A SIMULATION MODEL OF THE TOKYO METROPOLITAN REGION

Toshiro Shimada, I.Tokunaga, A.Otaki and T.Okubo
Meiji University

Summary

The population of the Tokyo Metropolitan Region increased by about 3 millions in the five years between 1965 and 1970. This increase was due mainly to the flow of populations from the outer field of the Tokyo Metropolitan Region. Until around 1955, population increases were noticeable within the special wards of the metropolis. However, while there has been a recent lull in the increase rate of in-migration, there has been a remarkable increase in the amount of out-migration from the special wards to the four adjoining districts, the Tama district, Chiba Prefecture, Saitama Prefecture, and Kanagawa Prefecture. Out-migration exceeded in-migration in 1967 for the first time since the end of the War and the gap has been increasing year by year. On the other hand there has been gradual rise due to natural increase (the difference between births and deaths) in recent years, which has come to occupy a greater part of the population increase within the area of the Tokyo Metropolitan Region.

Our model therefore was formulated to represent such relations between the ward area and the four adjoining districts, as migration, residential effect and commutation.

We have divided the whole system into 5 sectors, corresponding to the ward area, the Tama district, Chiba Prefecture, Saitama Prefecture and Kanagawa Prefecture. Each sector is subdivided into population, residence, and enterprise sub-sectors.

The simulation was run for the 150 years from 1900 to 2050 and the results contained World War II effect on the population, the number of residences and enterprises of the ward area.

(1)

I. The Tokyo Metropolitan Region

Tokyo is located in the south of the Kanto Plain, roughly in the middle of the Japanese archipelago. It is bounded to the east by Chiba Prefecture, to the west by Yamanashi Prefecture across mountains, to the south by Kanagawa Prefecture and to the north by Saitama Prefecture.

Tokyo is a vast self-governing unit consisting of 23 Special Wards and Tama District of 26 cities, seven towns and eight villages.

The Tokyo Metropolitan Region including the metropolis of Tokyo and three adjoining prefectures, Saitama, Kanagawa and Chiba has a population of about 25 percent of the nation. The metropolis of Tokyo and seven surrounding prefectures are called the National Capital Region.

II. General Description of the Model

2.1 Parts consisting the Model

The whole system is divided into 5 sectors; Tokyo Ward Area (W), Tokyo Tama District (T), Chiba Prefecture (C), Saitama Prefecture (S), and Kanagawa Prefecture (K). The letters in parentheses identify the sectors.

Each sector contains 3 subsectors of population, residences and enterprises.

Relation among sectors are shown in Fig.1, where only the relations between the Tokyo ward area and each of 4 surrounding sectors are treated, while relations among 4 sectors are not considered. Population increase in each sector is assumed to be restricted by the supposed upper limit of the population of the Tokyo metropolitan area.

