RESULTS OF OPERATIONAL SIMULATION ABOUT AN ORBITAL CONTROL MODEL FOR PLURAL SATELLITES

H. Watanabe, M. Mori, F. Sawada, S. Maruyama, H. Nakamura,

Kimitsu Satellite Control Center,
Telecommunications Advancement Organization of Japan (TAO)

ABSTRACT

An Eccentricity and Inclination Vector Separation Method is generally proposed for a colocation of plural satellites more than 3 in the same longitudinal slot.
TAO has examined the correlation among the minimum distance, the differences of Eccentricity and Inclination vectors of colocated 2 satellites by computer simulation. As the result of the simulation, it is confirmed that the adequate differences of Eccentricity and Inclination vectors can stably keep the distance of 2 satellites. However, it is also confirmed that in case that Relative Eccentricity and Inclination vectors intersect perpendicularly each other, 2 satellites can closely approach. Therefore, the Eccentricity and Inclination vectors should be controlled to be separated and also not to intersect perpendicularly in Relative E&I vectors in order to maintain the distance of 2 satellites.
In this paper, 4 Satellites Model and 8 Satellites Model are proposed as operational orbit control model for plural satellites. A feature of the proposed Model is a hybrid type which combines the Eccentricity and Inclination Vector Separation Method with the Longitude Separation Method. The proposed Model is also unique in controlling the Eccentricity and Inclination vectors .

1. INTRODUCTION

TAO has stably controlled two operational broadcasting satellites (BS-3a, BS-3b) in the same slot(110 ±0.1 ° E) on GEO by Longitude Separation Method since 1991.
In order to colocate more than 3 satellites in the same slot, an advanced method is required because the existence method basically has a limitation of the number of satellites. As an advanced method, Eccentricity and Inclination Vector Separation Method (called E&I Method henceforth) is generally proposed in which Eccentricity vectors (called E vectors henceforth) and Inclination vectors (called I vectors henceforth) of the satellites should be maintained to be separated. A computer simulation has been performed to examine the efficiency of E&I Method. Based on the result of the simulation, an orbital control model for plural satellites is proposed.

2. SIMULATION OF 2 SATELLITES

A computer simulation about the E&I Method has been performed and some guidelines for practical use are extracted. As a simulator , orbit prediction software program called PLANER in TAO is used. PLANER calculates the distance between 2 satellites over the specified term using the general perturbation method.

2.1. Simulation and result

2.1.1 Simulation-1

The relation among the minimum distance and the differences of E&I vectors is examined under the conditions that 2 satellites are close in longitude ; (0 , 0.001 , 0.005 , 0.01 , 0.02 ° at the start of the simulation).
The result of Simulation-1 is shown in Figure-1.
Two satellites can approach within 1 Km when the differences of E&I vectors are small(in CASE-1). Under the existence method, the difference of E vector of 2 satellites is almost equal in order to synchronize the daily longitudinal oscillation of 2 satellites. The distance between 2 satellites is kept stably more than 5 Km when the differences of E&I vectors are made larger (in CASE-2). And when the differences of E&I vectors are made still larger, the distance is kept stably more than 8 Km (in CASE-3). As a peculiar case when there is no difference in I vector, close approaches or tendencies of approach are recognized (in CASE-4).

2.1.2 Simulation-2

The relation among the minimum distance and the relative E&I vectors of 2 satellites is examined when the difference of I vectors is varied under the condition that the difference of E vectors is fixed at 30 ° and 45° . The result of Simulation-2 is shown in Figure-2.
Each point of A, B, C, D in Figure-2 is the highest point of the minimum distance, and E&I vectors of 2 satellites in these points are shown in Figure-3. The relative E vector is parallel with the relative I vector in all these points. On the contrary, each point of P, Q, R, S in Figure-2 is the lowest point of the minimum distance, and the relative E and I vectors intersect perpendicularly each other in these points shown in Figure-4.

