【土木計画学研究・講演集 No.11 1988年11月】

STUDY ON THE METHODOLOGY OF PLANNING OF INFRASTRUCTURE CONSTRUCTION FOR A NEW TOWN DEVELOPMENT PROJECT WITH LARGE-SCALE EARTH-MOVING*

By
Mamoru HARUNA **
Abas Bin Sabran***

In a way to improve the planning works and to provides the needly information for managerial part in management of construction project, a methodology of planning of infrastructure construction for a new town development project is discussed. Project area is divided into various Construction Blocks (CB) based on road network pattern and designed land shape. The CBs' shapes are then rearranged by checking the balance of earth volumes between cutting and banking sections, and by adjusting to the pattern of earth transportation routes and works volume. All work items in each CB and all CBs in project area are interrelated in a sequential form by designing networks for them, and scheduling them with resources. Then, alternatives of schedule are designed as to obtain the feasible schedule.

1. INTRODUCTION

In many cases of new town development projects, they are constructed in a hill-and-valley shape of mountainous or hilly land areas. So, they are involved in works of cutting and banking of earth and enormous volumes of earth to be transport. Other infrastructure constructions such as water supply, road, drainage, etc are also involved with large amount of works. In planning point of view, the problem is to makes an effective and economical earth transportation planning, to schedule all work items in each CB and totally. Also, to design alternatives of schedule and to obtains the feasible and preferable schedule as planning information for construction implementation.

---

* Keyword: New Town Development Project, Construction Planning, Planning Methodology.
** Assoc. Professor of Dept. of Civil Engineering, Kyoto University.
***Graduate Student of Engineering, Kyoto University.
(Yoshida Honmachi, Sakyo-ku, Kyoto 606)

The objective of this study is to make a systematic method of planning of infrastructure construction in a new town development project with large-scale earth-moving as the main work. The 'systematic' means to make a planning with an inclusion of planning model to the planning process and to solve the planning problem before an applying of suitable methods for solution. Besides it, for the realization of planning method to the actual construction field, a case study of planning of infrastructure construction for Nazio New Town Project, Hyogo Prefecture (240 ha. project) is carry out parallelly in the planning process. The scope of this study is in the stage of construction planning of new town development project after the land infrastructure facilities has been designed.

2. PLANNING PROCESS FLOW (OVERALL)

The overall process of developing a method of planning of infrastructure construction with large-scale earth-moving in a new town development project is illustrated by Figure 1 on Page 2.

