PROPOSED LOGIC SEQUENCE FOR DESIGNING PRELIMINARY URBAN LAND USE PLANS

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A formulated design concept is presented, and its potential role in the preparation and evaluation of alternative preliminary land use plans is described. The concept fundamentally aggregates a system of required land use activity space-time contents into subsets subject to certain design constraints. A second generation computer program that utilizes the aggregation concept is described. The 2 major components of the program are an activity subset formation routine and an activity location routine. The activity subset formation routine aggregates the activity into subsets subject to their participation order, duration times, and interactivity compatibility relations. The routine also generates the trip-time frequency distributions. The activity location routine places the required activity land use spaces into a location matrix subject to the transport ranges and the interactivity and activity-to-existing-environment compatibility relations. A priority is placed on filling existing vacant land use spaces before creating new space. The activity location routine plots a graphical representation that identifies the types and locations of the land uses and the transport links. The routine determines the amount of land use space to be supplied and the amount of excessive space supplied. An example output from an experiment using a 400-household schedule is illustrated.

• A SECOND generation logic sequence is described for heuristically allocating urban structural space as a function of the population's daily or weekly physical activity patterns. The description is preceded by a brief review of the formulated design concept. The theoretical background of the concept and first generation logic sequence is described in other reports (1, 2). The concept involves the aggregation of a system of activities as represented by their required space-time contents into subsets subject to certain land use and transport constraints. The logic sequence attempts to utilize the concept for the purpose of aiding in the preliminary synthesis of urban structural space.

The synthesis of urban space basically consists of the determination of the number, sizes, and locational arrangement of the various types of user spaces to be supplied based on the forecast spatial requirements of the particular population. The objectives of the concept and logic sequence as design aids are to (a) translate the forecast system of spatial requirements into a graphical representation in accordance with a set of design standards; (b) provide units of measurements that have the potential for being extended for the purpose of evaluating the plan; (c) create alternative plans by the exogenous adjustment of any of the determinants; and (d) reduce the number of alternative plans to a number that can be analyzed and subsequently synthesized in greater detail by more exact methods.

The logic sequence and its associated computer program are composed of an activity subset formation routine and an activity location routine. The activity subset formation routine attempts to maximize the temporal utilization of space by aggregating the activities into subsets subject to their participation order, duration times, and interactivity compatibility relations. The routine also generates the trip time frequency distributions.

The activity location routine attempts to maximize the utilization space by placing the required activity land use spaces into a location matrix subject to the transport ranges and the interactivity and activity-to-existing-environment compatibility relations. A priority is placed on fitting the existing vacant structural space before creating a new one. The routine output is a graphical representation of the structure including the transport links and the amount of structural space created and the excess amount supplied.

A number of formulated models have been developed for spatially allocating urban activities and their associated spaces. The major deficiencies of these models are that (a) they appear to be unduly influenced by the historical and contemporary form of the urban structure for synthesizing and, therefore, inhibit the study of the introduction of innovations in transport and building technology; and (b) at best they only indirectly recognize that activities are undertaken for short intervals of time during a time period. Greater temporal and spatial utilization of public structural spaces such as transport might be achieved by regrouping the activities, resizing their space requirements, or rearranging their locations or doing all of these.

BRIEF DESCRIPTION OF THE DESIGN CONCEPT

The urban phenomenon for the purpose of design is viewed as a physical instrument evolved by man by which he attempts to more efficiently satisfy his own self-perceived individual and collective psychological and biological needs. These needs are a manifestation of his voluntary and involuntary interaction with an imperfect environment.

The man-environment interaction is operationally conceptualized as a system of human physical activities. The system of activities is engaged in during a period of time. Each activity is associated with an individual and requires a known amount of space and time in order to be undertaken successfully. Structural space is to be supplied and maintained for each activity for the time period that the system of activities is undertaken.

Resources are expended, supplying and maintaining structural space. If it is assumed that the total amount of resources available to the population at any point in time is limited, then that which is expended to create and maintain structural space cannot be used for participating in the activities for which the space is supplied.

Resources are misallocated if the amount of structural space supplied or the amount of time that the space supplied for each activity or both of these are in excess of that required. An excessive amount of space is supplied if the activities are spatially and temporally undertaken independently of each other and if the minimum amount of space supplied and the minimum amount of time that the space is available are greater than that required by each individual to engage in the activity successfully.