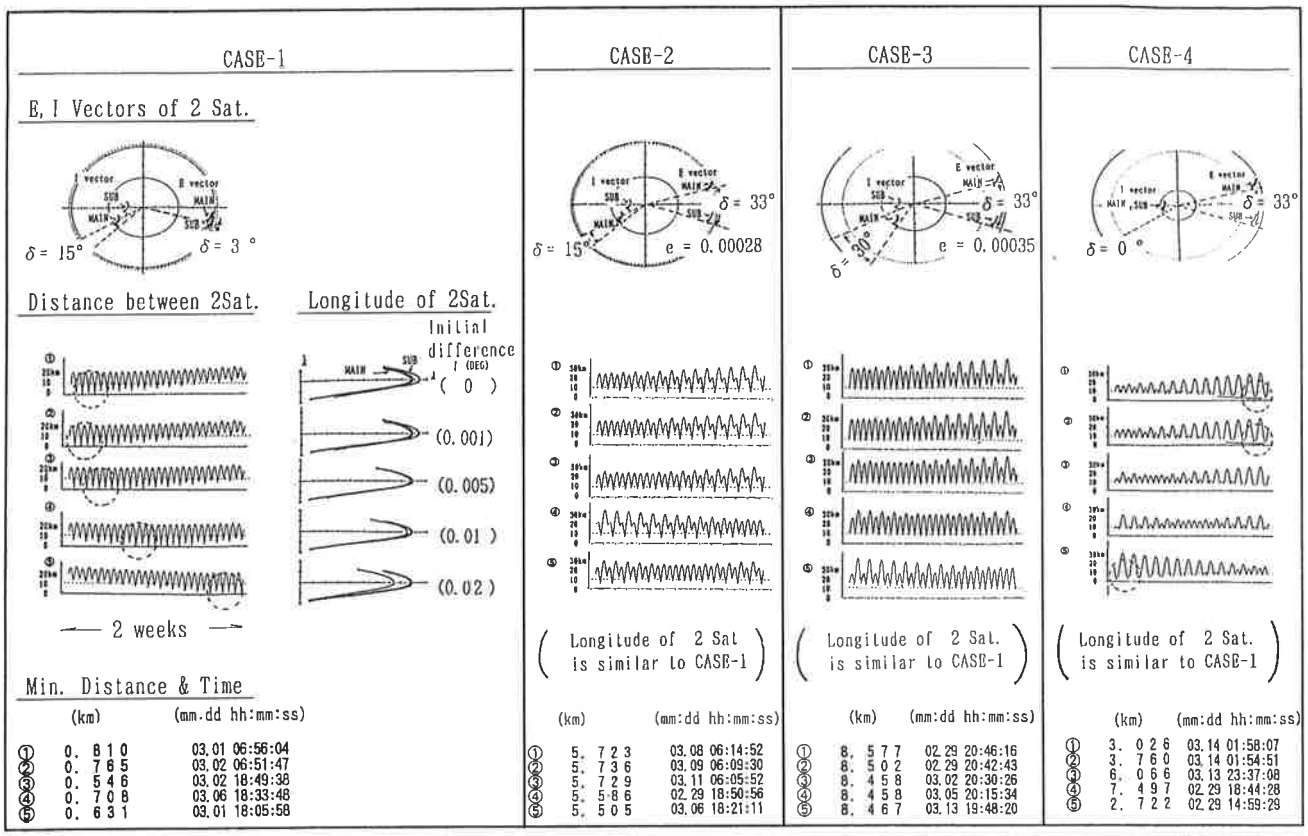

Figure 1. Result of Simulation-1.

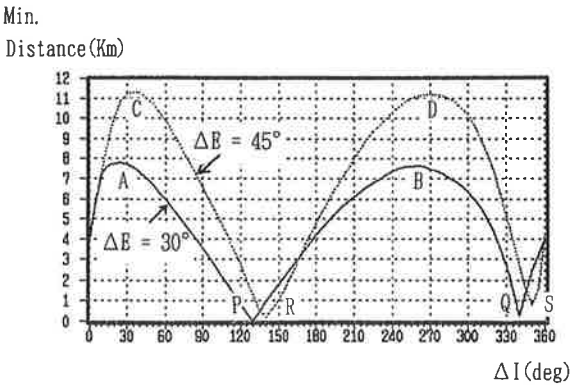

Figure 2. Result of Simulation-2.