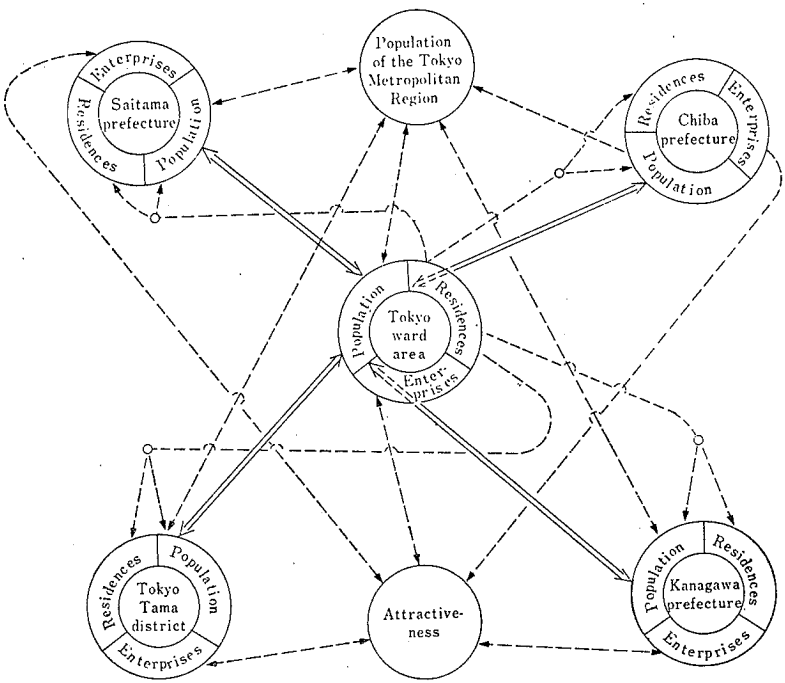

Fig.1 Relation among Sectors

2.2 Tokyo Ward Area Sector

2.2.1 Population Subsector of Tokyo Ward Area

The population of the ward area WP varies with social increase between in- and out-migration, and with natural increase, that is, excess of births over deaths.

We will discuss births, deaths and the moving rates into and out of the outer field of Tokyo metropolitan area, while migration into and out of Tama, Chiba, Saitama and Kanagawa will be explained later in each sector.

WPB.KL=WPBR*WP.K*WCRM.K (R) (2.2.1)
WPBR=0.04 (C)

Births in 1900 were assumed as 4% of the population of the ward area. This value of 4% is fixed as the ward area birth rate normal WPBR during the whole length of this simulation. Births WPB may be considered to decrease gradually as the population of the ward area increases and the standard of living rises. This birth rate decrease with population increase is treated as a multiplier in equation (2.2.1) and referred to as the ward area crowding ratio multiplier WCRM.

WCRM.K=TABHL(TWCRM,WCRR.K,0.3,1.8,0.3) (A) (2.2.2)
TWCRM=1,0.8,0.65,0.5,0.45,0.4 (T) (2.2.3)
WCRR.K=WP.K*100/WLV (A) (2.2.4)

The ward area crowding ratio WCRR, in other words, population density, is simply the area's population WP divided by the arable land area of the special wards WLV and is given by the equation (2.2.4) in persons/100m for convenience.

Next is the equation for deaths WPD.

WPD.KL=WPDR*WP.K*WDCRM.K (R) (2.2.5)
WPDR=0.01 (C)

Equation (2.2.5) is quite similar to the equation for the births WPB.

Next we consider in- and out-migration (WPIO,WPOO) as to the outer field. First WPIO is given as follows;

WPIO.KL=WPION*WP.K*WPIOR.K+WPIOW.K (R) (2.2.6)
WPION=0.04 (C)

In equation (2.2.6) in-migration from the outer field of the Tokyo Metropolitan area is assumed yearly as 4% of the population of the ward area normally,but the rate may be changed yearly, so is considered to be adjusted by the next multiplier WPIOR.

WPIOR.K=TABHL(TWPIOR,PR.K,0.14,0.28,0.02) (A) (2.2.7)
TWPIOR=1,1.2,1,.9,.7,.5,.3,.2 (T) (2.2.8)

In the beginning, a population corresponding to 4% of the population of the ward area moved into Tokyo ward area from the outer field of the Tokyo metropolitan region,but as the population of the ward area increases, the moving rate into the ward area will grow too large. Equations (2.2.7) and (2.2.8) represent this effect. As the ratio of the population of Tokyo metropolitan region to Japanese population PR approaches 0.3, the moving rate into the ward area is assumed to decrease.

The next equation represents out-migration to the outer field from the ward area.

WPOO.KL=WOA.K*WP.K (R) (2.2.9)
WOA.K=CWOA*API.K/(0.75*WPIU.K) (A) (2.2.10)

The equation (2.2.9) shows that people flowing out to the outer field WPOO is the population of the ward area multiplied by the out-migration rate WOA, which is assumed as the normal rate CWOA multiplied by the ratio of the average personal income of Japan API to 75% of the average personal income of the ward area WPIU. Now, API is assumed as a function of a yearly 3% increase.

2.2.2 Residence Subsector of Tokyo Ward Area

In this model, residences include not only houses but also boarding houses and condominiums.