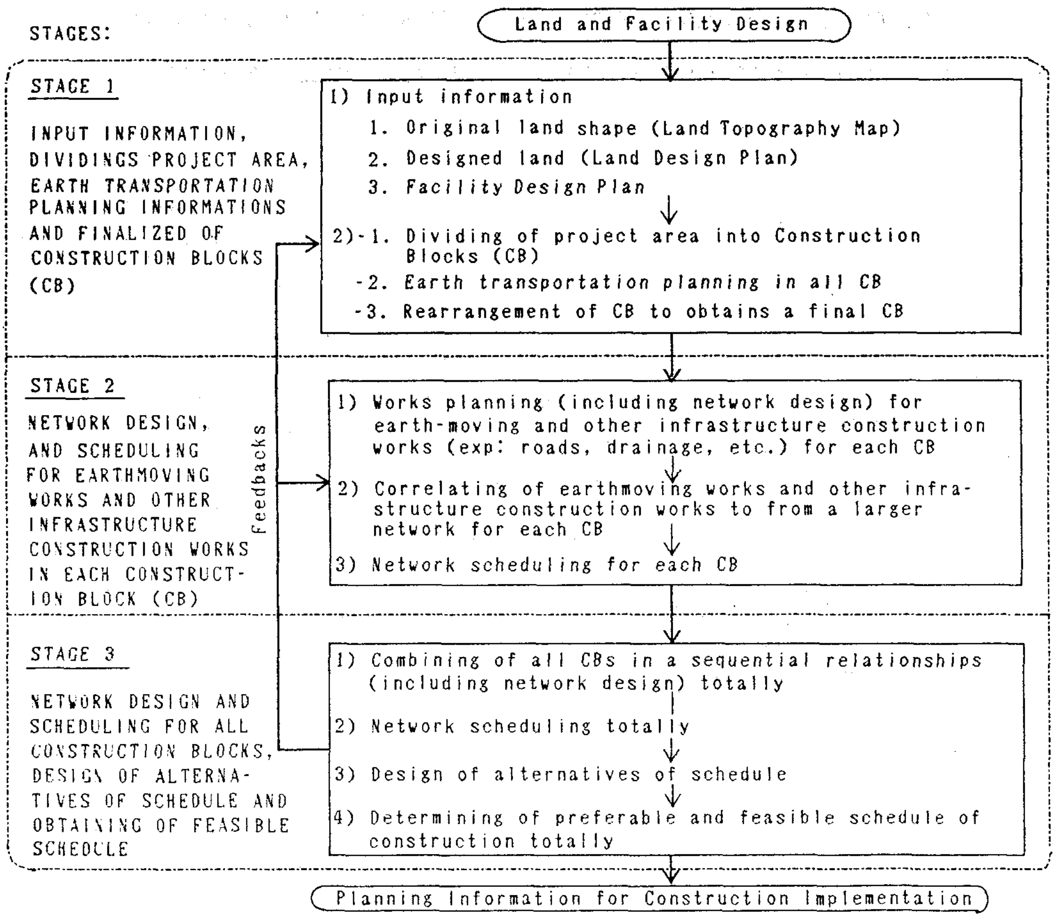

Figure 1 Planning process flow (overall)

It is stage-wise approach of planning, starting with acquisition of input information, that is, collecting of necessary data to be input in planning process. The data collected is subjected to problem characteristics, kinds of computation to be carry out and objecttive or goal setted. Then, transforming the data into a measurable form (i.e. mesh data) that can be input into the computation program. The later part of Stage 1 is concerned with dividing of project area into Construction Blocks (CB) based on the pattern of trunk roads and semi-trunk roads, land shape and rough estimated volumes of earth-moving between cutting and banking blocks. To move or to transport earth volume from cutting block to banking block, an earth transportation planning is then carry out. By obtaining the pattern of transportation routes and volume to be transport, the shape of CB can be adjusts to obtain the final shape of CB.

In Stage 2, every items of work in earth-moving and in other infrastructure construction in each CB are combined in a sequential relationships, and represented it in form of network. So, it is involved of designing of network for earth-moving work and other infrastructure construction works and a larger network from the combination of these networks. Then, followed with scheduling of networks with resources.

In Stage 3, the planning works are included of combining of all CB in a sequential relationships and designing a total network for them. Followed with scheduling the total network with resources. Then, alternatives of schedule are designed, and from these alternatives, a feasible and preferable schedule is selected as output of planning process.

Feedbacks shown in this figure indicates that any difficulties in planning in Stage 3 arised, we have to look back to Stage 1 to finds more informations, or to checks computation method or project dividing method. And/or to look back to Stage 2 to checks the appropriateness of works scheduling and network design method, or to checks necessary additional steps in the process and so on. Then, the improvement steps may carry out to each planning's stage.

The detail explanation on each stage of planning process is discussed in the following section of this paper.

3. PLANNING PROCESS IN STAGE 1

3-1 Input Information

The required information or data to be input into planning process are about of:

(1) original land shape, provide by Land Topography Map (LTM) or Plan,
(2) designed land shape, provide by Land Design Plan (LDP).
(3) Facility Design Plan.

The related datas that we were acquired are for Nazio New Town Project, develop by Housing and Urban Development Corporation (HUDC), a public developer.

3-2 Dividing of Project Area into Construction Blocks (CB)

Dividing of project area into CB is preceding step in construction planning after the land shape, road pattern and infrastructure facilities in the new town project has been designed, and informaabout them are given. So, the concept of dividing of project area is taken based on three main considerations:

(1) the shape of super-blocks (large blocks) enclosed within the designed trunk roads and semi-trunk roads,
(2) the volumes of cutting and banking of earth and the balance between them,
(3) the suitability of each CB from the point of view of other infrastructure construction works.

Concretely, the process of dividing of project area into CB can be divides into 3 steps as below.

