Spatial Economics of Information Flow between Head and Branch Offices

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This paper aims to develop a new spatial economic model for analyzing information flow between head and branch offices. The hierarchy between head and branch offices is modeled, and a way of treating information flow is proposed. Broadband Internet enables both home and office to send and receive much more information using personal computers, and the resulting changes and possibilities deserve analysis. This paper sets out how to decide the location of the head office and some branch offices, and the allocation of all employees and computers to head and branch offices. Also, an inter-regional Information Input-Output Table (Information IO Table) is proposed to express the information flow between the head office and the branch offices and between those offices and other enterprises.

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1. Introduction

This paper sets up a spatial economic model representing the activities of a head office and some branch offices, including internal and external information movements which aim to maximize the profit of the firm. The model first expresses the basic two-tier corporate hierarchical structure involving a single head office and branches. It also takes into account spatial factors including distances between the head and branch offices. Third, it considers internal information flows between a single head office and branch offices, and external information flows between the offices and their business area. This work clarifies the differences between *information flow* and communication via *business trips*, and introduces a new concept, the *Information Input-Output Table* for head and branch offices. The present work has developed from the earlier papers, Takita and Suda (1992) and Takita (1996, 1998), adding the concept of the information input-out table. Takita (1997) also created a comprehensive framework for analyzing information flows.

The sociologist Daniel Bell (1973) famously coined the term ‘post industrial society’ and emphasized the role of scientific and technical knowledge in information-based economies. Economic geographers have already explored the role of information in the urban economy. Since the 1960s there has been a concentration of business firms in London, U.K., and in Stockholm, Sweden, leading to various problems including traffic congestion, air pollution and housing. Wood (1969) recognized the importance of information linkages between firms, as well as commodity linkages. Törnqvist (1970) studied empirically both face-to-face and less direct contacts between head and branch offices, and between the offices and productive facilities. Goddard (1973) measured information flow between firms in the central business district (CBD) of London by dividing the center into grids with 500-meter sides. Pye (1977) studied office location cost, including telecommunication and transportation costs. The role of information

communication in urban growth is now recognized as significant. Machlup (1962) and Porat (1977) measured the effect of information or knowledge on specific industries. These works classified information industries and studied how they contribute to GNP or added value. Thel concept of information economy has been useful for OECD (1980), and in the work of Jonscher (1983) and Ohira and Hiromatsu (1990) and others. Around that time, the (then) Nippon Telephone and Telegram Company (NTT) planned a high-speed optical fiber communication system in Japan. In 1993 the Clinton Administration presented the Information Superhighway Project. The Internet is an acknowledged major conduit of information worldwide. Many countries accelerated their construction of an advanced information society, but experienced the IT bubble in 2001. The field of information economics is equal in importance to the economics of information stock and flow.

The concept of economic analyses of information flows was first introduced at the Kawatabi summer joint-seminar of Tohoku University and the University of Tokyo in 1990 (Takita (1990)). This initial model incorporated the effect of information activity, or a combination of face-to-face communication and telecommunication, on firm behavior. In Takita and Suda (1992) the initial economic model was developed to analyze the generation and flow of information in a firm with a head office and some branch offices. Takita (1994) recognized three patterns of firm behavior in an advanced information society. Mun (1993) presented a business office location model in an urban area, taking into account communication activities. Ota and Fujita (1993), Sasaki (1993) analyzed the effects of information technology on urban spatial structure. To present a comprehensive approach on information flow, Takita (1997, 1999) proposed a new system for information flow analysis that integrates transportation and telecommunication in a Ph.D. dissertation at Tohoku University, and presented at the Seminar of Center for Transportation Studies in MIT. Kobayashi and Fukuyama (1998) analyzed human contacts in knowledge society.

The present paper focuses on an economic formulation of a single head office and some branch offices. This spatial economic model treats the effect of communication activities from head and branch offices on sales of goods and services. It determines information flows in a firm and the amount of labor in each office. This defines an *Information Input-Output Table*. Regional economic characteristics of each region are decided by the number of head officers, who administer all branch offices and plant facilities in the enterprise, and the number of branch officers, which make business contacts with customers. Generally, communication, transportation and telecommunication have been examined separately. However, it is important for researchers in these three fields to clarify how “information flows” by face-to-face communication and telecommunication are involved in enterprise behavior, and also how telecommunication and transportation interact together. This facilitates integration of the studies. The interrelations are explained, and how to derive volumes of communication, transportation and telecommunication as the results of the corresponding profit maximization problem.

2. Assumptions

This section sets out the assumptions involved in explaining the behavior of head and branch offices in view of information flow. An enterprise generally has a hierarchical structure, such as a head office, branch offices and business offices, together with affiliated agents or subsidiary companies.

Here, it is necessary to simplify real behavior to construct a head and branch office model. We

make the following assumptions:

(a) The enterprise has a single head office and some branch offices. The enterprise therefore has two levels of hierarchy in its structure. The head office is the top hierarchical level and the branch offices comprise the second level. There are no differences in business efficiency between the branch offices.
(b) The locations of the head and the branch offices and their business areas reside in a two-dimensional space. The number of employees, computers and floor space at each office or the scale of each office can be changed.
(c) Office activities consist of routine work, internal communication activities and external communication activities. The level of business activity is determined by these three office activities.
(d) In routine work, the quality of each employee is equal and the capability of all computers is the same.
(e) Internal information activities exist between the head office and all the branch offices, but not between branch offices. Individual offices use up time when each office gives information to other offices.
(f) External information activities include high-level business contracts arranged by top executives and the business department in head office, and usual business contracts with regional firms or consumers in branch offices.
(g) Employees use two kinds of communication media: face-to-face communication, which involves business trips, and telecommunication.
(h) The output of the enterprise is proportional to the volume of business activities.
(i) The receiver of information gains access to communication media to use information in work-related activities.
(j) The enterprise maximizes the total profits of the head office and the branch offices.

3. Communication Network between a Single Head Office and Branch Offices

The present model clarifies the role of information flow from business offices in a firm, and determines the size of head and branch offices and their numbers of workers and computers. In this section the two-tier system of a head office and some branch offices is examined. The office activities of head and branch offices are explained. **Figure 1** shows this structure. Every office has employees, and installs office computer systems. The direction of each arrow means that each office contacts other offices inside the firm or customers of the business area to communicate information.

3.1 Head Office

The head office collects various kinds of *internal information* about sales, market and management from branch offices, and also various kinds of *external information* about national projects and sales from central government and the head offices of other enterprises. In Japan, the head offices of most major enterprises are concentrated into the central part of the Tokyo Metropolitan Area, known as the Marunouchi area. The economies of agglomeration in a city stem from the importance of face-to-face communication in the central business districts (CBD). Advanced information communication technology (ICT) has increased the variety of external information communications through the Internet. External communications run from Business to

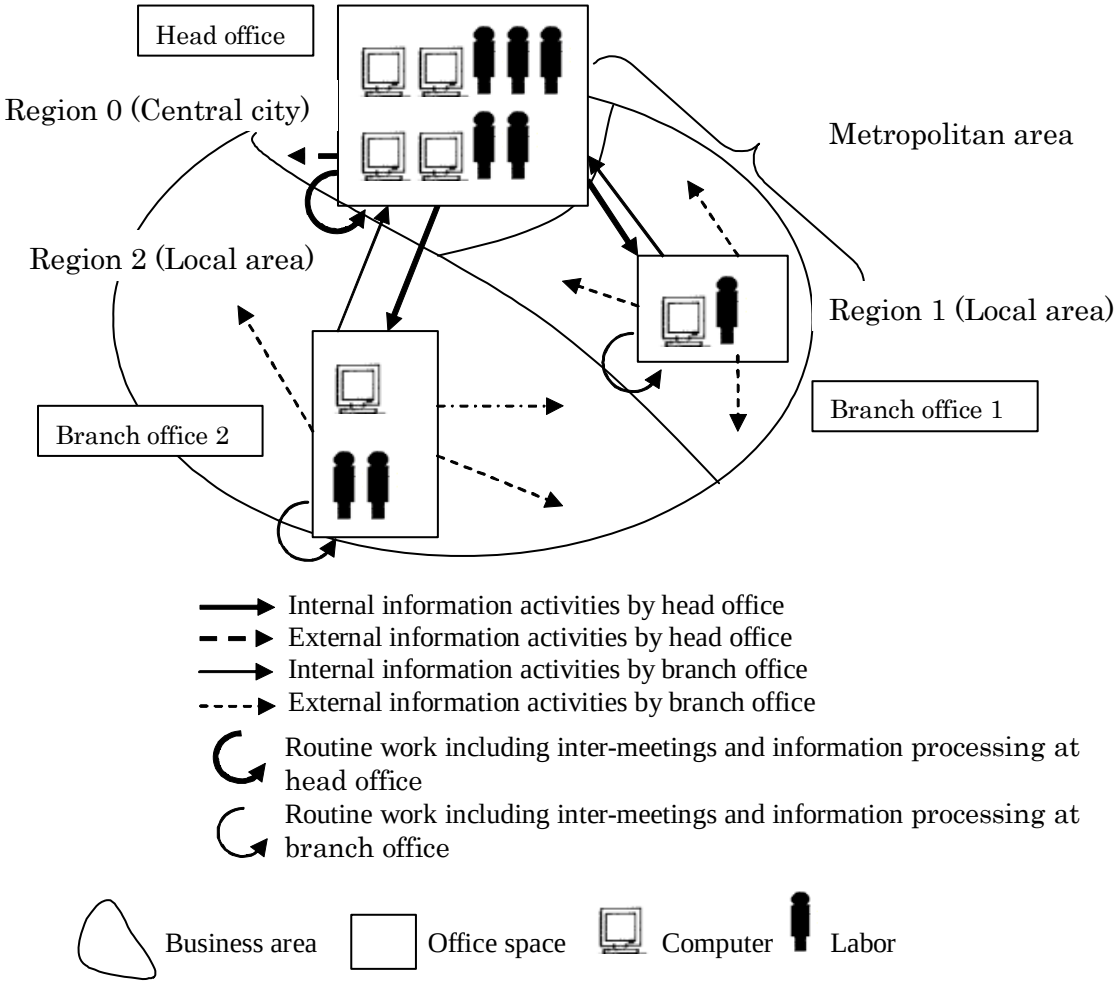

Figure 1: Enterprise with Head Office and Branch Offices

Note: Face-to-face communication and telecommunication are used in information activities