Ward area residences WR are considered to be increased by construction WRB and decreased by demolition WDR.

```
WRB.KL=MIN(WSTR.K,WDTR.K)*WCRB.K                (R)    (2.2.11)
WSTR.K=WRLA.K*WBC/WARR                          (A)    (2.2.12)
WDTR.K=WP.K/WPF.K                               (A)    (2.2.13)
```

Equation (2.2.13) means that residences desired in the special wards WDTR equal the population of the ward area divided by persons per family WPF, which are assumed as a decreasing table function. Residences to be supplied in the ward area WSTR in (2.2.12) are assumed to be residential land area WRLA multiplied by building coverage rate WBC divided by residential area/residence WARR. Here WBC is assumed to be 0.2 and WARR is assumed to be 28m/residential unit. Equation (2.2.11) means that residential construction WRB is a minimum of WSTR and WDTR multiplied by construction rate WCRB, which is set equal to 0.03.

Residential demolition WDR is simply considered to be proportional to residences in the ward area and the proportionality rate is assumed to be 0.2%.

Residential land area of the special wards WRLA used in (2.2.12) is calculated from arable land area WLV minus industrial and commercial land area of the special ward WICLA, which is obtained from WLV multiplied by the land transfer rate WLTR1. WLTR1 is given as follows: If inventory for housing construction WAP increases, WLTR1 decreases in correspondence to WAP, while if WAP decreases and inventory for enterprise building WBP increases, land transfer rate will increase in correspondence to WBP, but if both WAP and WBP decrease, land transfer rate is assumed to be unchanged.

2.2.3 Enterprise Subsector of Tokyo Ward Area

The enterprises of the ward area WE are considered to be increased by the new enterprises WNE and decreased by enterprise obsolescence WED. WNE is given as follows:

```
WNE.KL=WEB.K*WLAE.K/ED.K                        (R)    (2.2.14)
WEB.K=WEBR*WE.K*WDWE.K/WPWE.K                   (A)    (2.2.15)
ED.K=TABHL(TEDL,PR.K,0.2,0.28,0.02)             (A)    (2.2.16)
TEDL=1.5,2,3.5,5.7                              (T)    (2.2.17)
```

The new enterprises of the ward area are assumed as the enterprises to be built WEB multiplied by an attractiveness for enterprise WLAE, divided by the time delay ED in perceiving new enterprises. In (2.2.16) ED is assumed as a table function which increases gradually from one and a half years as the ratio of the population of the Tokyo metropolitan region to the population of the whole nation PR increases. In (2.2.15) the enterprises to be built WEB is assumed to be proportional to three factors; the number of enterprises in the ward area WE, new enterprise construction rate normal WEBR and the ratio of workers desired WDWE to workers employed WPWE. Here, WEBR is assumed as 1.8%.

WDWE is given by the next equation.

```
WDWE.K=WEE*WANE*WICLA.K/WARE                    (A)    (2.2.18)
```

WICLA Ward area, Industrial and Commercial Land Area (1000m)
WEE Ward area, Employee/Enterprise (persons/enterprise)
WANE Ward area, Land Availability for Enterprise (unitless)
WARE Ward area, firm Area/Enterprise (m/enterprise)

Workers corresponding to enterprises suitable for the industrial and commercial land area of the ward area WDWE are calculated by equation (2.2.18).

The workers in the ward area WPWE are assumed to be the sum of the resident workers of the ward area, which is set at 30% of the population of the special wards, out-commuters to the adjacent area corresponding to 6% of the workers in WE, and in-commuters from the Tama district and three prefectures.

The attractiveness factor for enterprises WLAE used in (2.2.18) is considered to be 1 minus the average attractiveness of enterprises in Tama district and three neighboring prefectures. Therefore the attractiveness for enterprises in the ward area decreases as attractiveness for enterprises in the adjacent districts increases. The attractiveness for enterprises in Tama or each prefecture will be calculated in each sector.