2.1.3 Simulation-3

The relation between the minimum distance and the difference of longitudinal drift-rate of 2 satellites is examined when the difference of drift-rate is varied under the condition that the difference of E&I vectors are fixed. The result is shown in Figure-5.
An example of the result is shown in Figure-6.
The difference of drift-rate reduces the distance margin of 2 satellites in radial component which results from the difference of E vectors .

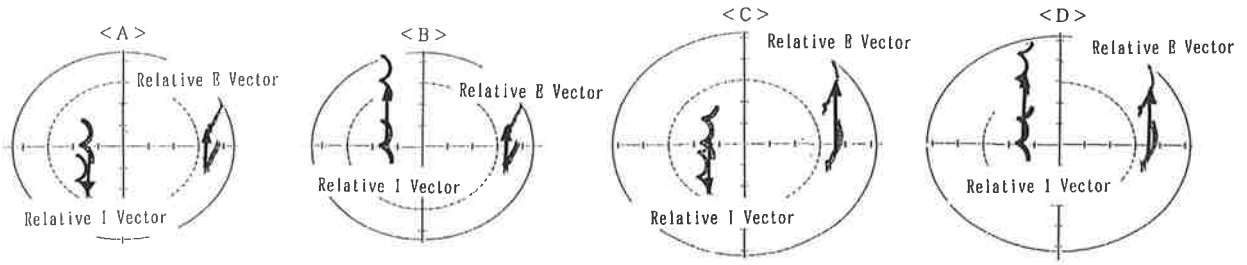

Figure-3. Relative E and I Vectors in Highest Point A, B, C, D .

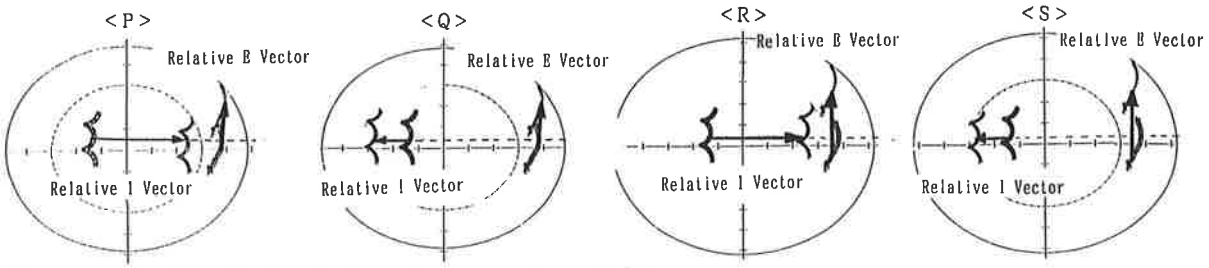

Figure-4. Relative E and I Vectors in Lowest Point P, Q, R, S .

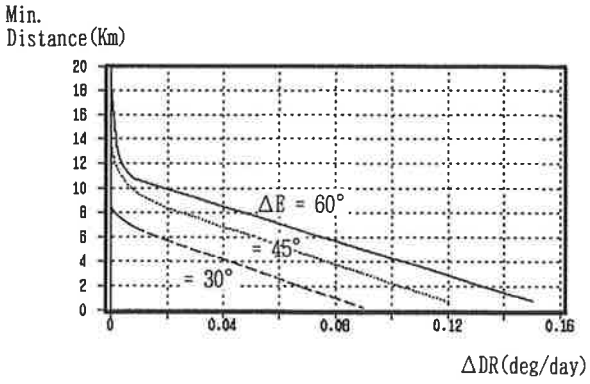

Figure 5. Result of Simulation-3.