Business (B to B) and Business to Consumer (B to C). Information communication is of two types: *face-to-face communication* and *telecommunication*. Also, the head office conducts *routine works* in each office, such as inside information collection and processing for business planning and market analysis. Computers and associated software are used for information processing in this routine work and in internal and external communications via the Internet.

3.2 Branch Office

Each branch office collects various kinds of *internal information* about management strategy, previous products, corporate market strategy and business management from the head office, and also various kinds of *external information* about public projects, sales of rival companies, trade from other enterprises and local government, using both traditional *face-to-face communications* and *telecommunications*. Also, the branch office conducts *routine work* such as business planning

and accounting. Computers in branch offices are used in information processing for assisting these routine operations, sending or receiving messages and files by E-mail. If consumers send personal and contract information to buy goods through the WWW site, business officers use computers to confirm their orders. In this way, telecommunications acts as a partial substitute for travel and face-to-face communication.

3.3 Information Input-Output Table

The aim is to complete the *Information Input-Output Table* that displays information flow so as to maximize the profit of the firm. This firm has a single head office in the metropolitan area and branch offices in two market areas: the metropolitan and another market area. We can observe information flows between a single head office and some branch offices. All endogenous variables in this spatial economic model of information flow between the head and branch offices are expressed by categories of labor, such as routine work and internal and external communications. These are shown as variables inside the thick frame of **Table 1**. The direction of each arrow signifies that head or branch officers contact other officers inside the firm or meet customers from the business area to communicate information including sales activities.

(1) Allocation of total labor time

The total labor time L_{H_0} of head office workers in region 0 is allocated into routine work R_{H_0} and internal and external information communication activities. Routine works R_{H_0} include information processing and meetings in the head office in region 0. Internal information is collected from branch offices in regions $1,\cdots,m$ by communication media including face-to-face communications, $X^{time}_{H_0\to B_1},\cdots,X^{time}_{H_0\to B_m}$, and telecommunications, $Y^{time}_{H_0\to B_1},\cdots,Y^{time}_{H_0\to B_m}$. External information is collected from market area 0 by face-to-face communication $X^{time}_{H_0\to Area_0}$ and telecommunication $Y^{time}_{H_0\to Area_0}$.

According to the internal and external face-to-face communications, $X^{time}_{H_0\to B_1},\cdots,X^{time}_{H_0\to B_m}$ and $X^{time}_{H_0\to Area_0}$, the head office considers travel time $T^{time}_{H_0\to B_1},\cdots,T^{time}_{H_0\to B_m}$ and $T^{time}_{H_0\to Area_0}$. Also, the head office consumes labor time $\sum_{i=1}^{m}\left(X^{time}_{B_i\to H_0}+Y^{time}_{B_i\to H_0}\right)$ to supply information to branch offices $1,\cdots,m$. The head office has to assign some of its time to branch offices, so that these can get "internal information" from head office by face-to-face communication and telecommunication.

The corresponding description is shown in the head office column in **Table 1**.

$$R_{H_0}+\sum_{i=1}^{m}\left(X^{time}_{H_0\to B_i}+Y^{time}_{H_0\to B_i}+T^{time}_{H_0\to B_i}\right)+\left(X^{time}_{H_0\to Area_0}+Y^{time}_{H_0\to Area_0}+T^{time}_{H_0\to Area_0}\right)+\sum_{i=1}^{m}\left(X^{time}_{B_i\to H_0}+Y^{time}_{B_i\to H_0}\right)=L_{H_0}$$

Here, the total travel time for round trips from head office in region 0 to branch office i or business area 0 is calculated as $T^{time}_{H_0\to B_i}=\frac{2k^{T}_{0i}}{k^{X}_{H\to B}}X^{time}_{H_0\to B_i}$ or $T^{time}_{H_0\to Area_0}=\frac{2k^{T}_{00}}{k^{X}_{H\to Area}}X^{time}_{H_0\to Area_0}$. Here $k^{X}_{H\to B}$ and $k^{X}_{H\to Area}$ are the average time for face-to-face communication from head office to the

Table 1: Information Input-Output Table between Head and Branch Offices

From \ To				Metropolitan area: Central city — Region 0 Head office		Metropolitan area: Suburb — Region 1 Branch office		Local area — Region 2 Branch office		Total output of information	
Types of Information				Internal	External	Internal	External	Internal	External		
Metropolitan area: Central city	Region 0	Head office	F	R_{H_0} *(Information use and processing)*		$X^{time}_{B_1 \to H_0}$	-	$X^{time}_{B_2 \to H_0}$	-	R_{H_0}	$X^{time}_{B_1 \to H_0}$ $X^{time}_{B_2 \to H_0}$
			T			$Y^{time}_{B_1 \to H_0}$		$Y^{time}_{B_2 \to H_0}$			$Y^{time}_{B_1 \to H_0}$ $Y^{time}_{B_2 \to H_0}$
		Others	F	-	$X^{time}_{H_0 \to Area_0}$	-	*2	-	*2		$X^{time}_{H_0 \to Area_0}$
			T		$Y^{time}_{H_0 \to Area_0}$						$Y^{time}_{H_0 \to Area_0}$
Suburb	Region 1	Branch office	F	$X^{time}_{H_0 \to B_1}$	-	R_{B_1} *(Information use and processing)*		*3	-	R_{B_1}	$X^{time}_{H_0 \to B_1}$
			T	$Y^{time}_{H_0 \to B_1}$							$Y^{time}_{H_0 \to B_1}$
		Others	F	-	*1	-	$X^{time}_{B_1 \to Area_1}$	-	*4		$X^{time}_{B_1 \to Area_1}$
			T				$Y^{time}_{B_1 \to Area_1}$				$Y^{time}_{B_1 \to Area_1}$
Local area	Region 2	Branch office	F	$X^{time}_{H_0 \to B_2}$	-	*3	-	R_{B_2} *(Information use and processing)*		R_{B_2}	$X^{time}_{H_0 \to B_2}$
			T	$Y^{time}_{H_0 \to B_2}$							$Y^{time}_{H_0 \to B_2}$
		Others	F	-	*1	-	*4	-	$X^{time}_{B_2 \to Area_2}$		$X^{time}_{B_2 \to Area_2}$
			T						$Y^{time}_{B_2 \to Area_2}$		$Y^{time}_{B_2 \to Area_2}$
Total input of information				R_{H_0}		R_{B_1}		R_{B_2}		*(Total of information flows)*	
				$X^{time}_{H_0 \to B_1}$ $Y^{time}_{H_0 \to B_1}$ $X^{time}_{H_0 \to B_2}$ $Y^{time}_{H_0 \to B_2}$	$X^{time}_{H_0 \to Area_0}$ $Y^{time}_{H_0 \to Area_0}$	$X^{time}_{B_1 \to H_0}$ $Y^{time}_{B_1 \to H_0}$	$X^{time}_{B_1 \to Area_1}$ $Y^{time}_{B_1 \to Area_1}$	$X^{time}_{B_2 \to H_0}$ $Y^{time}_{B_2 \to H_0}$	$X^{time}_{B_2 \to Area_2}$ $Y^{time}_{B_2 \to Area_2}$		
Communication time to give information to the other offices				$X^{time}_{B_1 \to H_0}$ $Y^{time}_{B_1 \to H_0}$ $X^{time}_{B_2 \to H_0}$ $Y^{time}_{B_2 \to H_0}$	0	$X^{time}_{H_0 \to B_1}$ $Y^{time}_{H_0 \to B_1}$	0	$X^{time}_{H_0 \to B_2}$ $Y^{time}_{H_0 \to B_2}$	0		
Travel time				$T^{time}_{H_0 \to B_1}$ $T^{time}_{H_0 \to B_2}$	$T^{time}_{H_0 \to Atra_0}$	$T^{time}_{B_1 \to H_0}$	$T^{time}_{B_i \to Area_i}$	$T^{time}_{B_2 \to H_0}$	$T^{time}_{B_2 \to H_0}$		
Total labor time				L_{H_0}		L_{B_1}		L_{B_2}			

Note: This information input-output table does not consider:

*1. External information flows from branch office business area to head office (e.g. head office visit to construction site)

*2. External information flows from business area of head office to branch office (e.g. branch office visit to head office business area to observe purchasing procedure at supplier)

*3. Internal Information flows between branch offices (e.g. meeting of branch office heads convened by head office) In this

business area; k_{ij}^{T} is traveling time from region i to region j, or the average traveling time within region i ($i \neq j$).