Step 1 : 3-dimensional presentation of land shape view.

Step 2 : Rough estimation of volumes of earth-moving, that is, cutting and banking volumes.

Step 3 : Divides of project area into CB.

To presenting the shape of land in 3-dimensional view, at first, the above datas must be transforms into a preferable form for computer application. The Land Topography Map, Land Design Plan Facility Design Plan which shows the shape of land and facilities on plan, all are transformed into mesh data where each mesh point (i.e. cross-section point of two mesh lines) has values of land height (i.e. original and designed height). An example of data transformation is given by Figure 2.

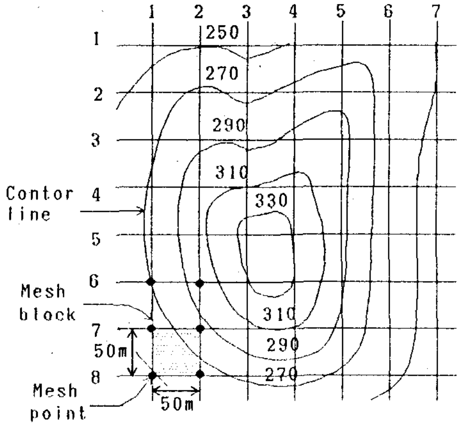

Figure 2 An example of transformation of land data into mesh data

Mesh datas are arranged and put into data table in form of matrix ixj, where i=1, 2, ..., m and j=1, 2, ..., n. For the case study project, m=39 and n=47, so, the matrix is 39x47, and total mesh points are 1833. of 3-dimensional presentation of land shape is given by Figure 3 on Page 4.

3-2-1 Rough estimation of volume of earth-moving

To estimates (rough) the volume of earth-moving (cutting and banking volumes), we computed earth volume in each mesh block as below.

$$V_{ij} = \left.\begin{array}{l}[(H_{des}-H_{org})_{i,j} + (H_{des}-H_{org})_{i,j+1} + (H_{des}-H_{org})_{i+1,j} \\ + (H_{des}-H_{org})_{i+1,j+1} \times 1/4 \times A_{mb}\end{array}\right\} \quad (1)$$

Where V_{ij}=volume of earth in each mesh

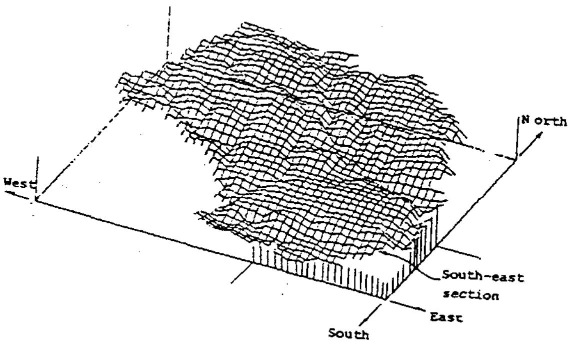

Figure 3 3-dimensional presentation of land shape

block represents by the starting point i, j in each mesh
H_{des}=designed land height
H_{org}=original land height
A_{mb}=area of mesh block (=2500m^2)

By suming-up all earth volume in each mesh block, the total volume of earth-moving can be obtain; and we can checks either it is balance (=0) or unbalance (≠), as given by equation 2 below.

$$V_{tot} = \sum_{i=1}^{m} \sum_{j=1}^{n} V_{ij} \quad ......(2)$$

Where V_{tot}=total volume of earth-moving.

If V_{tot} = -ve, the total earth volume is unbalance and has extra cutting volume; if V_{tot} = +ve, the total earth volume is is unbalance and has extra banking volume; but, if V_{tot} = 0, the total earth volume is balance.

3-2-2 Dividing of project area into CB

By considering three important criterias of project divisioning given by Section 3-2, together with information on the shape of land from 3-dimensional view and the pattern of cutting and banking blocks shown by Figure 4 (example), we can divides the project area into CBs accordingly. The result of project divisioning for Nazio New Town Project is shown by Figure 4 below.

3-3 Earth Transportation Planning

The planning process for earth transportation planning for total project area is illustrated by Figure 5 on Page 5.