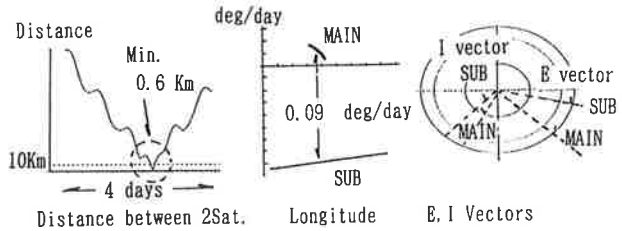

Figure 6. An Example of Simulation-3.

2.2 The essential points of E&I Method

Based on the results of Simulation-1, 2, 3 the essential points of E&I Method are extracted as follows.

(1) Both of E&I vectors of 2 satellites should be controlled in order to be separated each other.
The angle difference of E vectors is desirable to be more than 30° .

(2) Both of E&I vectors of 2 satellites should be controlled in order that relative E and I vectors should not intersect perpendicularly each other.
The intersecting angle of relative E and I vectors is desirable to be less than 60 ° .

(3) The difference of longitude drift-rate of 2 satellites should be avoided to become extremely large.
The difference is desirable to be less than 0.05 deg/day .

3. OPERATIONAL MODEL

As operational model, 4 Satellites Model and 8 Satellites Model are proposed here in after. The essential points of E&I Method are taken into account. A common feature of these Models is a hybrid type which combines the E&I Method with the existence Longitude Separation Method, by grouping satellites into 2 longitude areas.

3.1 4 Satellites Model

The concept of the orbital control is shown in Figure-7. The major points of this model are as follows.

- Both E&I Method and Longitude Separation Method are applied for each pair as shown in Table-1.
- I vectors of each pair (for which E&I Method is applied) should be controlled to locate in each separated area which is set along the evolution line of I vector as shown in Figure-7. Consequently, the relative I vectors are held within a certain direction usually.
- E vectors of each pair (for which E&I Method is applied) should be controlled in order that relative E and I vectors should not intersect perpendicularly each other as shown in Figure-7.

Long. Separation Method	E&I Method
a-x , b-y	a-b , a-y , x-b , x-y

Table 1. Applied Method for each satellite pair. (4 Satellites Model)

3.2 Operational Simulation for 4 Satellites Model

The operational simulation for 4 Satellites Model has been performed. The result is shown in Figure-8 and Table-2 . The term of simulation is one year (1993.4.1 ~1994.4.1).
In this simulation, the time of east-west maneuver has been accommodated to control E vector adequately.
Consequently, the distance can be kept more than 6.5 Km for a year without 2-part east-west maneuver and there is no extra amount of Δv (over cost of fuel) to the normal present operation.

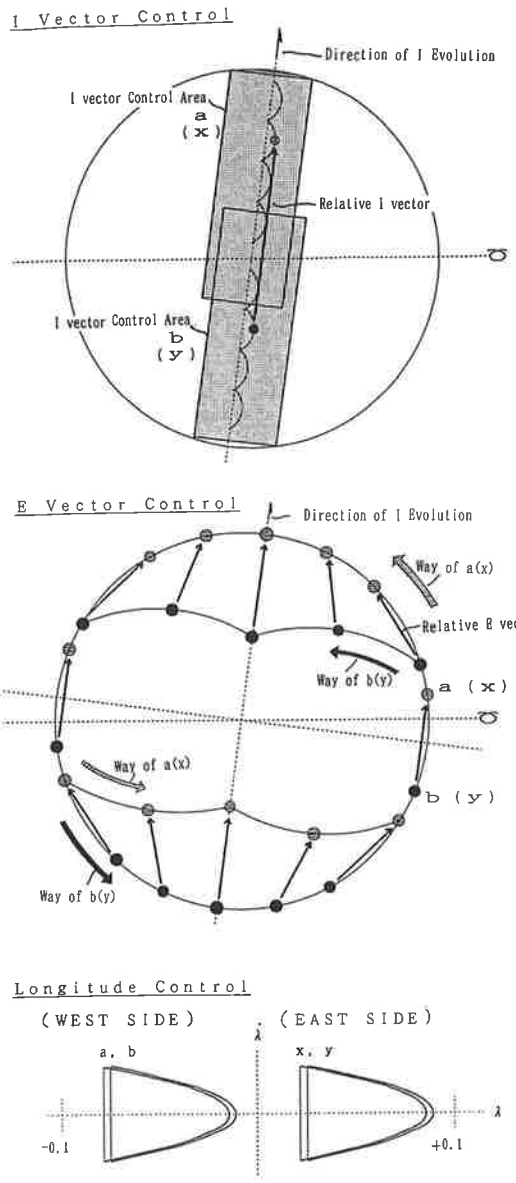

Figure 7. Conceptual Drawing of 4 Sat. Model.