The total labor time L_{B_i} of branch office workers in region i is allocated into routine work R_{B_i}, internal information by face-to-face communication $X_{B_i \to H_0}^{time}$ and telecommunication $Y_{B_i \to H_0}^{time}$ from the branch office in region i to head office in region 0, and also external information activities such as face-to-face communication $X_{B_i \to Area_i}^{time}$ and telecommunication $Y_{B_i \to Area_i}^{time}$ from the branch office in region i to business firms and customers in market area i. According to the face-to-face communications, $X_{B_i \to H_0}^{time}$ and $X_{B_i \to Area_i}^{time}$, each branch office uses travel time $T_{B_i \to H_0}^{time}$ and $X_{B_i \to Area_i}^{time}$. Also, the branch office consumes labor time $X_{H_0 \to B_i}^{time} + Y_{H_0 \to B_i}^{time}$ in supplying information to a head office.

The corresponding description is set out in each column of branch offices, as shown in **Table 1**.

$$R_{B_i} + \left(X_{B_i \to H_0}^{time} + Y_{B_i \to H_0}^{time} + T_{B_i \to H_0}^{time}\right) + \left(X_{B_i \to Area_0}^{time} + Y_{B_i \to Area_i}^{time} + T_{B_i \to Area_i}^{time}\right) + \left(X_{H_0 \to B_i}^{time} + Y_{H_0 \to B_i}^{time}\right) = L_{B_i}$$

The total travel time for round trips from the branch office in region i to head office in region 0 or the business area in region i is calculated by $T_{B_i \to H_0}^{time} = \frac{2k_{i0}^{T}}{k_{B \to H}^{X}} X_{B_i \to H_0}^{time}$ and $T_{B_i \to Area_i}^{time} = \frac{2k_{ii}^{T}}{k_{B \to Area}^{X}} X_{B_i \to Area_i}^{time}$. Here $k_{B \to H}^{X}$ and $k_{B \to Area}^{X}$ are the average time of face-to-face communication and of telecommunication from the branch office to the business area; k_{ij}^{T} is the traveling time from region i to region j.

(2)Expression of information flow

Information flows are described in the information activity matrix using two variables: the amount of information and the number of communications.

(a) The Amount of Information Flow

The information activity matrix is defined to indicate "internal information" and "external information" activities from head and branch offices.

The "internal information activity matrix" from head office and m branch offices by face-to-face communication and telecommunication are as follows:

$$\mathbf{X}_{\mathbf{Internal}}^{\mathbf{time}} = \left(\begin{array}{c|ccc} 0 & X_{B_1 \to H_0}^{time} & \cdots & X_{B_m \to H_0}^{time} \\ \hline X_{H_0 \to B_1}^{time} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ X_{H_0 \to B_m}^{time} & 0 & \cdots & 0 \end{array}\right) \quad \mathbf{Y}_{\mathbf{Internal}}^{\mathbf{time}} = \left(\begin{array}{c|ccc} 0 & Y_{B_1 \to H_0}^{time} & \cdots & Y_{B_m \to H_0}^{time} \\ \hline Y_{H_0 \to B_1}^{time} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ Y_{H_0 \to B_m}^{time} & 0 & \cdots & 0 \end{array}\right).$$

The leading diagonal elements of these matrices are all zero. Intra-office negotiation and communication are included in the routine work. Other zeros in these matrices imply no consideration of "internal information" activities between branch offices.

The "external information activity matrix" from head office 0, branch office 1 to m by

face-to-face communication and telecommunication are:

$$\mathbf{X}_{External}^{time}=\left(\begin{array}{c|ccc} X_{H_0\to Area_0}^{time} & 0 & \cdots & 0 \\ \hline 0 & X_{B_1\to Area_1}^{time} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & X_{B_m\to Area_m}^{time} \end{array}\right) \quad \mathbf{Y}_{External}^{time}=\left(\begin{array}{c|ccc} Y_{H_0\to Area_0}^{time} & 0 & \cdots & 0 \\ \hline 0 & Y_{B_1\to Area_1}^{time} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & Y_{B_m\to Area_m}^{time} \end{array}\right)$$

The total inter-regional information activity between offices is calculated for internal and external information activities, for each type of communication.

The "information activity matrix" from head office 0, branch office 1 to m by face-to-face communication is:

$$\mathbf{X}^{\mathbf{time}}=\mathbf{X}_{\mathbf{Internal}}^{\mathbf{time}}+\mathbf{X}_{\mathbf{External}}^{\mathbf{time}}=\left(\begin{array}{c|ccc} X_{H_0\to Area_0}^{time} & X_{B_1\to H_0}^{time} & \cdots & X_{B_m\to H_0}^{time} \\ \hline X_{H_0\to B_1}^{time} & X_{B_1\to Area_1}^{time} & & 0 \\ \vdots & & \ddots & \\ X_{H_0\to B_m}^{time} & 0 & & X_{B_m\to Area_m}^{time} \end{array}\right)$$

The "information activity matrix" from head office 0, branch office 1 to m by telecommunication is:

$$\mathbf{Y}^{\mathbf{time}}=\mathbf{Y}_{\mathbf{Internal}}^{\mathbf{time}}+\mathbf{Y}_{\mathbf{External}}^{\mathbf{time}}=\left(\begin{array}{c|ccc} Y_{H_0\to Area_0}^{time} & Y_{B_1\to H_0}^{time} & \cdots & Y_{B_m\to H_0}^{time} \\ \hline Y_{H_0\to B_1}^{time} & Y_{B_1\to Area_1}^{time} & & 0 \\ \vdots & & \ddots & \\ Y_{H_0\to B_m}^{time} & 0 & & Y_{B_m\to Area_m}^{time} \end{array}\right)$$

(b) The number of information flows

The total number of internal and external communications by face-to-face communication and telecommunication are presented below.

$$\mathbf{X}_{Internal}^{number}=\left(\begin{array}{c|ccc} 0 & X_{B_1\to H_0}^{number} & \cdots & X_{B_m\to H_0}^{number} \\ \hline X_{H_0\to B_1}^{number} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ X_{H_0\to B_m}^{number} & 0 & \cdots & 0 \end{array}\right)=\left(\begin{array}{c|ccc} 0 & \dfrac{X_{B_1\to H_0}^{time}}{k_{B\to H}^{X}} & \cdots & \dfrac{X_{B_m\to H_0}^{time}}{k_{B\to H}^{X}} \\ \hline \dfrac{X_{H_0\to B_1}^{time}}{k_{H\to B}^{X}} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{X_{H_0\to B_m}^{time}}{k_{H\to B}^{X}} & 0 & \cdots & 0 \end{array}\right)$$

$$\mathbf{Y}_{Internal}^{number}=\left(\begin{array}{c|ccc} 0 & Y_{B_1\to H_0}^{number} & \cdots & Y_{B_m\to H_0}^{number} \\ \hline Y_{H_0\to B_1}^{number} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ Y_{H_0\to B_m}^{number} & 0 & \cdots & 0 \end{array}\right)=\left(\begin{array}{c|ccc} 0 & \dfrac{Y_{B_1\to H_0}^{time}}{k_{B\to H}^{Y}} & \cdots & \dfrac{Y_{B_m\to H_0}^{time}}{k_{B\to H}^{Y}} \\ \hline \dfrac{Y_{H_0\to B_1}^{time}}{k_{H\to B}^{Y}} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{Y_{H_0\to B_m}^{time}}{k_{H\to B}^{Y}} & 0 & \cdots & 0 \end{array}\right).$$

Here, $k_{H\to B}^{X}$ and $k_{H\to B}^{Y}$ are the average time for face-to-face communication and telecommunication from head office to branch office. Also, $k_{B\to H}^{X}$ and $k_{B\to H}^{Y}$ are the average time of face-to-face communication and telecommunication per number of instances of access from branch office to head office.

The "external information activity matrix" from head office 0 and branch offices 1 to m by face-to-face communication and telecommunication are:

$$\mathbf{X}_{External}^{number}=\left(\begin{array}{c|ccc} X_{H_0\to Area_0}^{number} & 0 & \cdots & 0 \\ \hline 0 & X_{B_1\to Area_1}^{number} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & X_{B_m\to Area_m}^{number} \end{array}\right)=\left(\begin{array}{c|ccc} \dfrac{X_{H_0\to Area_0}^{time}}{k_{H\to Area}^{X}} & 0 & \cdots & 0 \\ \hline 0 & \dfrac{X_{B_1\to Area_1}^{number}}{k_{B\to Area}^{X}} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & \dfrac{X_{B_m\to Area_m}^{number}}{k_{B\to Area}^{X}} \end{array}\right)$$

$$\mathbf{Y}_{External}^{number}=\left(\begin{array}{c|ccc} Y_{H_0\to Area_0}^{number} & 0 & \cdots & 0 \\ \hline 0 & Y_{B_1\to Area_1}^{number} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & Y_{B_m\to Area_m}^{number} \end{array}\right)=\left(\begin{array}{c|ccc} \dfrac{Y_{H_0\to Area_0}^{number}}{k_{H\to Area}^{Y}} & 0 & \cdots & 0 \\ \hline 0 & \dfrac{Y_{B_1\to Area_1}^{number}}{k_{B\to Area}^{Y}} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & \dfrac{Y_{B_m\to Area_m}^{number}}{k_{B\to Area}^{Y}} \end{array}\right)$$

Here $k_{H\to Area}^{X}$ and $k_{H\to Area}^{Y}$ are respectively the average time of face-to-face communication and telecommunication from head office to the business area; $k_{B\to Area}^{X}$ and $k_{B\to Area}^{Y}$ are the average time of face-to-face communication and telecommunication from a branch office to the business area.