The degree to which the structural space is utilized is assumed to be capable of being expressed as the total sum of the difference between the product of the amount of structural space supplied and the amount of time it is supplied and the product of the amount of space required and the amount of time it is required by an activity or a system of activities. The difference is termed the wasted space-time content. Wasted space-time content is an indication of the operational efficiency or performance of the urban structure. The urban structure is inefficient if it is high and efficient if it is low.

The objective is to maximize the utilization of the structural space by minimizing the total amount of wasted space-time content. The total amount of wasted supplied space-time content can be reduced if the total amount of supplied space-time content is decreased. The total amount of supplied space-time content can be decreased if the activities and their associated required space-time contents are grouped or formed into subsets at any point in time or space, i.e., minimize W, where W is the total amount of wasted space-time content supplied and where

$$W = N \times f_k \times T - \sum_{k=1}^{N} \left\{ \sum_{(a_i) \epsilon k} \left[x_{(a_i)} k \right] \left[\phi_{(a_i)} \; \tau_{(a_i^{\ell})} \right] \right\}$$

where (a_i) is a finite, discrete, and unique activity, such as manufacturing, shopping, or household, that is associated with a particular individual j, exhibits scalar characteristics of a certain magnitude, and has meaning in space allocation. Each activity is composed of an elementary transport activity (a_i^t) and an elementary land use activity (a_i^ℓ); i.e., $(a_i) = [(a_i^t), (a_i^\ell)]$. Also, in $(a_i) \epsilon U$, U is the universal set of activities undertaken by the urban population composed of Q number of people such that $U = [(a_1), (a_2), (a_3), \ldots, (a_H)]$ and $H = \sum_i (a_i)$, the total number of activities undertaken, where i = 1, 2, 3, . . ., H.

Also, $H >> Q$ and therefore $Q = \sum_i s_j$, where j = 1, 2, 3, . . ., Q and where s_j is the particular schedule of activities of individual j such that $s_j = [(a_1), (a_2), (a_3), \ldots, (a_g), (a_i), \ldots, (a_p)]$, where $(a_1) \rightarrow (a_2) \rightarrow (a_3), \ldots, \rightarrow (a_g) \rightarrow (a_i), \ldots, \rightarrow (a_p)$ and $(a_i^t) \rightarrow (a_i^\ell)$. The urban-wide activity schedule $S = (s_1, s_2, s_3, \ldots, s_j, \ldots, s_Q)$, which for purposes of design is engaged in a cylical or repetitive manner.

$\tau_{(a_i^\ell)}$ is the finite, discrete, and unique amount of time required by individual j in order to engage in the elementary land use activity (a_i^ℓ) and $\tau_{(a_i^\ell)} \epsilon \tau_{(a_i)}$, where $\tau_{(a_i)} = \tau_{(a_i^t)} + \tau_{(a_i^\ell)}$, where $\tau_{(a_i)}$ and $\tau_{(a_i^t)}$ are respectively the finite, discrete, and unique amounts of time required by individual j in order to engage in the activity (a_i) and the elementary transport activity (a_i^t).

$\phi_{(a_i)}$ is the finite, discrete, and unique amount of space in the form of a horizontal square area required by individual j in order to engage in the activity (a_i). The area is determined by summing all of the area requirements of the lower orders of activities and expressing the total as an equivalent amount of ground space. Also, $\phi_{(a_i)} = \phi_{(a_i^t)} + \phi_{(a_i^\ell)}$, where $\phi_{(a_i^t)}$ and $\phi_{(a_i^\ell)}$ are respectively the amounts of space required to engage in the elementary activities (a_i^t) and (a_i^ℓ). The amount of transport space $\phi_{(a_i^t)}$ is defined as that required for immediate access and $\Phi = \sum_{i=1}^{H} \phi_{(a_i)}$, where Φ is the total amount of space required by the population Q to engage in the system of activities. The remainder of the transport space required is defined as a straight line representing the transport range or distance of the elementary transport activity, $d_{(a_i^t)} = v_{(a_i^t)} \times \tau_{(a_i^t)}$, where $v_{(a_i^t)}$ is the average straight-line velocity of the elementary transport activity (a_i^t).