sat. pair & Min. Distance & Occurred Date	a-b(x-y)		6.5 km	93.4.17
	a-y(b-x)		12.3 Km	93.7.10
	a-x(b-y)		19.8 Km	93.6.26
Maneuver Times & Maneuver Interval	NS		36	1/ W
	EW	1 PART	26	1/ 2W
		2 PART	0	
Extra Amount of ΔV & Ratio to Normal Δv	NS		0	0
	EW		0	0

Table 2. Result of operational simulation of 4 sat.

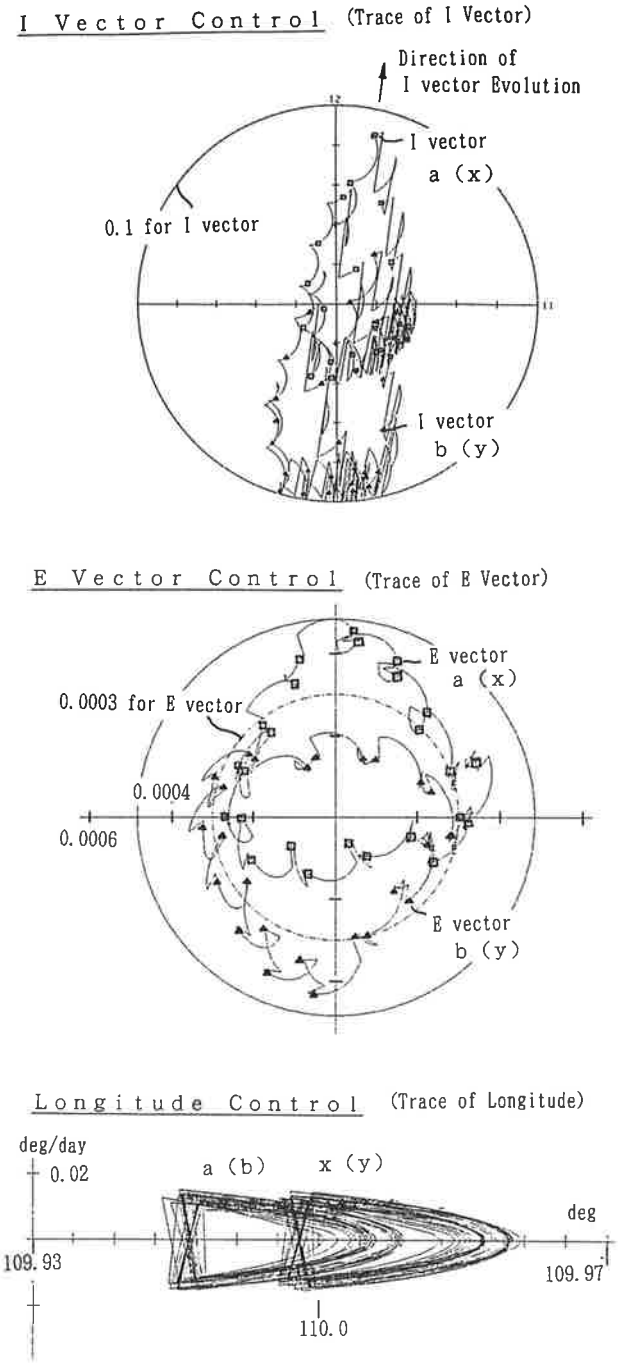

Figure 8. Operational Simulation for 4 Sat. Model.