The "information activity matrix" from head office 0, branch office 1 to m by face-to-face communication is:

$$\mathbf{X}^{number}=\mathbf{X}_{Internal}^{number}+\mathbf{X}_{External}^{number}$$

$$=\left(\begin{array}{c|ccc} X_{H_0\to Area_0}^{number} & X_{B_1\to H_0}^{number} & \cdots & X_{B_m\to H_0}^{number} \\ \hline X_{H_0\to B_1}^{number} & X_{B_1\to Area_1}^{number} & & 0 \\ \vdots & & \ddots & \\ X_{H_0\to B_m}^{number} & 0 & & X_{B_m\to Area_m}^{number} \end{array}\right)=\left(\begin{array}{c|ccc} \dfrac{X_{H_0\to Area_0}^{time}}{k_{H\to Area}^{X}} & \dfrac{X_{B_1\to H_0}^{time}}{k_{B\to H}^{X}} & \cdots & \dfrac{X_{B_m\to H_0}^{time}}{k_{B\to H}^{X}} \\ \hline \dfrac{X_{H_0\to B_1}^{time}}{k_{H\to B}^{X}} & \dfrac{X_{B_1\to Area_1}^{time}}{k_{B\to Area}^{X}} & & 0 \\ \vdots & & \ddots & \\ \dfrac{X_{H_0\to B_m}^{time}}{k_{H\to B}^{X}} & 0 & & \dfrac{X_{B_m\to Area_m}^{time}}{k_{B\to Area}^{X}} \end{array}\right)$$

The "information activity matrix" from head office 0, branch office 1 to m by telecommunication is:

$$\mathbf{Y}^{number}=\mathbf{Y}_{Internal}^{number}+\mathbf{Y}_{Internal}^{number}$$

$$= \left(\begin{array}{c|ccc} Y^{number}_{H_0 \to Area_0} & Y^{number}_{B_1 \to H_0} & \cdots & Y^{number}_{B_m \to H_0} \\ \hline Y^{number}_{H_0 \to B_1} & Y^{number}_{B_1 \to Area_1} & & 0 \\ \vdots & & \ddots & \\ Y^{number}_{H_0 \to B_m} & 0 & & Y^{number}_{B_m \to Area_m} \end{array} \right) = \left(\begin{array}{c|ccc} \dfrac{Y^{time}_{H_0 \to Area_0}}{k^{Y}_{H \to Area}} & \dfrac{Y^{time}_{B_1 \to H_0}}{k^{Y}_{B \to H}} & \cdots & \dfrac{Y^{time}_{B_m \to H_0}}{k^{Y}_{B \to H}} \\ \hline \dfrac{Y^{time}_{H_0 \to B_1}}{k^{Y}_{H \to B}} & \dfrac{Y^{time}_{B_1 \to Area_1}}{k^{Y}_{B \to Area}} & & 0 \\ \vdots & & \ddots & \\ \dfrac{Y^{time}_{H_0 \to B_m}}{k^{Y}_{H \to B}} & 0 & & \dfrac{Y^{time}_{B_m \to Area_m}}{k^{Y}_{B \to Area}} \end{array} \right)$$

(3) Business trips

We next clarify the relations between information flows and business trips. It is assumed that the receiver of information accesses the sender of information. Business trips are assumed to be return journeys, and can be written as:

$$\mathbf{T}^{number} = \left(\begin{array}{c|ccc} T^{number}_{00} & T^{number}_{01} & \cdots & T_{0m}{}^{number} \\ \hline T^{number}_{10} & T^{number}_{11} & & 0 \\ \vdots & & \ddots & \\ T_{0m} & 0 & & T^{number}_{mm} \end{array} \right) = \left(\begin{array}{c|ccc} \dfrac{2T^{time}_{H_0 \to Area_0}}{k^{T}_{00}} & \dfrac{T^{time}_{H_0 \to B_1}}{k^{T}_{01}} + \dfrac{T^{time}_{B_1 \to H_0}}{k^{T}_{10}} & \cdots & \dfrac{T^{time}_{H_0 \to B_m}}{k^{T}_{0m}} + \dfrac{T^{time}_{B_m \to H_0}}{k^{T}_{m0}} \\ \hline \dfrac{T^{time}_{B_1 \to H_0}}{k^{T}_{10}} + \dfrac{T^{time}_{H_0 \to B_1}}{k^{T}_{01}} & \dfrac{2T^{time}_{B_1 \to Area_1}}{k^{T}_{11}} & & 0 \\ \vdots & & \ddots & \\ \dfrac{T^{time}_{B_m \to H_0}}{k^{T}_{m0}} + \dfrac{T^{time}_{H_0 \to B_m}}{k^{T}_{0m}} & 0 & & \dfrac{2T^{time}_{B_m \to Area_m}}{k^{T}_{mm}} \end{array} \right)$$

$$= \left(\begin{array}{c|ccc} 2X^{number}_{H_0 \to Area_0} & X^{number}_{H_0 \to B_1} + X^{number}_{B_1 \to H_0} & \cdots & X^{number}_{H_0 \to B_m} + X^{number}_{B_m \to H_0} \\ \hline X^{number}_{B_1 \to H_0} + X^{number}_{H_0 \to B_1} & 2X^{number}_{B_1 \to Area_1} & & 0 \\ \vdots & & \ddots & \\ X^{number}_{B_m \to H_0} + X^{number}_{H_0 \to B_m} & 0 & & 2X^{number}_{B_m \to Area_m} \end{array} \right)$$

$$= \left(\begin{array}{c|ccc} \dfrac{2X^{time}_{H_0 \to Area_0}}{k^{X}_{H \to Area}} & \dfrac{X^{time}_{H_0 \to B_1}}{k^{X}_{B \to H}} + \dfrac{X^{time}_{B_1 \to H_0}}{k^{X}_{H \to B}} & \cdots & \dfrac{X^{time}_{H_0 \to B_m}}{k^{X}_{B \to H}} + \dfrac{X^{time}_{B_m \to H_0}}{k^{X}_{H \to B}} \\ \hline \dfrac{X^{time}_{B_1 \to H_0}}{k^{X}_{B \to H}} + \dfrac{X^{time}_{H_0 \to B_1}}{k^{X}_{H \to B}} & \dfrac{2X^{number}_{B_1 \to Area_1}}{k^{X}_{B \to Area}} & & 0 \\ \vdots & & \ddots & \\ \dfrac{X^{time}_{B_m \to H_0}}{k^{X}_{B \to H}} + \dfrac{X^{time}_{H_0 \to B_m}}{k^{X}_{H \to B}} & 0 & & \dfrac{2X^{number}_{B_m \to Area_m}}{k^{X}_{B \to Area}} \end{array} \right)$$

Here, $T^{time}_{H_0 \to B_i}$ is the total travel time needed for head office 0 to get internal information from branch office i. Also, $T^{time}_{H_0 \to Area_0}$ is the total traveling time involved for head office 0 to get external information from the business area 0, and k^{T}_{0i} is the travel time from region 0 to region i. Furthermore, $T^{time}_{B_i \to H_0}$ is the total traveling time needed for branch office i to get information from head office 0, and k^{T}_{i0} is the traveling time from region i to region 0. Next, $X^{number}_{B_i \to Area_{ii}}$ and $Y^{number}_{B_i \to Area_i}$ are the total numbers of "information flow events" by face-to-face

communications and telecommunications respectively for branch office i to get information TTfrom business area i. The quantities $k^{X}_{B\to Area}$ and $k^{Y}_{B\to Area}$ are the average time of face-to-face communication and telecommunication per number of instances of access from a branch office to the business area. The relation between traveling time by transportation and the number of face-to-face communications is written as $T^{time}_{B_i\to Area_i} = 2k^{T}_{ii} X^{number}_{B_i\to Area_i}$, where $T^{time}_{B_i\to Area_i}$ is the total traveling time for branch office i to get information from the business area i. Also, k^{T}_{ii} is the traveling time from region i to region i, or in other words the average traveling time within region i.

Finally, **Table 2** below summarizes travel from point of origin to destination for head and branch offices.

Table 2: Travel Origin-Destination Table (OD Table)for Head and Branch Offices

	Head Office (Region 0)	Branch Office 1 (Region 1)	Branch Office 2 (Region 2)	Origin
Head Office 0 (Region 0)	T_{00}	T_{01}	T_{02}	$\sum T_{0j}$
Branch Office 1 (Region 1)	T_{10}	T_{11}	T_{12}	$\sum T_{1j}$
Branch Office 2 (Region 2)	T_{20}	T_{21}	T_{22}	$\sum T_{2j}$
Destination	$\sum T_{i0}$	$\sum T_{i1}$	$\sum T_{i2}$	$\sum\sum T_{ij}$

4. Spatial Economic Model of Head and Branch Offices

This section quantifies enterprise behavior involving head and branch offices. The total profit of the enterprise is maximized, subject to constraints on the number of employees in the enterprise.