3-3-1 Input data and detail estimation of volume of earth-moving

From Figure 5, the input data is mesh data obtained from Section 3-2-2. For the purposes of avoiding of difficulties in preparing input data into the acquired Linear Programming Package, volume of the above mesh data is reduced four times by enlarging the size of mesh block four times to 200m x 200m as shown by Figure 6 on Page 5.

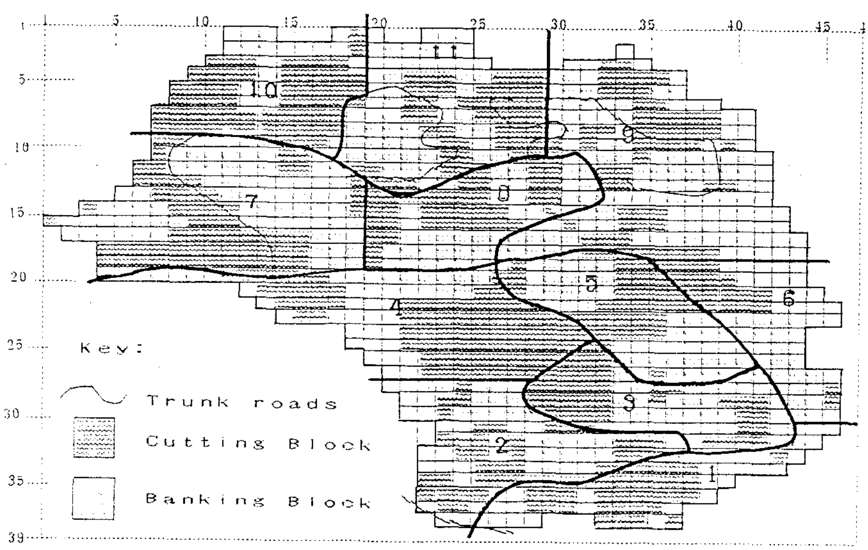

Figure 4 The result of project divisions into CB

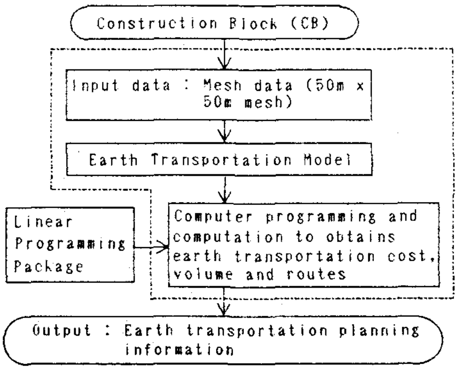

Figure 5 Earth transportation planning process for total project area

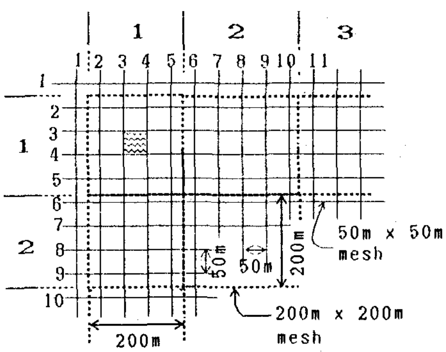

Figure 6 Reduction of mesh blocks from 50m x 50m to 200m x 200m in size

From this figure, the position of 200m x 200m mesh block (large) is shifted to the inner part of the original mesh position as to increases the accuracy of estimation of earth volume in each mesh block and to cover the total project area as much as possible.

The method for estimating of earth volume in each larger mesh block is given as below. Earth volume in each mesh block is the summing-up of earth volumes from smaller blocks, that is;

$$V_{IJ} = \sum_{K=1}^{16} V_K \qquad \ldots\ldots\ (3)$$

where $K=1,2\ldots\ldots 16$, $I=1,2,\ldots M$ and $J=1,2,\ldots.N$

$V_K = (H_{des}-H_{org})_k \times A_{mb}$

$= \Delta Z_K \times A_{mb}$

A_{mb} = area of the larger mesh block ($40000m^2$)

Then, $$V_{IJ} = \sum_{K=1}^{16} \Delta Z_K \times A_{mb} \qquad \ldots\ldots\ (4)$$