k is a finite and discrete object called an urban activity subset, such as industry, retail, or neighborhood, that is composed of one or more activities; i.e., $k = \sum_{(a_i) \epsilon k} (a_i)$ and $k \epsilon \Omega$, where Ω is the family of subsets such that $\Omega = (k_1, k_2, k_3, \ldots, k_N)$.

f_k is the finite and discrete amount of structural space supplied for the land use activity subset k and $f_k \geq \phi_{(a_i)}$ at each and every point in time. It is defined for computational simplicity as being square in shape and of a constant area regardless of the type or class of urban activity for which it is being supplied. The amount of transport range supplied, D_{Jk}, is a finite and discrete straight line in the form of a single path or roadway or a subsystem of connected paths joining the centroids of 2 supplied land use structural spaces f_J and f_k, where $(a_g) \epsilon J$ and $(a_i) \epsilon k$. Also, $d_{(a_i^t)} = D_{Jk}$ at each and every point in time, where lower limit ≤ upper limit. Stated otherwise, the supplied land use spaces f_J and f_k must be located spatially relative to each other such that the elementary transport ranges $d_{(a_i^t)}$ are equal to the centroidal distance D_{Jk} within prescribed tolerances.

T is a finite and discrete amount of time, such as a day or a week, that the structural space f_k is supplied for activity subset k. The urban-wide schedule of activities S and each of the individual schedules s_j are undertaken during the time period such that $T = \sum_{(a_i) \epsilon s_j} \tau_{(a_i)}$, $Q_T = \sum_{i=1}^{H} \tau_{(a_i)}$, and $T \geq t_{(a_i)}$ at each and every point in space.

$x_{(a_i)k}$ is the complementary relation between (a_i) and k, where $x_{(a_i)k} = 1$ when (a_i) is compatible with k, and $x_{(a_i)k} = 0$ when (a_i) is not compatible with k.

The relation encompasses those characteristics that are primarily of a subjective nature. A home-living activity, for example, is complementary to a neighborhood or a residential area but not complementary to a commercial or industrial area regardless of the spatial or temporal compatibilities. The relation can also express locational constraints or attributes other than transport range such as existing structural investments, higher priority design commitments of a prescriptive nature, or amenable physiological land features. The relation has precedence and is capable of being expanded such that $x_{(a_1)k} = [x'_{(a_1)k}] \times [x''_{(a_1)k}] \times [x'''_{(a_1)k}]$, and so on, where $x_{(a_1)k} = 1$, when and only when $[x'_{(a_1)k}]$, $[x''_{(a_1)k}]$, and $[x'''_{(a_1)k}]$ are each equal to unity where each is a requirement that must be satisfied before (a_1) and its associated space-time content $\phi_{(a_1)} \times \tau_{(a_1)}$ can be assigned to activity subset k and its associated space-time content $f_k T$.

N is the number of activity subsets (k), the number of subsets of required space-time contents $\left\{\left[\sum_{(a_1)\epsilon k} (\phi_{(a_1)} \cdot \tau_{(a_1^{\ell})}\right]_k\right\}$, the number of structural space-time contents supplied $(f_k \times T)$ and the number of structural spaces supplied (f_k).

If it is assumed that f_k, T, $x_{(a_1)k}$, $\phi_{(a_1)}$, and $\tau_{(a_1^{\ell})}$ are given and remain invariant and that $f_k \geq \phi_{(a_1)}$ and $T \geq \tau_{(a_1^{\ell})}$ and are the minimum and maximum amounts, then the total amount of wasted space-time content W assumes its minimum value when the number of supplied structural spaces N reaches its minimum value subject to the following:

1. S (and, therefore, H and Q) are given;
2. $T = \sum_{(a_1)\epsilon S_j} [\tau_{(a_1^t)} + \tau_{(a_1^{\ell})}]$;
3. $x_{(a_1)k} = 1$ or 0;
4. $T \geq \sum_{(a_1)\epsilon k} \tau_{(a_1)}$ at each and every point in space;
5. $f_k \geq \sum_{(a_1)\epsilon k} \phi_{(a_1)}$ at each and every point in time; and
6. $d_{(a_1^t)} \approx D_{Jk}$, where $v_{(a_1^t)}$ and $\tau_{(a_1^t)}$ are given and all remain invariant and are satisfied.