Lastly enterprise obsolescence WED is simply assumed to be 0.5% of the enterprises of the ward area WE divided by the time delay, which is set equal to the delay of construction in (2.2.16).

2.3 Tama District Sector

2.3.1 Population Subsector of Tama District

The population of Tama district TP varies with excess of births over deaths and with social increase between in- and out-migration as dose the Tokyo ward area and the outer field of the Tokyo metropolitan region.

Quite similarly as the case of Tokyo ward area, the births of the Tama district in 1900 were assumed as 4% of Tama's population and are considered to decrease gradually as Tama's population increases. Here, we introduce an auxiliary function, called the Tama-district-crowding-ratio multiplier TCRM similarly as the Tokyo- ward-area-crowding-ratio multiplier WCRM.

The deaths for the Tama district in 1900 were assumed as 1% of Tama's population and are considered to decrease gradually. Here we use an auxiliary function , the Tama-district-death-rate-from-crowding- ratio multiplier.

Next, we will consider out-migration from the Tama district PTWM. With regard to this variable, we consider that the migration into the ward area from the 4 surrounding sectors may be divided, in proportion to residences to be supplied in each sector.

PTWM.KL=PTWMR.K*WP.K (R) (2.3.1)
PTWMR.K=CPTWMR*TRR.K*PTWMR1.K (A) (2.3.2)
TRR.K=TSTR.K/(TSTR.K+CSTR.K+SSTR.K+KSTR.K) (A) (2.3.3)

TSTR,CSTR,SSTR,KSTR Residences to be supplied in Tama, Chiba, Saitama and Kanagawa (1000 residential units)

The equation (2.3.1) means that the CPTWMR % of the population of the ward area WP(2% in the basic model) is assumed to move into the special wards from the 4 surrounding sectors and this migration may be divided in proportion to residences to be supplied in each sector.As to Tama district the residence ratio is TRR. Now, according to the equation (2.3.1), the migration to the special wards grows as the population of the ward area increases, but actually, unreasonable growth of the population of the ward area will force down the above migration. This effect is represented by a table function PWTMR1, in which the migration rate to the ward area decreases as the population of the Tokyo metropolitan region approaches 30% of the Japanese population.

TSTR, an important factor for the Tama residential ratio TRR, is obtained similarly as WSTR, by the residential land area in Tama district TRLA times the building coverage rate (0.02) divided by the residential area per residential unit,which is assumed as 32m/residential unit. Next, quite similarly as WRLA, the residential land area of Tama district TRLA is obtained from arable land area, which is the arable land area times the land transfer rate. The land transfer rate of the Tama district is quite similar to that of the ward area, so is not given here.

Next, we can calculate in-migration to the Tama district from the special wards PWTM.

PWTM.KL=PWTM1.K+PWTM2.K (R) (2.3.4)

PWTM consists of two terms. The first term PWTM1 corresponds to in-migration from the ward area by an attractiveness for residences. The second term PWTM2 means the out-migration from the ward area because of a housing shortage in the special wards.

The last terms of the population subsector of the Tama district are in- and out- migration TPIO, TPOO as to the outer field of the Tokyo metropolitan region.

TPIO.KL=TPION*TP.K*TCRM.K (R) (2.3.5)

Similarly as the case of the ward area, the population corresponding to the in-migration rate TPION(4.5%) of the population of the Tama district TP moved into the Tama district in the beginning from the outer field of the Tokyo metropolitan region, then gradually decreases as the crowding ratio changes.

TPOO.KL=TOA.K*TP.K (R) (2.3.6)

TOA.K=CTOA*API.K/(0.75*TPIU.K) (A) (2.3.7)

It is shown in (2.3.6) that the out-migration from the Tama district to the outer field of the Tokyo metropolitan region TPOO equals the population of the Tama district TP multiplied by the out-migration rate TOA, which is assumed as 2% originally, proportional to the average personal income of the whole nation, and inversely proportional to 75% of that of the Tama district.

2.3.2 Residence Subsector of Tama District

The number of residences in Tama district TR is considered to be increased by construction TRB and decreased by demolition TDR.