If V_{IJ} = -ve, the earth volume in that mesh block is cutting volume; if V_{IJ} = +ve, the earth volume is banking volume; but, if $V_{IJ} = 0$, it is balance and cutting or banking volumes. Total earth volume in project area, that is for total mesh blocks, V_{TOT} is the summation of earth volume from every mesh blocks, given by:

$$V_{TOT} = \sum_{I=1}^{M} \sum_{J=1}^{N} V_{IJ} \qquad \ldots\ldots\ (5)$$

For the case of Nazio New Town Project, total number of mesh blocks is 99 (=9x11) that is, M=9 and N=11. The value of V_{IJ} for each mesh block is the necessary input data into Linear Programming Package.

3-3-2 Earth Transportation Model

To makes an earth transportation planning, we redeveloped earth transportation model based on Linear Programming method for earth transportation problem. The objective function of this model is to minimize the cost of earth transportation from cutting blocks to banking blocks. In this model, it is assumed that the cost coefficient is depend upon the transportation distance. The structure of this model is described in the later part of this section.

Firstly, we simulates the activity (work) of earth transportaion from cutting block to banking block, including required type of machinery as shown by Figure 7 below.

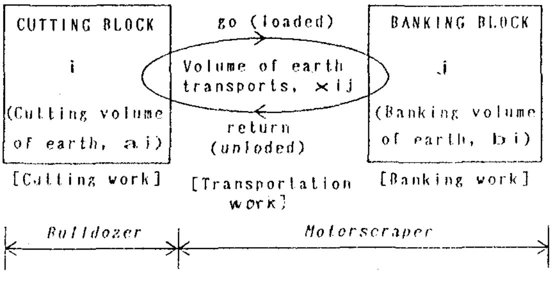

Figure 7 Simulation on earth transportation work

By considering of this figure, the subjective conditions (i.e. constraints) for this model are given by Equation 6 below.

$$\left.\begin{aligned} &\sum_{j=1}^{n} x_{ij} = a_i \quad \text{and} \quad \sum_{i=1}^{m} x_{ij} = b_j \\ &\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} = \sum_{j=1}^{n} a_i = \sum_{i=1}^{m} b_j \\ &x_{ij} \geqq 0, \quad i \in B_c, \quad j \in B_b \end{aligned}\right\} \quad \ldots (6)$$

Where x_{ij} = volume of earth transports from cutting block i to banking block j, which i=1,2,..m and j=1,2,..n.
a_i=volume of earth in each cutting block i.
b_j=volume of earth in each banking block j.
B_c=a set of cutting blocks.
B_b=a set of banking blocks.

The objective function of the model is to minimize transportation cost, Z, as given by Equation (7) below.

$$Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij} \longrightarrow \text{min.} \quad \ldots\ldots (7)$$

Where c_{ij} = a cost coefficient, assumed depend upon the distance of transportation, d_{ij}.
d_{ij} = transportation distance, taken from centroid of cutting block i to centroid of banking block j.

For computation purposes, c_{ij} is taken as unit cost equal to 1/m-distance/m³-volume. It is very difficult to set the actual value of cost coefficient, c_{ij}, since the unit cost of earth transportation in the actual construction field is changes due to time and transportation market situation. So, for the application of this model to the actual earth transportation problem, value of unit cost at that time is input into the computation program to obtain the actual value of Z in unit money.

3-3-3 A feasible earth transportation planning

In this paper, we didn't use the word of 'optimal' instead of 'feasible' for the reason of very difficult to obtain the optimal solution when related to the planning problems for the actual construction field.

The computer program used for computation of the feasible earth transportation planning is Linear Programming (LP) Package. But, to input data to the package's program, we made a program for it to suits a large amount of datas obtained