LOGIC SEQUENCE AND COMPUTER PROGRAM

The operational objective of the design function is as follows: Given a set of structural space-time contents of an invariant and constant shape and size, determine the minimum number that must be supplied by assigning the maximum number of invariant required space-time contents to each structural space, subject to a set of constraints. The problem thus falls within the general classification of an assignment problem. It is a member of a particular group that is highly combinatoric in nature.

The problem in many respects is analogous to that of assembly-line balancing (3, 4, 5) and the relative location of facilities (6). It is essentially a combination of the two. Characteristically, at this point in time it is not computationally practical to enumerate the number of potential combinations of required space-time contents because the number is so great. This stems from the fact that there are potentially a large number and variety of individual schedules and spatial locations. Just how many types of individual schedules there are that would influence space allocation is not known. There may be fewer types because of man's socioeconomic interdependency and the natural environment's control over his psychobiological mechanism.

The potential number of combinations is also dependent on the degree of detail wanted. The restrictions of order, range, shape and size of structural space, and land use activity time and compatibility reduce the number of potential combinations. The only feasible method of solving the formulation appears to be with a heuristic routine. The routine contained in the logic sequence is a second generation routine. It is an attempt to improve on the operational efficiency of the first one developed (1). The major differences between the 2 models are that the second one has been restructured such that the heuristic routine is subdivided into 2 routines and the compatibility index is expanded. The major results of the modifications are that program accessibility is improved, the execution time is reduced, and the model is more comprehensive.

The program is composed of 8 major components: raw data file, primary setting up routine (SETUP I), primary input file, design criteria file, activity subset formation routine (SUBFOR), secondary setting up routine (SETUP II), secondary input file, and activity location routine (ACTLOC). The procedure by which the components are utilized is shown in Figure 1. Two assumptions are made in order to simplify the description; (a) Only one mode of transport is considered, and (b) the trips are all home-based.

Raw Data File

The raw data file is composed of information that describes the urban-wide schedule of activity participation. It is assumed to be representative of the activities undertaken by the population during a finite and discrete design time period, such as a day or a week, and is invariant. The information would be generated from trend studies of longitudinal transportation origin-destination home-interview data if the plan is designed for some future horizon year.

The information in the file is structured in the form of family or individual schedules or both. Each schedule is described in the following manner: family or household identity number, identity number of the individual schedule, identity number of the land use activities engaged in by the individual, order of activity participation, and elementary transport and land use activity times.

The activities must be identified and described by the use of a classification system that accounts for various qualitative and quantitative activity requirements for space. For example, an activity described simply as work is not sufficient. It is necessary to describe the kind of work involved, such as retailing or manufacturing.

SETUP I

The primary setting up routine, SETUP I, draws a portion of the information contained in the raw data file and deposits it in the primary input file. The routine transfers the family and individual identity numbers. The identity of each activity in each individual schedule is transferred and is assigned a unique identity number. The preceding activity engaged within each schedule is identified, and its unique number is placed in the primary input file. The procedure continues until all of the activities in the raw data file have been transferred.

The routine scans the raw data file and identifies the smallest elementary activity time (land use or transport). This value becomes the smallest interval of time. The elementary activity times are extracted from the raw data file, normalized, and rounded off to the nearest whole interval of time and deposited in the primary input file. When all of the elementary activity times have been transferred, the normalized times of each individual schedule are checked and, if necessary, adjusted to ensure that they sum to the time period. The start time of each elementary land use activity is determined and entered in a separate column of the primary input file.

Primary Input File

The file is composed of a number of rows; each row represents an activity undertaken by an individual. Each activity is described with the following information:

Information	Column
Identity number of the family or household	1
Identity number of the individual schedule	2
Land use activity identity number	3
Unique identity number of the activity	4
Unique identity number of the preceding activity	5
Normalized elementary transport activity time	6
Normalized elementary land use activity time	7
Elementary land use activity start time	8

One or more rows of activities constitute an individual schedule. The number of rows is dependent on the number of activities engaged in by the individual during the time period. The activities are ordered in rows from top to bottom within each individual schedule in accordance with their participation order.

One or more sets of rows form a family schedule. The number of rows should equal the total number of activities undertaken by the population or its representatives during the time period. The identity of the family and individual schedules is necessary for it ensures that the household activities can be separated one from the other and that each family is supplied a unique structural space.

Design Criteria File

The design criteria file contains data that are capable of being manipulated by the designer in order to generate alternative plans. The information in the file is as follows: amount of land use space required by each type of activity, velocity of transport, and activity-to-activity and activity-to-existing-environment compatibility indexes.