TRB.KL=TRB1.K+TRB2.K (R) (2.3.8)

The first term of the right side TRB1 corresponds to the natural

increase of the residences in Tama district and the second term TRB2 is house construction corresponding to TWTM2 explained in (2.3.4), namely, the in-migration to Tama district according to residential shortage of the ward area.

Next we will consider residence demolition in the Tama district TDR.

TDR.KL=0.002*TR.K (R) (2.3.9)

Residential demolition is simply assumed as 0.2% of Tama residences TR.

2.3.3 Enterprise Subsector of Tama District

The enterprises of the Tama district TE are considered to be increased by the new enterprises TNE and decreased by enterprise obsolescence TED.

The new enterprises TNE is given as follows:

TNE.KL=TEB.K*TLAE.K/ED.K (R) (2.3.10)

TEB.K=TEBR*TE.K*TDWE.K/TPWE.K (A) (2.3.11)

The new enterprises of the Tama district TNE are assumed as the enterprises to be built TEB multiplied by an attractiveness for enterprise TLAE, divided by the time delay ED, for which the same value is used as the case of the ward area. In (2.3.11) the enterprises to be built TEB is assumed to be proportional to three factors;the number of enterprises in the Tama district TE, new enterprise construction rate normal TEBR and the ratio of workers desired TDWE to workers employed TPWE. Here, TEBR is assumed as 1.8% the same as for the ward area.

Workers desired TDWE is given by the next equation.

TDWE.K=TEE*TANE*TICLA.K/TARE (A) (2.3.12)

TEE=11.6,TANE=0.7,TARE=500 (C)

Workers corresponding to enterprises suitable for the industrial and commercial land area of the Tama district are assumed as workers desired TDWE in equation (2.3.12).

Next we will consider workers to be supplied TPWE.

TPWE.K=0.5*TP.K+0.2*TE.K*TEE+WNOZ.K (A) (2.3.13)

This equation means that the workers in the TAma district TPWE are the sum of the resident workers of the Tama district, which is set at 50% of the Tama district population, out-commuters to the adjacent area corresponding to 20% of workers in TE, and in-commuters from the ward area.

The attractiveness factor for enterprises TLAE used in (2.3.10) is assumed as follows:

TLAE.K=(WA*VA.K+WB*VB.K+WC*VC.K)/(WA+WB+WC) (A) (2.3.14)

The attractiveness for enterprises in the Tama district is given by (2.3.14) as a weighted average of VA,VB VC. Here, VA is the proportional ratio of the land area of the Tama district to that of the ward area. VB is the proportional ratio of building expenses/m and is used instead of the land value, and VC is the proportional ratio of population change.

TED.KL=0.005*TE.K/ED.K (R) (2.3.15)

Lastly, enterprise obsolescence in the Tama district TED is simply assumed to be 0.5% of the enterprises in the Tama district. Here the time delay ED in (2.3.15) is set equal to the delay of

construction (2.3.10).

The values of several variables in this sector, PWTM and PTWM in the population subsector and TLAE in the enterprise subsector are used in the ward area sector. On the other hand, the values of WP, WLV and so on are introduced into this sector.

III Simulation Results

Fig.2, Fig.3 and Fig.4 are the simulation results of the base model as to population,residences, and enterprises, respectively, each of which contains curves of 5 sectors.

People flowing out from the ward area during World War II and flowing into the ward area during about 10 years after World War II were assumed as table functions.

IV Conclusion

We have attempted to formulate a system dynamics model of the Tokyo metropolitan region, which has five sectors of Tokyo ward area and Tokyo Tama district and prefecture sectors of Saitama, Chiba and Kanagawa.Each sector has been subdivided into three subsectors of population, residences and enterprises. In this paper sectors of the Tokyo ward area and the Tokyo Tama district were discussed.

We showed three simulation results with regard to population, residences and enterprises, for which the length of the simulation was 150 years from 1900 to 2050.