3.3 8 Satellites Model

The concept of the control is shown in Figure-9.
The major points of this model are as follows

- Both E&I Method and Longitude Separation Method are applied for each pair as shown in Table-3.
  The concept of Longitude control is similar to 4 Satellites Model.
- I vectors of each pair (for which E&I Method is applied) should be controled to locate in each separated area as shown in Figure-9. Consequently, the relative I vectors are held within a certain direction usually.

In 4 Satellites Model each I vector area overlap partially. But in 8 Satellites Model each area should not overlap because of tight control.

- E vectors of each pair (for which E&I Method is applied) should be controled in order that each E vectors is shut up in the definite area of E vector plane as shown in Figure-9. Consequently, the relative E vectors are held within a certain direction usually not to intersect perpendicularly with relative I vectors. E vectors should be more tightly controled against 4 Satellites Model. This way of control for E vector is a feature of 8 Satellites Model.

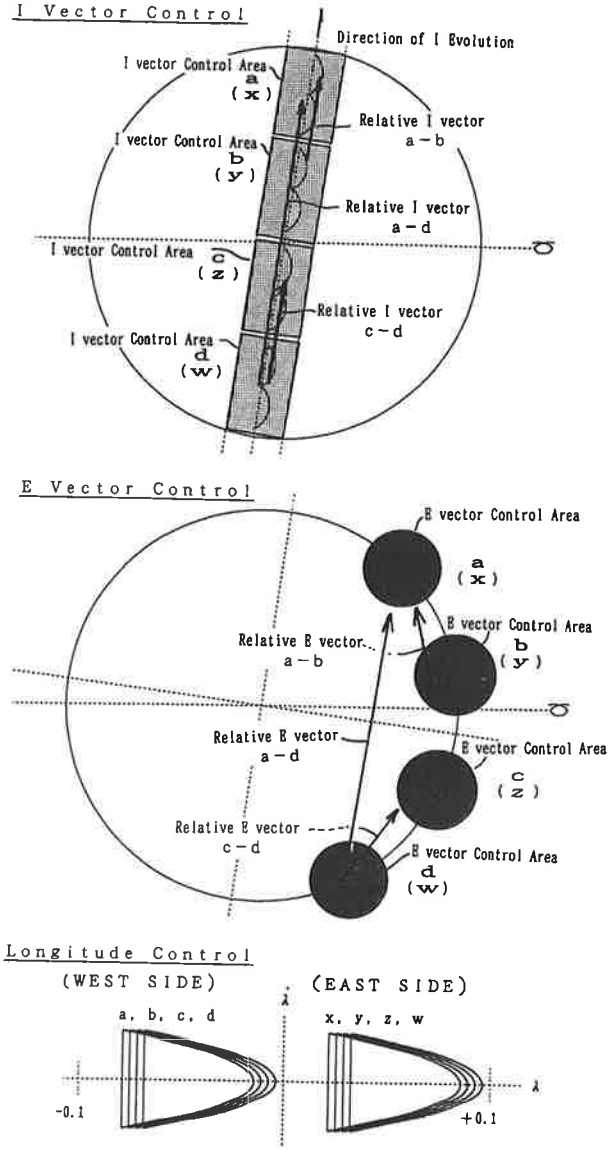

Figure 9. Conceptual Drawing of 8 Sat. Model.

Long. Separation Method	E&I Method
a-x , b-y , c-z , d-w	a-b , a-c , a-d , a-y a-z , a-w , b-c , b-d b-x , b-z , b-w , c-d c-x , c-y , c-w , d-x d-y , d-z , x-y , x-z x-w , y-z , y-w , z-w

Table 3. Applied Method for each satellite pair. (8 Satellites Model)

3.4 Operational Simulation for 8 Satellites Model

The operational simulation for 8 Satellites Model has been performed. The result is shown in Figure-10 and Table-4 . The term of simulation is one year (1993.4.1 ~1994.4.1).

The distance can be kept more than 10.1 Km for a year. Because of tight control for E vector , the number of 2 part east-west maneuver amounts to 40. The total extra amount of Δv is 3.8 m/s . This is about 7.1 % to total Δv for a year.