The information is determined from trend studies. The amount of land use space required includes the following, in addition to the net space required: space for transport accessibility; space for demands that occur outside the time period under consideration; and space for lower order activities that are not considered overtly, such as space for playgrounds, primary schools, or churches for the household activity.

An average transport velocity is used initially. Various velocities representing either different modal or different linkage characteristics can be used for finer adjustments of the land use plan. The modes to be used and their potential operating velocities would have to be determined.

The activity-to-activity and the activity-to-existing-environment compatibility indexes are a function of many factors that are very imperfectly understood. This aspect of the design is as a consequence of a subjective nature. The role of the indexes from a design point of view is that they provide the planner with an opportunity to readily test various mixes of activities and generally retain control of the program.

Land Use Activity Subset Formation Routine (SUBFOR)

The purposes of the routine are to determine the minimum feasible amount of structural space to be supplied and the approximate size of the structural land use subset to be supplied.

Because each and every land use activity is to be supplied structural space, then the minimum feasible amount of structural space to be supplied is equivalent to the minimum amount of space required. The amount of structural space is termed the minimum feasible because it is determined exclusive of the constraints of transport range, existing investment, and physiological characteristics of the land.

The routine determines the minimum amount of space required in the following manner.

1. The routine extracts the household-to-household land use activity subset compatibility index from the design criteria file and by scanning columns 1 and 3 of the primary input file accumulates the number of household activities undertaken subject to each family or individual being engaged in a household activity once and only once during the time period. This number is stored by the routine.

2. The routine then extracts the first nonhousehold-to-nonhousehold subset compatibility index from the design criteria file and by starting at time 0 of the time period scans columns 3 and 8 of the primary input file to determine the number of participants in the activity subset at each interval of time. The maximum number of participants engaged in the activity subset at any single interval of time is identified and stored by the routine. The procedure is repeated for each compatible nonhousehold activity subset until all of the activities in the primary input file have been assigned.

3. The routine then totals the peak numbers of participants engaged in each nonhousehold activity subset and in turn adds this to the number of household activities determined in step 1. The value determined is the minimum feasible number of land use subset spaces required by the population. The minimum amount of space required is determined by successively multiplying the peak number of participants engaged in each activity subset by the appropriate unit amount of land use space required from the design criteria file and then totaling the products. The minimum feasible amount of

wasted space-time content is determined by summing the products of the amounts of structural spaces for each activity subset and the differences between the values of the time period and the average activity time required by the participants in order to engage in each activity subset.

The routine determines the approximate size of the structural land use subset to be supplied in the following manner.

1. The routine draws the first nonhousehold-to-nonhousehold compatibility index from the design criteria file and by beginning with the lowest trip-time interval scans columns 3 and 6 of the primary input file and determines the total number undertaken during the time period. The procedure is repeated for each successively larger interval of trip time until all of the elementary transport activities of the subset have been aggregated. The procedure is then repeated for every other nonhousehold activity subset, and the results within the routine are recorded.
2. The routine next identifies the land use activity subset associated with a particular interval of trip time that has the smallest number of participants. The routine extracts this number and divides it into the total number of household activities engaged in and the total number of each nonhousehold activities of each trip-time duration engaged in. When the normalizing is complete, the individual number of participants in each trip-time subset is rounded off to the nearest integer.
3. The routine determines the minimum structural land use subset to be supplied by extracting the amount of space required for each household from the design criteria file and multiplying it by the number of households in a subset determined above. The maximum holding capacity of the nonhousehold subsets can be determined by dividing the size of the supplied structural subset by the appropriate amount of space required contained in the design criteria file.
4. The maximum size of structural subset is determined by extracting the transport velocity from the design criteria file and multiplying it by the smallest interval of trip time. Should this value be smaller than the value determined in step 3, then the alternatives to rectifying the situation are (a) to decrease the amount of elementary land use space required, (b) to increase the velocity of transport, or (c) to arbitrarily reduce the subset size and rework the trip-time frequency distributions and the maximum holding capacities, or (d) to do all of these.