References

1.Tokyo Metropolitan Government.(1980). Plain Talk about Tokyo, the Editorial and Distribution Office, the Tokyo Metropolitan Government, Tokyo.
2.Forrester, J.W.(1969). Urban Dynamics. Cambridge, MA:MIT Press.
3.Pugh, A.L.,III.(1976). DYNAMO User's Manual. MIT Press, 5th edition.
4.Shimada, T, I. Tokunaga, A. Otaki and T. Okubo.(1981). A System Dinamics Model of the Tokyo Metropolitan Region. R.I.S.T.,Special Project No.1, Meiji University, (in Japanese).

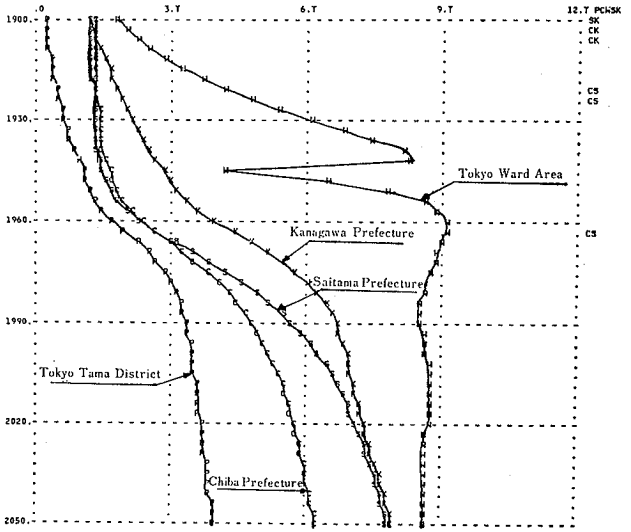

Fig. 2 Population

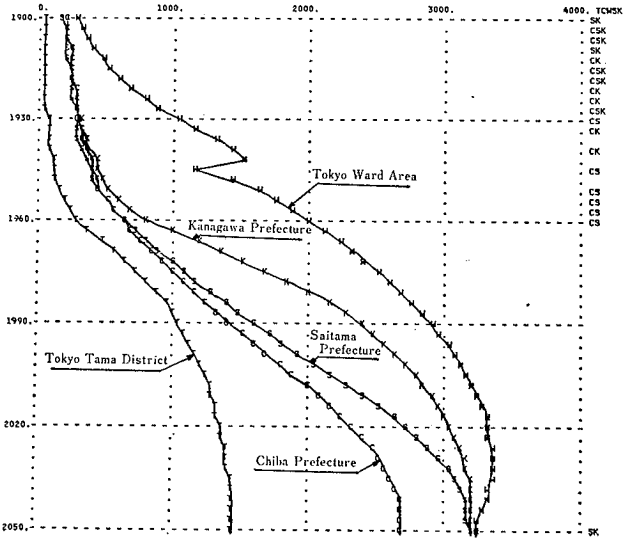

Fig. 3 Residences

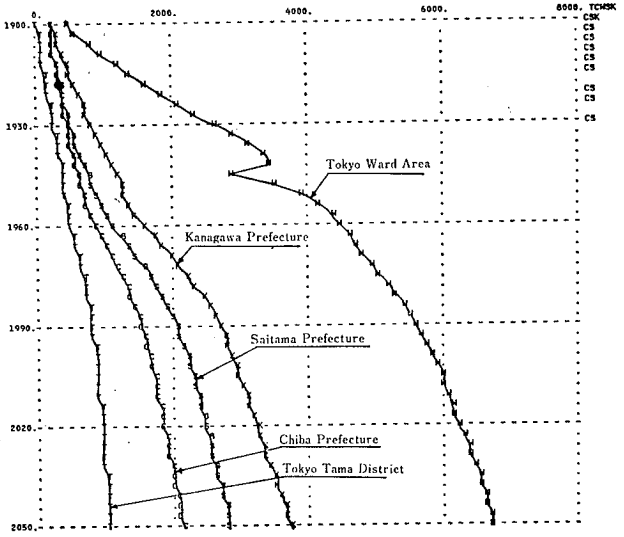

Fig. 4 Enterprises