4.1 Total Profit Maximization of Enterprise

The enterprise consists of a head office and m branch offices. The total profit π of this enterprise is the sum of the head office's profit and all branch offices' profits:

$$\pi = \pi_{H_0} + \sum_{i=1}^{m} \pi_{B_i} \qquad (1)$$

Here H_0 refers to the head office (H) located in region 0, and B_i to a branch office (B) located in region i; π_{H_0} and π_{B_i} are the profits of the head office, and of the branch office located in region i. The head and branch office models will be explained in **Sections 4.2** and **4.3**.

The enterprise's *N* employees are allocated to the head office and branch offices, so that

$$N = N_{H_0} + \sum_{i=1}^{m} N_{B_i} \qquad (2)$$

where N_{H_0} is the number of employees at head office, and N_{B_i} is the number at the branch office in region i.

The enterprise aims to maximize the total profit (1) of head office and m branch offices,

under the constraint (2). By solving this problem, the allocation of all employees at each business office is determined. The function (3) below expresses how the firm aims to increase labor at profitable business offices and reduce labor at unprofitable business offices. The profit of head office is explained in Section 4.2, and that of each branch office is explained in Section 4.3.

The Lagrange function to be maximized for this problem is expressed as

$$\max \Psi = \pi + \lambda \ (N - N_{H_0} - \sum N_{B_i}) \qquad (3),$$

where ψ is the Lagrange function, and λ (>0) is a Lagrange multiplier. The number of employees in head and branch offices is to be determined.

The number of employees at head office is:

$$N_{H_0} = \frac{1}{u_H^L}\left[R_{H_0} + \sum_{i=1}^{m}\left\{\left(1+\frac{2k_{0i}^T}{k_{H\to B}^X}\right)X_{H_0\to B_i}^{time} + Y_{H_0\to B_i}^{time}\right\} + \left\{\left(1+\frac{2k_{00}^T}{k_{H\to Area}^X}\right)X_{H_0\to Area_0}^{time} + Y_{H_0\to Area_0}^{time}\right\} + \sum_{i=1}^{m}(X_{B_i\to H_0}^{time} + Y_{B_i\to H_0}^{time})\right] \qquad (4)$$

The number at each branch office is:

$$N_{B_i} = \frac{1}{u_B^L}\left[\left\{\left(1+\frac{2k_{i0}^T}{k_{B\to H}^X}\right)X_{B_i\to H_0}^{time} + Y_{B_i\to H_0}^{time}\right\} + \left\{\left(1+\frac{2k_{ii}^T}{k_{B\to Area}^X}\right)X_{B_i\to Area_i}^{time} + Y_{B_i\to Area_i}^{time}\right\} + \left(X_{H_0\to B_i}^{time} + Y_{H_0\to B_i}^{time}\right)\right] \qquad (5)$$

By dividing the total working hours, L_{H_0} and L_{B_i}, by the working hours, u_H^L and u_B^L, per employee of head and branch offices, the numbers of employees are found.

The Lagrange function Ψ will be expressed by the following variables and a Lagrange multiplier λ: In the head office, routine work R_{H_0}, including information processing and inter-meetings; internal information activities by face-to-face communication $X_{H_0\to B_1}, \cdots, X_{H_0\to B_m}$, and telecommunication from head office in region 0 to branch offices in regions $1, \cdots, m$; and external information activities such as face-to-face communication $X_{H_0\to Area_0}$ and telecommunication $Y_{H_0\to Area_0}$ from head office in region 0 to business firms or customers in market area 0. In the branch offices, routine work R_{B_i} of branch office; internal information activities by face-to-face communication $X_{B_i\to H_0}$ and telecommunication $Y_{B_i\to H_0}$ from branch office in region to head office in region 0; and external information activities such as face-to-face communication $X_{B_i\to Area_i}$ and telecommunication $Y_{B_i\to Area_i}$ from branch office in region i to business firms and customers in market area i.

By solving this constrained optimization problem Ψ, a set of the optimal solution parameters is obtained.

4.2 Head Office Model considering Information Flow

In this section, an economic model of head office is suggested by considering its information

flow. The four subsections immediately below explain this head office model in detail: (1) profit of head office, (2) head office activities and production function, (3) function of business activities, (4) measure of information flow to head office, and (5) total cost of head office.

(1) Profit of Head Office

The profit of head office is sales by the sales department of head office minus the costs of running the head office. This profit is expressed as

$$\pi_{H_0} = pf_{H_0} - C_{H_0} \quad (6),$$

where sales of the sales department at head office is the product of goods/services price p and the volume of product of goods and services f_{H_0}, related to business activities of head office. The price p is taken as the sales price p_1 minus the producer price p_2, and it is assumed that f_{H_0} is equal to the sales volume of head office. Here C_{H_0} is the total cost of head office.

(2) Head Office Activities and Production Function

This subsection explains the effect of the business activities of head office on the production of goods and services throughout an enterprise. The business activities of head office are related to the production of goods and services in some production departments. In the head office, top executives or sales department managers perform the most important business negotiations. Contracts are then made and goods and services are sold. At the same time, goods and services are produced according to the inventory of products.

Here, assuming that production activities are related to the level of business activities, the production function of the head office is represented as

$$f_{H_0} = c_H E_{H_0} \quad (7)$$

where c_H is the coefficient of sales efficiency by head office, and E_{H_0} is the amount of business activity at head office.

(3) Function of Business Activities at Head Office

The amount of business activity of head office involves three kinds of office activities: internal information movement from head office to some branch offices; external information movements involving top executives or the sales department; and routine work at head office to process various internal and external information. Accordingly, a measure of business activities at head office is written as

$$E_{H_0} = E_H(Information_{H_0 \to B_i}, \cdots, Information_{H_0 \to B_i}, Information_{H_0 \to Area_0}, R_{H_o}) \quad (8),$$

where $Information_{H_0 \to B_i}$ and $Information_{H_0 \to Area_0}$ are the measured amounts of internal information activities to branch office i and external information activities to business area 0. R_{H_0} is the measured amount of routine work at head office 0. In the next subsection, we tackle the most difficult question, of what is the amount of information.

(4) Measure of Information Flow to Head Office

How should *information* be evaluated? Let us introduce the *Level of information flow* to head office. The *Level of information flow* can be defined as the information receiver's utility,

or the receiver's degree of satisfaction, as decided by quantity and quality of information. The amount of information flow is a combination of face-to-face communication and telecommunication.

The effect of face-to-face communication on the level of information flow has been always important. However, as telecommunication advances, the total level of information flow has increased. In particular, the Internet provides new-style communications such as E-mail, which enables the movement of documents, TV conferencing, and WWW-based communication. This recent advance has caused information flows to jump in quantity.

Measures of internal and external information flow at head office are defined as follows.

$$Information_{H_0 \to B_i} = Information_{H \to B}(X^{time}_{H_0 \to B_i}, Y^{time}_{H_0 \to B_i}; \alpha_{H \to B})$$

$$= A_{H \to B}\left[\alpha_{H \to B} X^{time}_{H_0 \to B_i}{}^{-\rho_{H \to B}} + (1-\alpha_{H \to B}) Y^{time}_{H_0 \to B_i}{}^{-\rho_{H \to B}}\right]^{-\frac{1}{\rho_{H \to B}}} \quad (9)$$

$$Information_{H_0 \to Area_0} = Information_{H \to Area}(X^{time}_{H_0 \to Area_0}, Y^{time}_{H_0 \to Area_0}; \alpha_{H \to Area})$$

$$= A_{H \to Area}\left[\alpha_{H \to Area} X^{time}_{H_0 \to Area_0}{}^{-\rho_{H \to Area}} + (1-\alpha_{H \to Area}) Y^{time}_{H_0 \to Area_0}{}^{-\rho_{H \to Area}}\right]^{-\frac{1}{\rho_{H \to Area}}} \quad (10),$$

Here $X^{time}_{H_0 \to B_i}$ and $Y^{time}_{H_0 \to B_i}$ are the total time of internal information flow by face-to-face communications and telecommunications respectively, from head office in region 0 to branch offices in region i. Also $X^{time}_{H_0 \to Area_0}$ and $Y^{time}_{H_0 \to Area_0}$ correspond to external information flows from head office 0 to its own business area 0. The parameters $\alpha_{H \to B}$ and $\alpha_{H \to Area}$ indicates technological progress in internal and external business telecommunications. Telecommunication media have progressed from telegraph, telephone and facsimile to E-mail, IP phone and visual phone via the Internet.

(5) Total Cost of Head Office

The total cost of head office consists of communication costs, information processing costs, labor costs, office rental cost of head office, and sundries. Assuming the sundries are much smaller, this total cost is as follows.

$$C_{H_0} = C^{Communication}_{H_0} + C^{Information\ Processing}_{H_0} + C^{Labor}_{H_0} + C^{Office\ Rental}_{H_0} \quad (11)$$

where $C^{Communication}_{H_0}$ is the communication cost of head office, $C^{Information\ Processing}_{H_0}$ is the information processing cost of head office, $C^{Labor}_{H_0}$ is the labor cost of head office and $C^{Office\ Rental}_{H_0}$ is head office rental cost.