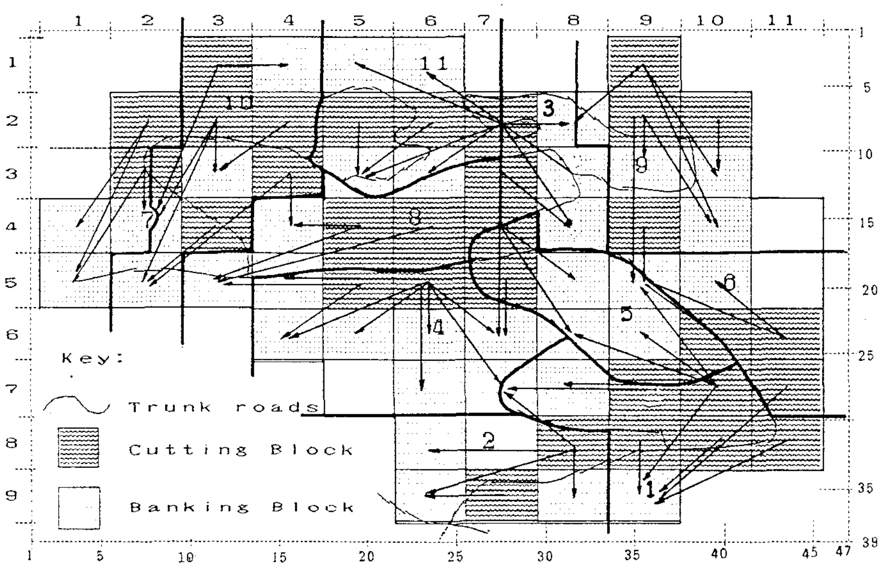

Figure 8 Earth transportation routes and CB divisions

from Section 3-1-2. From the computation result, we made an earth transportation diagram as shown by Figure 8 on Page 6.

3-4 Rearrangement of CB to obtains final shape of CB

The planning process in rearrangement of CB in a way to obtains the final shape of CB can be structuralized as below.

Step 1 : Checks on the early determined CB's shape to finds of;
- (1) earth transportation routes which crossed the boundary lines of CB,
- (2) the position of mesh blocks which lies on the boundary lines of CB,
- (3) the position of boundary lines of CB which are not lies on the trunk roads and semi-trunk roads.

Step 2 : Realigns the position of boundary lines of CB subjects on the priorities that;
- (1) to minimize the routes that crossed the boundary lines of CB,
- (2) not to changes the position of CB's boundary lines that lies on the trunk roads and semi-trunk roads,
- (3) to maintains the area of CB as close to the early determined CB's area.

Form the process's works we can determine the new shape of CB, as example for Nazio New Town Project is shown by Figure 8.

4 PLANNING PROCESS IN STAGE 2

The process for making of works planning (including network design) and scheduling in each CB is illustrated by Figure 9. The work items for earth-moving and other infrastructure construction works such as roads, water supply, drainages, etc are correlates together.

In this figure, it stated that the process of combining of earth transportation routes as work activities for each CB, but the schedule of execution of each activity must be structuralized in stagewise schedule to solve of some difficulties (problem) in the actual transportation work. The problem is to transport of earth form one cutting block to other banking block through valley area although the transportation route shown on plan is a straight line route. The problem simulation is shown by Figure 10.