SETUP II

The secondary setting up routine creates the location matrix by (a) extracting the minimum feasible amount of space required from SUBFOR and increasing the amount by a factor of 2 to 5 to take into account the space that will be wasted, (b) extracting the subset size from SUBFOR and creating a grid (cells), (c) determining the location of the cell centroids and numbers the cells in order starting at the center cell and spiraling outward, and (d) utilizing a plotter routine to present a graphical output.

The existing investment to be retained and the physiological features of the land are exogenously mapped onto the location matrix. The degree to which each cell is compatible or incompatible with the various land use activities is determined. If the design problem is one of expanding an existing urban structure and the schedule is representative of the anticipated population increase, then the degree to which the existing structure is capable of being utilized more completely is determined. The minimum feasible amount of space required in the expansion problem is the sum of the amount of existing structural space being utilized and will be retained and the minimum feasible amount of space required by the additional population. When all of the cells have been classified and the holding capacities of the existing investment have been determined, the information is placed into the secondary input file.

Secondary Input File

The secondary input file is the location matrix. Associated with the file is a plotter routine that will present a graphical output after the activities have been transferred from the subset formation routine by the activity location routine.

Figure 1. Program procedure.

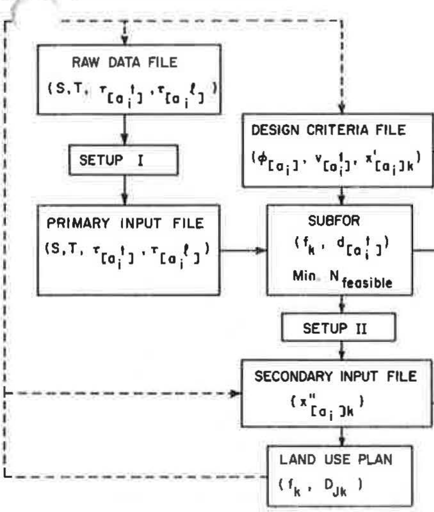


Figure 3. Example land use plan.

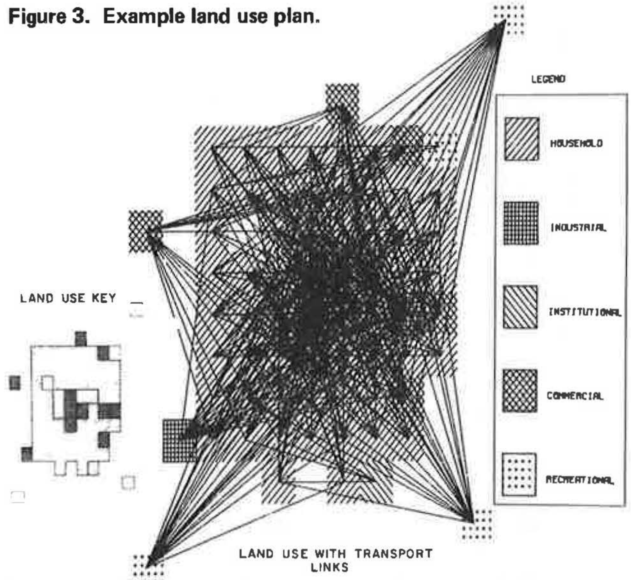
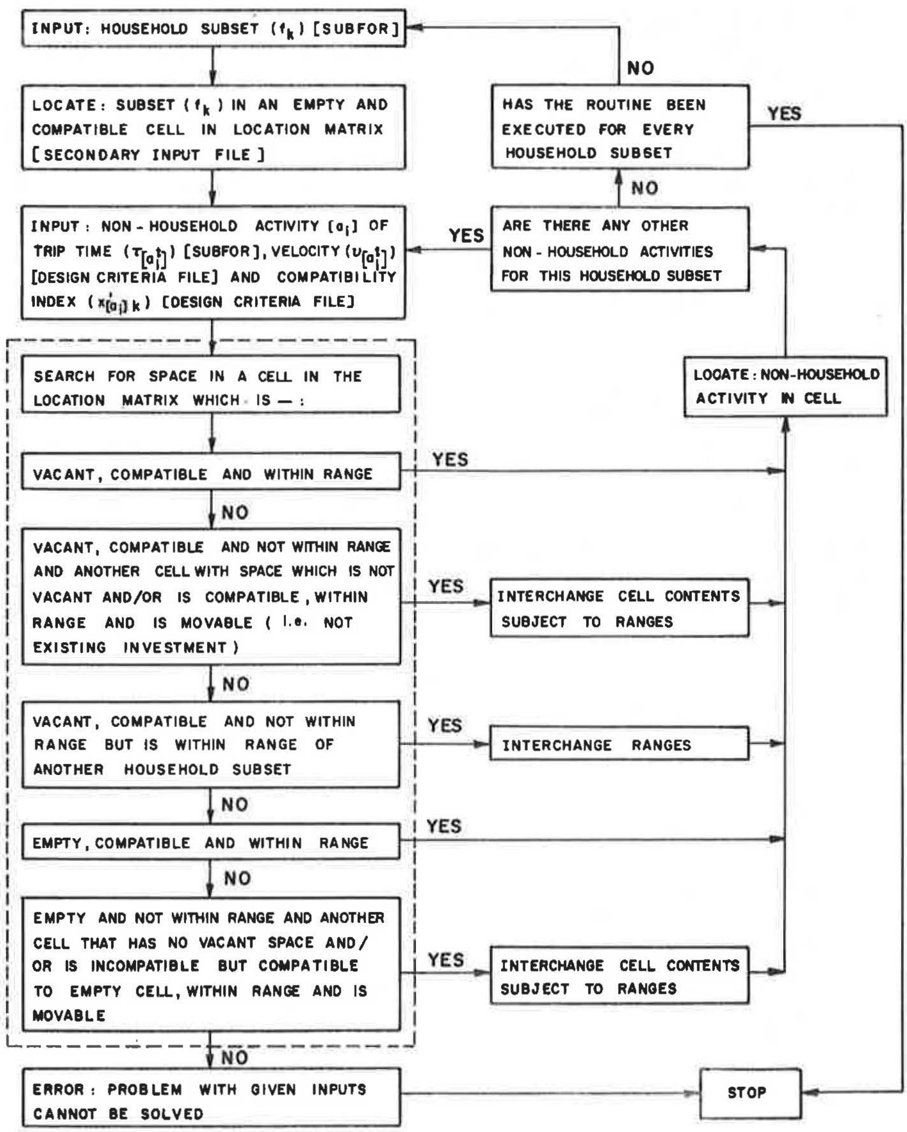