The staffs of head office make face-to-face communication, including transportation, to obtain external information, and incur telecommunication costs to get internal information from branch offices and external information from the business area. Such costs can be written as

$$C^{Communication}_{H_0} = \left\{\sum_{i=1}^{m} 2\omega^T_{0i} X^{number}_{H_0 \to B_i} + \sum_{i=1}^{m} \omega^Y_{0i} Y^{time}_{H_0 \to B_i}\right\} + \left\{(2\omega^T_{00} + \omega^X_{H \to Area}) X^{number}_{H_0 \to Area_0} + \omega^Y_{00} Y^{time}_{H_0 \to Area_0}\right\} \quad (12).$$

The first part of this equation expresses the communication cost for internal information, and consists of transportation cost and telecommunication cost. The transportation cost for internal information communication is the product of $2\omega^T_{0i}$, the round trip cost between region 0 and

region i, and $X_{H_0 \to B_i}^{number}$, the total numbers of face-to-face information flow events for head office in obtaining information from branch office i. The telecommunication cost for internal information communication is the product of ω_{0i}^{Y}, the telecommunication cost per hour from region 0 to region i, and $Y_{H_0 \to B_i}^{time}$, the total time of face-to-face information flows for head office in getting information from branch office i. The next part of the equation expresses the communication cost for external information, and, as for internal information, consists of transportation costs and telecommunication costs. The transportation cost for internal information communication is the product of $(2\omega_{00}^{T} + \omega_{H \to Area}^{X})$, the round trip cost within region 0 plus the entertainment cost per number of face-to-face communication events for head office to get information from the business area, and $X_{H_0 \to Area_{0i}}^{number}$, the total number of information flow events by face-to-face communication by which head office gets information from its business area 0. The telecommunication cost for internal information communication is the product of ω_{00}^{Y}, the telecommunication cost per hour from region 0 to region 0, or within region 0, and $Y_{H_0 \to Area_0}^{time}$, the total time of face-to-face information flow events for head office in getting information from its business area 0. From **Equations (9)** and **(12)**, the total communication costs of head office is

$$C_{H_0}^{Communication} = \left\{ \frac{2}{k_{H \to B}^{X}} \sum_{i=1}^{m} \omega_{0i}^{T} X_{H_0 \to B_i}^{time} + \sum_{i=1}^{m} \omega_{0i}^{Y} Y_{H_0 \to B_i}^{time} \right\} + \left\{ \frac{2\omega_{00}^{T} + \omega_{H \to Area}^{X}}{k_{H \to Area}^{X}} X_{H_0 \to Area_0}^{time} + \omega_{00}^{Y} Y_{H_0 \to Area_0}^{time} \right\} \tag{13}$$

The second cost component of head office, its information-processing cost, is

$$C_{H_0}^{Information\ Processing} = \omega^{M} M_{H_0} = \frac{\omega^{M} r_H}{u_H^{L}} R_{H_0} \tag{14}$$

where ω^{M} represents depreciation and maintenance costs per number of computer systems, and M_{H_0} is the number of computer systems at head office. The number of computer systems in head office is obtained by dividing the total time required for information processing in head office by the working hours per person in head office, or the annual business hours at head office. Here γ_H is the ratio of time of information processing to that of routine work in head office, and u_H^{L} is the working hours per employee in head office.

The third cost of head office is its labor cost,

$$\begin{aligned} C_{H_0}^{Labor} &= \omega_{H_0}^{N} N_{H_0} = \omega_{H_0}^{N} \frac{L_{H_0}}{u_H^{L}} \\ &= \frac{\omega_{H_0}^{N}}{u_H^{L}} \left[R_{H_0} + \sum_{i=1}^{m} \left\{ \left(1 + \frac{2k_{0i}^{T}}{k_{H \to B}^{X}} \right) X_{H_0 \to B_i}^{time} + Y_{H_0 \to B_i}^{time} \right\} + \left\{ \left(1 + \frac{2k_{00}^{T}}{k_{H \to Area}^{X}} \right) X_{H_0 \to Area_0}^{time} + Y_{H_0 \to Area_0}^{time} \right\} \right. \\ &\qquad \left. + \sum_{i=1}^{m} (X_{B_i \to H_0}^{time} + Y_{B_i \to H_0}^{time}) \right] \end{aligned} \tag{15}$$

where $\omega_{H_0}^{N}$ is the average income per employee of head office.

The fourth cost of head office is its office rental cost:

$$C_{H_0}^{Office\,Rental} = \omega_0^S S_{H_0} = \omega_0^S a_H N_{H_0}$$
$$= \frac{\omega_0^S a_H}{u_H^L}\left[R_{H_0} + \sum_{i=1}^{m}\left\{\left(1+\frac{2k_{0i}^T}{k_{H\to B}^X}\right)X_{H_0\to B_i}^{time} + Y_{H_0\to B_i}^{time}\right\} + \left\{\left(1+\frac{2k_{00}^T}{k_{H\to Area}^X}\right)X_{H_0\to Area_0}^{time} + Y_{H_0\to Area_0}^{time}\right\}\right.$$
$$\left. + \sum_{i=1}^{m}(X_{B_i\to H_0}^{time} + Y_{B_i\to H_0}^{time})\right] \qquad (16)$$

where ω_0^S is the office rental cost per square meter of floor space in region 0, and S_{H_0} is the floor space of head office. The scale of floor area at head office are represented by $S_{H_0} = a_H N_{H_0}$, where a_H is the average floor space (square meter) per employee at head office.

4.3 Branch Office Model considering Information Flow

In this section, a branch office model is proposed by considering linkage with the head office. Several subsections explain the branch office model in detail: (1) profit of the branch office; (2) branch office activities and production function; (3) function of business activities at branch office; (4) measure of information flow to branch office; and (5) total cost of branch office.

(1) Profit of Branch Office

The profit of a branch office is its sales minus its costs. This profit is expressed as

$$\pi_{B_i} = pf_{B_i} - C_{B_i} \qquad (17)$$

where the sales of a branch office is the product of goods/services price p and the volume of production of goods and services f_{B_i}, which is related to the business activities of branch office i. The price p is sales price p_1 minus producer price p_2, and it is assumed that f_{B_i} is equal to the sales volume of branch office i; C_{B_i} is the total cost of branch office i.

(2) Branch Office Activities and Production Function

This subsection explains the relation between the business activities of a branch office and the production activities of goods/services. The production function of branch office will be explained. Each enterprise covers its business territory by locating regional places of business, or branch offices and sales offices, in several cities. The business section or department is at the center of the "external information" activities of business offices and sales offices. In addition, the executive classes, such as branch office managers, are sometimes involved in final decisions on important contracts, etc. This external information from the business area, internal information from head office and routine work all determine the level of business activities.

This level of business activities at each branch office is related to the sales volume of the branch office, and furthermore to the production volume of goods and services in production departments such as factories. In the present model, we assume that the level of business activities at a branch office i is proportional to the production volume in production departments according to the following production function of a branch office i.

$$f_{B_i} = c_B E_{B_i} \qquad (18)$$

Here c_B is the production efficiency coefficient of branch office i, and E_{B_i} is the level of

business activity at branch office i.

(3) Function of Business Activities at Branch Office

The level of business activities at a branch office is defined in the same way as the level of business activities at head office. The level of business activities at a branch office involves various office activities: internal information activities to head office; external information activities to the business area of the branch office; and routine work at the branch office. Here, the level of business activities at branch office i is written as

$$E_{B_i} = E_B(Information_{B_i \to H_0}, Information_{B_i \to Area_i}, R_{B_i}) \tag{19}$$

where $Information_{B_i \to H_0}$ and $Information_{B_i \to Area_i}$ are two kinds of information that branch office i gets from business area i, and R_{B_i} is routine work of branch office i.

(4) Measure of Information Flow to Branch Office

We discussed the level of information flow to head office in **Section 4.2**. In the same way, the level of information flow to a branch office is introduced. Here, levels of internal and external information flows involving a branch office are defined as

$$Information_{B_i \to H_0} = Information_{B \to H}(X^{time}_{B_i \to H_0}, Y^{time}_{B_i \to H_0}; \alpha_{B \to H})$$
$$= A_{B \to H}\left[\alpha_{B \to H} X^{time}_{B_i \to H_0}{}^{-\rho_{B \to H}} + (1-\alpha_{B \to H}) Y^{time}_{B_i \to H_0}{}^{-\rho_{B \to H}}\right]^{-\frac{1}{\rho_{B \to H}}} \tag{20}$$

$$Information_{B_0 \to Area_0} = Information_{B \to Area}(X^{time}_{B_i \to Area_i}, Y^{time}_{H_i \to Area_i}; \alpha_{B \to Area})$$
$$= A_{B \to Area}\left[\alpha_{B \to Area} X^{time}_{B_i \to Area_i}{}^{-\rho_{B \to Area}} + (1-\alpha_{B \to Area}) Y^{time}_{B_i \to Area_i}{}^{-\rho_{B \to Area}}\right]^{-\frac{1}{\rho_{B \to Area}}} \tag{21}$$

where $X^{time}_{B_i \to H_0}$ and $Y^{time}_{B_i \to H_0}$ are the total time of information flow by face-to-face communication and telecommunication for branch office i when obtaining information from head office. Also $X^{time}_{B_i \to Area_i}$ and $Y^{time}_{B_i \to Area_i}$ are the total time of information flow by face-to-face communication and telecommunication respectively for branch office i to get information from its business area i. Finally, $\alpha_{B \to H}$ and $\alpha_{B \to Area}$ are parameters of technical progress of telecommunication media.