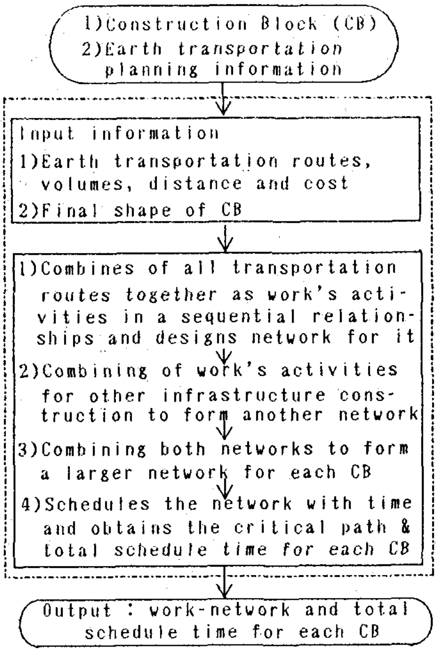

Figure 9 Planning process flow in Stage 2

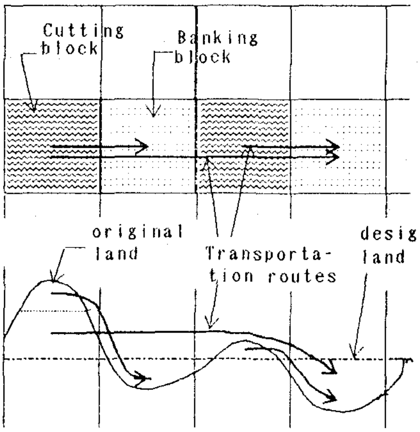

Figure 10 Simulation on transportation problem through hill-and-valley

By analyzing the distances and shapes of transportation routes shown by Figure 8, there are nine kinds of route's shape and distance shown by Table 1 on Page 8. Then, the schedule for works execution can be divides into three stages of time, t_1, t_2, and t_3 based on routes' distance as below.

In t_1, distance, d_{ij} is for d_1, d_2.
t_2, distance, d_{ij} is for d_3, d_4.

Table 1

Route No	Shape of route	Distance (m)
d1	→	200
d2	↗	$200\sqrt{2}$ (=282.8)
d3	→	400
d4	↗	$200\sqrt{5}$ (=447.2)
d5	↗	$400\sqrt{2}$ (=565.6)
d6	→	600
d7	↗	$200\sqrt{10}$ (=632.5)

t_3, distance d_{ij} is for d_5, d_6, d_7 This method of scheduling is subject to the case by case of construction project after examing the actual transportation routes and distances obtained from earth transportation planning.

By knowing of all work items in each CB, the work-network and network scheduling can be done wby utilizing of available scheduling techniques such as CPM, PERT, RAMPS and so on.

5 PLANNING PROCESS IN STAGE 3

The planning process flow for this stage is illustrated by Figure 11. One method that we want to introduced in this process stage is a method to obtain an feasible job sequence (i.e. for all CBs) amount of useful resources in the project is given. The problem formulation is described below.

Let λ is the completion time of the project. This λ is a function of only the job sequence X_p when all the duration time of each job are given. Furthermore, since X_o which composes X_p is predetermined and constant, λ becomes a function of only the set of resource sequences $X_1, X_2, \ldots, X_r$. Then we may set

$$\lambda = \lambda(X_1, X_2, \ldots, X_r).$$

Since the objective function of this problem is defined as the above equation, the problem to find the feasible resource sequence is formulated as follows:
Minimize

$$\lambda = \lambda(X_1, X_2, \ldots, X_r) \qquad \ldots (8)$$

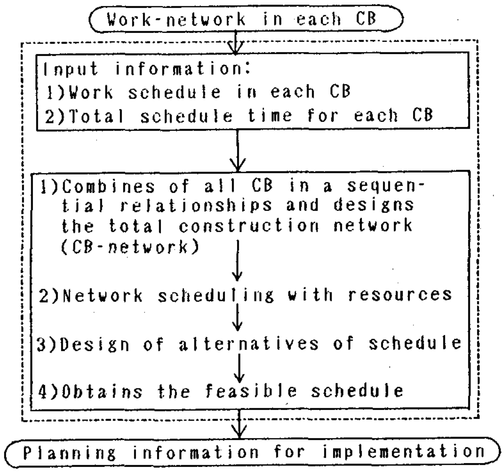

Figure 11 Planning process in stage 3

subjected to

$$\left.\begin{array}{l} \sum_{i=1}^{N} x^k_{ij} \leqq 1, \\ \sum_{j=1}^{N} x^k_{ij} \leqq 1, \\ L(X_p) = L(X)_k = 0 \\ \sum_{j=1}^{N}\sum_{i=1}^{N} x^k_{ij} = n_k - q_k \\ k = 1, 2, \ldots, r \end{array}\right\} \cdot (9)$$

where k=type of resources
kij=resource sequence for resource k between job i and j
k=number of competitive job
k=amount of resource k

The application of this scheduling method is in making of sequential schedule for all CB in total construction level.

6. CONCLUSION

From the result of process of planning carried in the above, we can concluded that it is a kind of systematic approach of planning of infrastructure construction for a new town project. We have shown a stage-wise approach of making of planning, with an inclusion of some planning model and utilization of data of the actual construction work as case study. But, there are less examples and application of planning model and method in the Stage 2 and Stage 3, because of lack of information on actual construction works related to these stages of planning process.