Figure 2. Flow diagram for ACTLOC routine.



Activity Location Routine (ACTLOC)

The main-line program, ACTLOC, is a heuristic routine. The objective of the routine is to locate the elementary nonhousehold land use activities in subsets such that the number of nonhousehold subsets is minimized subject to the transport ranges and the activity-to-activity and activity-to-existing-environment compatibility relations being satisfied and each and every activity being supplied a structural space.

The routine extracts the land use activities from the activity subset formation routine, combines them with the amount of space required from the design criteria file, and then attempts to place them in the location matrix. This is done subject to the range constraint (which is determined by extracting the elementary transport times from the activity subset formation routine and by combining them with the transport velocity contained in the design criteria file) and the compatibility relations. The routine attempts to minimize the amount of structural space to be supplied by placing a priority of filling vacant structural spaces before creating additional ones. The routine is shown in greater detail in Figure 2.

When all of the activities have been transferred to the location matrix, the routine plots a graphical representation and calculates the amount of structural space, the amount of wasted structural space-time content, and the trip-time distributions for each household subset. (The number of trips per household subset remains invariant.) The graphical representation is the land use plan. The plan also shows the transport links supplied. Figure 3 shows an example of a land use plan created from a 400-household urban schedule.

If the output is unsatisfactory, there are a number of exogenous decisions that can be made in order to achieve a more satisfactory one. Some of the more readily applied decisions are modify or use a variable transport velocity, change the compatibility relations, adjust the space requirements (density) of the activities, and modify the subset size.

DISCUSSION OF CONCEPT

Experimental work is under way in an attempt to improve the operational characteristics of the computer program. Additional locational determinants are being incorporated in an attempt to improve its synthetic characteristics. A transport activity subset formation routine is being developed in order that the transport network can be more explicitly synthesized.

A larger schedule of daily activities has been created from a home-interview study. The larger schedule will provide an opportunity for a more complete evaluation of the concept and the logic sequence. Particular aspects that will be investigated are the influence of the various determinants and simplifying assumptions and the use of a heuristic routine as a method of assignment. Sensitivity tests are planned to determine the influence of the precedence relations, compatibility relations (activity classification), density, activity times, subset size, and transport velocity.

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