(5) Total Cost of Branch Office

The total cost of a branch office involves the communication cost, information processing cost, labor cost, office rental cost of branch office and other costs. Assuming the other costs can be neglected, this total cost is as follows.

$$C_{B_i} = C^{Communication}_{B_i} + C^{Information\ Processing}_{B_i} + C^{Labor}_{B_i} + C^{Office\ Rental}_{B_i} \tag{22}$$

where $C^{Communication}_{B_i}$ is the cost of communications at branch office i, $C^{information\ Processing}_{B_i}$ is the information processing cost at branch office i, $C^{Labor}_{B_i}$ is the labor cost of branch office i and $C^{Office\ Rental}_{B_i}$ is the office rental cost.

The total communication costs of the branch office consist of face-to-face communication

costs (including transportation costs and, in the case of external information, entertainment costs), telecommunication costs to get internal information from branch offices and to get external information from the business area, as follows.

$$C_{B_i}^{Communication} = \left\{2\omega_{i0}^{T} X_{B_i \to H_0}^{number} + \omega_{i0}^{Y} Y_{B_i \to H_0}^{time}\right\} + \left\{(2\omega_{ii}^{T} + \omega_{B \to Area}^{T}) X_{B_i \to Area_i}^{number} + \omega_{ii}^{Y} Y_{B_i \to Area_i}^{time}\right\}$$

$$= \left\{\frac{2\omega_{i0}^{T}}{k_{B \to H}^{X}} X_{B_i \to H_0}^{time} + \omega_{i0}^{Y} Y_{B_i \to H_0}^{time}\right\} + \left\{\frac{2\omega_{ii}^{T} + \omega_{B \to Area}^{X}}{k_{B \to Area}^{X}} X_{B_i \to Area_i}^{time} + \omega_{ii}^{Y} Y_{B_i \to Area_i}^{time}\right\} \quad (23)$$

The first term expresses the communication cost for internal information, and consists of transportation costs and telecommunication costs. The next term expresses the communication cost for external information and, in the same way as for internal information, consists of transportation costs and telecommunication costs. Here ω_{ij}^{T} and ω_{ij}^{Y} are the traveling cost per trip and the telecommunication cost per hour from region i to region j. Also $\omega_{B \to Area}^{T}$ is the entertainment cost per number of face-to-face communication events for the branch office to get information from the business area.

The second cost component of the branch office, its information-processing costs, is

$$C_{B_i}^{Information\,Processing} = \omega^{M} M_{B_i} = \frac{\omega^{M} r_B}{u_B^{L}} R_{B_i} \quad (24)$$

where ω^{M} is depreciation and maintenance costs per number of computer systems, and M_{B_i} is the number of computer systems at branch office i. The number of computer systems in the branch office is obtained by dividing the total time required for information processing in the branch office by the working hours per person working in branch office, or the annual business hours at the branch office. Here γ_B is the ratio of time on information processing to that of routine work in the branch office, u_B^{L} is the working hours per employee in the branch office, and γ_B is the ratio of the time on information processing to that of routine work in the branch office.

The third cost component of the branch office, its labor cost, is

$$C_{B_i}^{Labor} = \omega_{B_i}^{N} N_{B_i} = \omega_{B_i}^{N} \frac{L_{B_i}}{u_B^{L}}$$

$$= \frac{\omega_{B_i}^{N}}{u_B^{L}}\left[\left\{\left(1 + \frac{2k_{i0}^{T}}{k_{B \to H}^{X}}\right) X_{B_i \to H_0}^{time} + Y_{B_i \to H_0}^{time}\right\} + \left\{\left(1 + \frac{2k_{ii}^{T}}{k_{B \to Area}^{X}}\right) X_{B_i \to Area_i}^{time} + Y_{B_i \to Area_i}^{time}\right\}\right.$$

$$\left. + \left(X_{H_0 \to B_i}^{time} + Y_{H_0 \to B_i}^{time}\right)\right] \quad (25)$$

where $\omega_{B_i}^{N}$ is the average income per employee at branch office i.

The fourth cost of the branch office, the office rental cost, is

$$C_{B_i}^{Office\,Rental} = \omega_i^{S} S_{B_i} = \omega_i^{S} a_B N_{B_i}$$

$$= \frac{\omega_i^{S} a_B}{u_B^{L}}\left[\left\{\left(1 + \frac{2k_{i0}^{T}}{k_{B \to H}^{X}}\right) X_{B_i \to H_0}^{time} + Y_{B_i \to H_0}^{time}\right\} + \left\{\left(1 + \frac{2k_{ii}^{T}}{k_{B \to Area}^{X}}\right) X_{B_i \to Area_i}^{time} + Y_{B_i \to Area_i}^{time}\right\}\right. \quad (26)$$

$$\left. + \left(X_{H_0 \to B_i}^{time} + Y_{H_0 \to B_i}^{time}\right)\right]$$

where ω_i^S is the office rental cost per square meter of floor space in region i, S_{B_i} is its floor space and a_B is the average floor space (square meter) per employee at the branch office.

4.4 Inter-regional Information IO Table and Travel OD Table

As stated above, the ultimate goal of the head and branch office model is to calculate the Information IO Table for inter-regional information flow between head and branch offices. This section calculates this table, using the outputs of various office activities, according to steps one through two below.

We have discussed the constrained profit maximization problem for the head and branch office model considering information flow. In this model, the total working hours of all employees in the enterprise can be allocated into routine work, and internal and external communication by face-to-face communication and telecommunication, both at head office and in branch offices.

(Step 1) Total Time of Various Office Activities

It is first necessary to solve the constrained profit maximization problem in the head and branch office model of information flow, to get the optimal total time of various activities of the head and branch offices.

Specifically, we need to obtain the first order conditions from Equation (3) with respect to the following total time of various activities of head and branch offices, and solve the resulting system of simultaneous equations: routine work $R_{H_0}, R_{B_1}, \cdots, R_{B_m}$ at head and branch offices; internal information activities at head office by face-to-face communications $X_{H_0 \to B_1}, \cdots, X_{H_0 \to B_m}$ and telecommunications $Y_{H_0 \to B_1}, \cdots, Y_{H_0 \to B_m}$; internal information activities at branch office by face-to-face communications $X_{B_1 \to H_0}, \cdots, X_{B_m \to H_0}$ and telecommunications $Y_{B_1 \to H_0}, \cdots, Y_{B_m \to H_0}$; external information activities at head and branch offices by face-to-face communications $X_{H_0 \to Area_0}, X_{B_1 \to Area_1} \cdots, X_{B_m \to Area_m}$ and telecommunications $Y_{H_0 \to Area_0}, Y_{B_1 \to Area_1} \cdots, Y_{B_m \to Area_m}$.

Second, because of the system of nonlinear simultaneous equations, these office activities need to be obtained using the Newton method. Strictly, second-order conditions are needed in order to verify that the stationary point is a maximum, although this is intuitively obvious from the formulation.

(Step 2) Inter-regional Information IO Table and Travel OD Table

Finally, the *Interregional Information Input-Output Table and Travel OD Table* are presented to express information flow between business offices, substituting all kinds of labor into the cells of **Table 1**.

5. Numerical Example

From **Sections 2** to **4**, we have constructed a head and branch office model to consider information flow. In this section, this model is used to determine the *Information IO Table* and *Travel OD Table*, and the number of employees at the head and branch offices, for a given set of

unit prices.

5.1 Various Unit Prices and Traveling Time

(1) Telecommunication and Transportation

Various unit prices in the society must first be given.

Unit prices (yen per trip) of transportation between regions are as follows:

Internal: $\omega_{01}^T = \omega_{10}^T = 4{,}000$, $\omega_{02}^T = \omega_{20}^T = 10{,}000$,

External: $\omega_{00}^T = 200$, $\omega_{11}^T = 200$, $\omega_{22}^T = 200$.

Similarly, unit prices (yen per minute) of telecommunication between regions are as follows:

Internal: $\omega_{01}^Y = \omega_{10}^Y = 10$, $\omega_{02}^Y = \omega_{20}^Y = 30$,

External: $\omega_{00}^Y = 3.333$, $\omega_{11}^Y = 3.333$, $\omega_{22}^Y = 3.333$.

Traveling times (minutes) between regions are:

$k_{00}^T = 20$, $k_{11}^T = 20$, $k_{22}^T = 20$, $k_{01}^T = k_{10}^T = 60$, $k_{02}^T = k_{20}^T = 150$.

(2) Computer and Labor

Otherwise, the annual rental price (yen) of computer systems is $\omega^M = 200000$.The average income (yen) of employees of head office 0, branch office 1 and branch office 2 are given as

$\omega_H^N = 5{,}500{,}000$, $\omega_{B_1}^N = 5{,}000{,}000$, $\omega_{B_2}^N = 5{,}000{,}000$.

(3) Office Rent

The office rental cost (yen) in every region per square meter is taken as

$\omega_0^S = 6{,}000$, $\omega_1^S = 4{,}000$, $\omega_2^S = 3{,}000$.

5.2 Example of an Enterprise

Details of the enterprise are as follows. The head office is located in a metropolitan area, and two branch offices are located in other business areas. The number of branch offices is $m = 2$. The total number (persons) of employees in this enterprise is $N = 500$. These employees are allocated to a head office and two branch offices. The price of goods and services that this enterprise produces are decided as $p = 1{,}500$ in a perfectly competitive market.