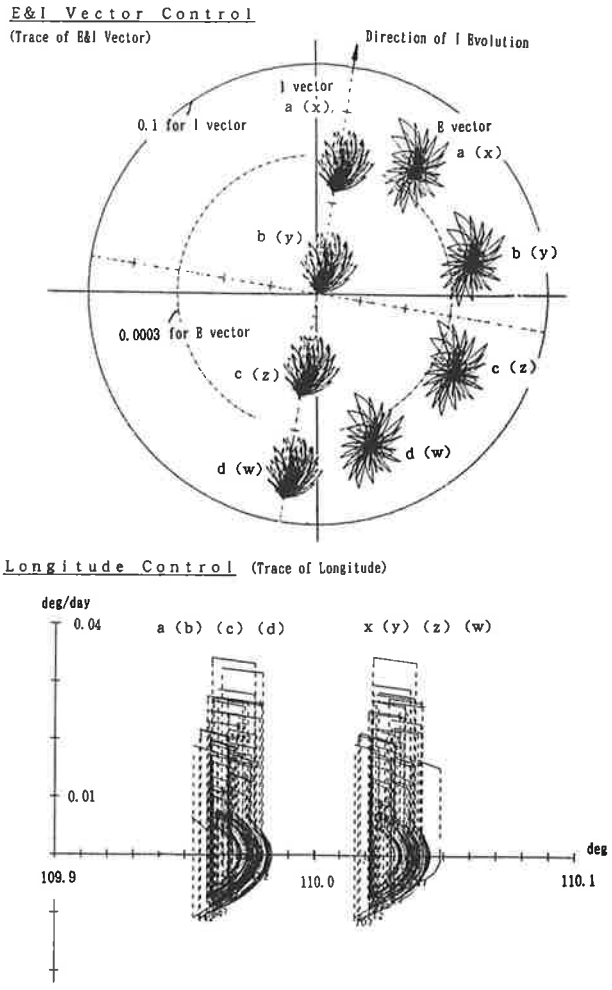

Figure 10. Operational Simulation for 8 Sat. Model.

sat. pair & Min. Distance & Occurred Date (Top 3 & Last)	1st Min.	b-c	10.1 km	93.7.4
	2nd Min.	a-b	14.3 Km	94.2.26
	3rd Min.	c-d	14.4 Km	93.12.25
	Last Min	a-w	45.3 Km	93.4.11
Maneuver Times & Maneuver Interval	NS		53	1/ W
	EW	1 PART	13	1/ W
		2 PART	40	
Extra Amount of ΔV & Ratio to Total Δv	NS		0.6m/s	1.1 %
	EW		3.2m/s	6.0 %

Table 4. Result of operational simulation of 8 sat.

4. CONCLUSION

The essential points of E&I Method are extracted from the result of computer simulation, and as operational model, 4 Satellites Model and 8 Satellites Model are proposed. These Models are desirable to be assessed in more detail and extensively to be put into practical use.

5. REFERENCES

1. Susan M. Hubert and James F. Swale, STATIONKEEPING OF A CONSTELLATION OF GEOSTATIONARY COMMUNICATIONS SATELLITES, RCS Astro-Electronics, AAS/AIAA Astrodynamics Conference, Seattle, No AIAA 84-2042, 1984.

2. M.C.Eckstein et al. ,COLOCATION STRATEGY AND COLLISION AVOIDANCE FOR THE GEOSTATIONARY SATELLITES AT 19 DEGREES WEST, DLR GSOC, CNES International Symposium on SPACE DYNAMICS, 1989.

3. F. DUFOR, ONE YEAR OF CO-LOCATION AT 19 DEGREES WEST WITH TDF-1 AND TDF-2 SPACECRAFTS, CNES, 3rd International Symposium on Spacecraft Flight Dynamics, 1991.

4. H. WATANABE et al. , An Experimental Model of Orbital Control for Plural Satellites in The Same Longitudinal Position, 18th International Symposium on Space Technology and Science, 1992.