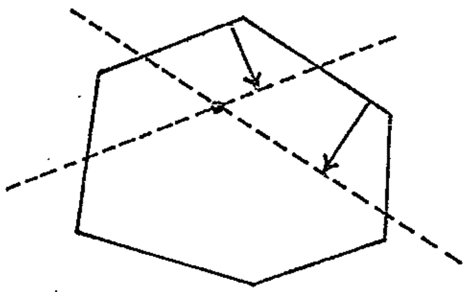

Fig. 4

Contraction of Feasible Region

TABLE 1. VARIABLES AND PARAMETERS

Problem	Variables		Input Parameter	Output Opt. Sol.	Management
	Primal	Dual			
C_P^ℓ	g_k^i	$p_0,\ \pi_k$	x_k^i	p_0^ℓ	Common Resource
C_D^ℓ	h_k^j	$x_0,\ \xi_k$	p_k^j	x_0^ℓ	Common Activity
D_k^ℓ	x_k	p_k	$p_0^\ell,\ x_0^\ell$	$x_k^\ell,\ p_k^\ell$	Divisional Activity