(1) Head Office

Some functions and characteristics of head office are assumed. First, we assume three kinds of functions: a production function of head office, a function of business activities of head office, and functions of information flows to head office. We also assume some labor characteristics and office space of head office.

(a) Production Function of Head Office--- Assuming that the production efficiency coefficient of head office located in region 0 is $c_{H_0} = 1.5$, then the production function of head office 0 is written as $f_H = 1.5 \cdot E_{H_0}$.

(b) Function of Business Activities--- In function (6), the level of business activities was expressed by a combination of various information activities and routine work. The level of business activities of head office is written as

$E_{H_0} = Information_{H_0 \to B_1}^{0.1} Information_{H_0 \to B_2}^{0.1} Information_{H_0 \to Area_0}^{0.45} R_{H_0}^{0.32}$.

(c) Functions of Information Flow--- Assuming that the services of telecommunication networks are the same in each region, the level of information flow of head office is written as $Information_{H_0 \to B_1} = X_{H_0 \to B_1}^{time\ 0.8} Y_{H_0 \to B_2}^{time\ 0.2}$, $Information_{H_0 \to B_2} = X_{H_0 \to B_2}^{time\ 0.8} Y_{H_0 \to B_2}^{time\ 0.2}$ and $Information_{H_0 \to Area_0} = X_{H_0 \to Area_0}^{time\ 0.8} Y_{H_0 \to Area_0}^{time\ 0.2}$.

(d) Labor Characteristics and Office Space--- The average time of face-to-face communication and telecommunication per number of access events from head office to branch office or to the business area are given as $k_{H \to B}^{X} = 180$, $k_{H \to B}^{Y} = 8$, $k_{H \to Area}^{X} = 120$ and $k_{H \to Area}^{Y} = 10$. Otherwise, the meeting and entertainment cost (in yen) per number of face-to-face communication events for branch office in getting information from the business area is $\omega_{H \to Area}^{X} = 10{,}000$. The floor space per employee at the head office is $a_H = 18$ square meters. The ratio of time on information processing to that of routine work in head office is $\gamma_H = 0.7$. The working hours per employee in head office is $u_H^L = 120{,}000$.

(2) Branch Office

As in head office, we assume some characteristics of branch offices. We suppose there are three kinds of functions: a production function of branch office, the function of business activities of a branch office, and the functions of information flow into the branch office. We next assume some labor characteristics and office space of the branch office.

(a) Production Function of Branch Office--- Assuming that the production efficiency coefficient of the branch office located in region i is $c_{B_i} = 1$, the production function of branch office i is written as $f_{B_1} = 1 \cdot E_{B_1}$ and $f_{B_2} = 1 \cdot E_{B_2}$.

(b) Function of Business Activities of Branch Office---- The level of business activities is written as $E_{B_i} = Information_{B_i \to H_0}^{0.1} Information_{B_i \to Area_i}^{0.4} R_{B_i}^{0.3}$

(c) Functions of Information Flow--- Assuming that the services of telecommunication networks are the same in each region, the levels of internal and external information flow of branch office i are written as $Information_{B_i \to H_0} = X_{B_i \to H_0}^{time\ 0.8} Y_{B_i \to H_0}^{time\ 0.2}$ and $Information_{B_i \to Area_i} = X_{B_i \to Area_i}^{time\ 0.8} Y_{B_i \to Area_i}^{time\ 0.2}$

(d) Labor Characteristics and Office Space--- The communication time per number of face-to-face communication and telecommunication events are given, in minutes, by $k_{B \to H}^{X} = 180$, $k_{B \to H}^{Y} = 8$, $k_{B \to Area}^{X} = 90$ and $k_{B \to Area}^{Y} = 10$. The meeting and entertainment cost (in yen) per number of face-to-face communication events by branch offices in local cities is $\omega_{B \to Area}^{X} = 5{,}000$. The floor space per person working at the branch office is $a_B = 18$ square meters. The ratio of information processing time to routine work time is $\gamma_B = 0.7$. The working hours per person is $u_B^L = 120{,}000$.

5.3. Result of Simulation

Results of the head and branch office model with information flow are presented below.

First, the management scales of head office and branch offices are calculated

The number of employees in head office in region 0, and branch offices in regions 1 and 2, is $N_{H_0} = 375$, $N_{B_1} = 69$ and $N_{B_2} = 56$. The floor space per employee at head office in region 0, and branch offices in regions 1 and 2, is $S_{H_0} = 6{,}752$, $S_{B_1} = 1{,}236$ and $S_{B_2} = 1{,}012$. The number of computer systems at head office in region 0, and branch offices in regions 1 and 2, is $M_{H_0} = 127$, $M_{B_1} = 15$ and $M_{B_2} = 13$.

The information activity matrix is calculated as

$$\mathbf{X}^{\mathbf{time}} = \begin{pmatrix} 8{,}355{,}523 & 223{,}794 & 127{,}493 \\ 1{,}842{,}266 & 1{,}436{,}437 & 0 \\ 1{,}228{,}571 & 0 & 1{,}221{,}232 \end{pmatrix}, \quad \mathbf{Y}^{\mathbf{time}} = \begin{pmatrix} 3{,}984{,}589 & 80{,}640 & 64{,}007 \\ 666{,}737 & 661{,}307 & 0 \\ 623{,}460 & 0 & 562{,},{,}629 \end{pmatrix},$$

.

$$\mathbf{X}^{number} = \begin{pmatrix} 69{,}629 & 1{,}243 & 708 \\ 10{,}235 & 15{,}960 & 0 \\ 1{,}228{,}571 & 0 & 13{,}569 \end{pmatrix}, \qquad \mathbf{Y}^{\mathbf{time}} = \begin{pmatrix} 398{,}459 & 10{,}080 & 8{,}001 \\ 83{,}342 & 66{,}131 & 0 \\ 77{,}933 & 0 & 56{,}262 \end{pmatrix}.$$

Furthermore, based on **Table 1**, the Inter-regional Information IO table for head office and branch offices" is shown in **Table 3**.

In addition, the transportation traffic matrix is calculated as:

$$\mathbf{T}^{number} = \begin{pmatrix} 139{,}259 & 11{,}478 & 7{,}534 \\ 11{,}478 & 31{,}921 & 0 \\ 7{,}534 & 0 & 27{,}138 \end{pmatrix}$$

Considering the characteristic of transportation traffic, this matrix is transformed into the "Business-trip OD Table for Head and Branch Office" as shown in **Table 4.**

Table 3: Information Input-Output Table between Head and Branch offices (minutes)

From \ To				Metropolitan area: Central city, Region 0, Head office		Metropolitan area: Suburb, Region 1, Branch office		Local area, Region 2, Branch office		Total output of information	
Types of Information				Internal	External	Internal	External	Internal	External		
Metropolitan area: Central city	Region 0	Head office	F	21,757,989 *(Information use and processing)*		223,794	-	127,493	-	21,757,989	351,288
			T			80,640		64,007			144,647
		Others	F	-	8,355,523	-	-	-	-		8,355,523
			T		3,984,589						3,984,589
Metropolitan area: Suburb	Region 1	Branch office	F	1,842,266	-	2,541,238 *(Information use and processing)*		-	-	2,541,238	1,842,266
			T	666,737							666,737
		Others	F			-	1,436,437	-	-		1,436,437
			T				661,307				661,307
Local area	Region 2	Branch office	F	1,228,571	-	-	-	2,161,275 *(Information use and processing)*		2,161,275	1,228,571
			T	623,460							623,460
		Others	F	-	-	-	-	-	1,221,232		1,221,232
			T						562,629		562,629
Total input of information				21,757,989		2,541,238		2,161,275		*(Total of information flows)*	4,7539,189
				4,361,035	12,340,112	304,434	2,097,744	191,500	1,783,861		
Communication time to give information to the other offices				495,934	0	2,509,003	0	1,852,031	0		
Travel time				3,275,796	2,785,174	149,196	638,417	212,489	542,770		
Total labor time				45,016,041		8,240,033		6,743,927			

Table 4. Business-Trip OD Table for Head and Branch Office

	Head Office (Region 0)	Branch Office 1 (Region 1)	Branch Office 2 (Region 2)	Origin
Head Office 0 (Region 0)	139,259	11,478	7,534	158,271
Branch Office 1 (Region 1)	11,478	31,921	0	43,399
Branch Office 2 (Region 2)	7,534	0	27,138	34,672
Destination	158,271	43,399	34,672	236,342

.

6. Conclusion

This paper has constructed a model of an enterprise containing a head office and branch offices with information flow, and has conducted a simulation for one case.

Conclusions are summarized below:

(1) The behavior of an enterprise with two levels of hierarchy, a head office and multiple branch offices, has been modeled.

(2) A model was constructed which explains endogenously internal and external information flows, the size of head and branch offices, the number of employees working at the head and branch offices and the number of computer systems.

(3) The relation between transportation and communication is clearly demonstrated by the inter-regional information IO table for head and branch offices, and the business trip OD Table for head and branch offices.

(4) Finally, a simulation using a fictional company successfully determined the number of computer systems and number of employees working at the head and branch offices, and also the inter-regional information IO table for head and branch offices and business trip OD table for head and branch offices.

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