APPENDIX D

Documentation of the Lowry Model

HIGHWAY LAND-USE FORECASTING MODEL

REFERENCE MANUAL

Alan J. Horowitz

Center for Urban Transportation Studies
University of Wisconsin -- Milwaukee

July 31, 1985
NOTICE

The software described in this manual and the manual itself are made available without warranties, either expressed or implied, with respect to their quality, performance, merchantability, or fitness for any particular purpose. This software and manual are made available "as is." In no event will the University of Wisconsin or its employees be liable for direct, indirect, incidental, or consequential damages resulting from any defect in the software or manual.

Portions of this program were compiled with TASC by Microsoft, Inc.

HLFM contains a high-speed operating system called Diversi-DOS (tm), which is licensed for use with HLFM only. To legally use Diversi-DOS with other programs, you may send $30 directly to: DSR Inc., 5848 Crampton Ct., Rockford, IL 61111. You will receive a Diversi-DOS utility disk with documentation.

ACKNOWLEDGEMENTS

The Highway Land-Use Forecasting Model was developed under a contract with the Wisconsin Department of Transportation. The contract was administered through the Transportation Policy Studies Institute of the University of Wisconsin -- Extension.
# TABLE OF CONTENTS

## INTRODUCTION

1. 1

- Using HLFM
- System Requirements
- Getting Started
- If You Have Questions

## OPERATING THE HIGHWAY LAND-USE FORECASTING MODEL

2. 1

- The Grand Tour
- Using the Sketch Pad
- Entering a Small Network
- Saving a Network
- Using the Work Sheets
- The Five Function Calculator
- Maintaining Data Files
- Keyboard Macros
- Printer Utilities
- Install Feature
- Play Time
- What's Missing

## DEVELOPING NETWORKS FOR THE HIGHWAY LAND-USE FORECASTING MODEL

3. 1

- Network Nodes, Centroids and Links
- Determining Automobile Times
- Zonal Centroid Data
- Whole Urban Area Data
- Meanings of Parameters
- Brute Force Calibration and Sensitivity Analysis

## INSIDE THE HIGHWAY LAND-USE FORECASTING MODEL

4. 1

- Garin Version of the Lowry Model
- Trip Distribution
- Adjustments to Residential Attractiveness
- Adjustments to Service Attractiveness
- Traffic Assignment
- Other Computational Considerations
- For Further Reading
CHAPTER 1
INTRODUCTION

Welcome to the Highway Land-Use Forecasting Model. This program is designed to help you identify the likely developmental impacts on small urban areas owing to improvements in the highway system. HLFM draws its steps from traditional traffic theory and from urban economic theory. If you are already familiar with land-use and traffic forecasting, then you should find HLFM exceptionally easy to use. However, if land-use forecasting is new to you, then you should pay particular attention to this manual. In it you will find everything you need to know for generating a high quality forecast.

Land-use forecasting is not predicting the future. No one, even with the most powerful computer, can do that. All HLFM can do is to take available data and interpret it in a manner that shows the magnitude and location of impacts on population and employment, if almost everything else remains the same. We can only make transportation and urban development decisions on the basis of facts at hand. HLFM is a tool for improving those decisions.

HLFM produces a very long-term forecast. It tells us where city development is ultimately heading. Obviously, unanticipated events or attempts at mitigating impacts can redirect development along some other path. But, HLFM will let us know what is going to happen if nothing interferes with existing transportation and development processes. Because HLFM reveals fundamental trends, it can be used for medium-range planning, too.

Although HLFM runs on a small microcomputer, it is a sophisticated model. HLFM will produce very useful information if good common sense is exercised, and if care is taken when preparing the data and when performing the necessary calibration step.

Using HLFM

As you follow through the example problems, you will see that HLFM wants specific information from you. It is best to first assume that everything HLFM wants is necessary. As you become more familiar with land-use forecasting in your own city, you may be able to take shortcuts.

If you can remember when using a computer meant hours of coding and keypunching, you will find HLFM a pleasure. HLFM
capitalizes on those features of the Apple II+/e/c that help remove the pain of giving the computer information. HLFM is made up of a sketch pad; on it, the highways being considered and their surrounding areas are drawn. In addition, several work sheets prompt you for required information; they then do the necessary calculations. Chapter 2 will show you how to use the various features of HLFM, and Chapter 3 talks about how HLFM can be used to analyze highway impacts. Chapter 4 explains the inner workings of HLFM. Although some of the discussion in Chapter 4 is highly technical, you are encouraged to read it -- so that you won't consider HLFM a mysterious black box.

**System Requirements**

To run HLFM you will need, at the minimum, an Apple II+/e/c with one disk drive. An Apple II+ requires a 16K RAM board. Drawing the network on the sketch pad is facilitated if game paddles or a mouse are installed. A joystick will do the same thing, but control is less precise. A color monitor (or a color television with an RF modulator) will make the sketch pad both more convenient and more enjoyable to look at over long periods of time. If a printer with dot addressable graphics (for example, the Epson FX-80) and a Grappler (or similar) graphics interface are available, then HLFM will print pictures of the network. A second disk drive will permit more convenient storage of data. If you can equip your Apple IIe with an extended 80 column card, then HLFM can greatly decrease its need to retrieve information from disk.

If you plan to use the Apple II+/e/c for more than just HLFM, then you should read one of the many introductions to the BASIC language. You need not know how to program in BASIC to use HLFM, but a little knowledge of how the computer works will make the whole process less intimidating. By the way, HLFM is written in Applesoft BASIC, but many portions have been converted to machine language and cannot be easily modified. This manual only discusses the features of the Apple II+/e/c that are essential for running HLFM.

**Getting Started**

HLFM normally uses only the first disk drive that is installed on the Apple II+/e/c. If there are two disk drives, start by using the one that is marked "1". If there are more than two disk drives, you must make sure you use the first drive that connects to "slot 6". If the disk drives are not properly marked, then you can either ask someone who knows or try HLFM in all the drives -- only one will work properly. When inserting the disk make sure that the Apple II+/e/c is turned off; the switch is in the rear of the Apple II+/e/c near the left corner. Open the little door and insert the disk into the drive, with the
disk's label up and toward you. It should slide in with little force. If it shows some resistance, then check the drive for obstructions, such as another disk. After the disk is fully inserted, close the door. Turning the Apple II+/e/c on again will automatically load HLFM. When it is not in the computer, treat the disk with tender loving care. Always store it in the paper envelope. Don't "flex" it, "flop" it, expose it to magnetism or heat, or touch the brown surface.

After the Apple II+/e/c is switched on, the disk drive will run for a couple of seconds and the screen will display a title and a question about which part of HLFM you wish to access. Also listed is the default graphics input device (paddles, mouse, or keyboard). You can initiate HLFM with this graphics input device by hitting "H" and then <return>. The <return> button is a very important item. It tells HLFM to start processing the information that you have just typed on the screen. HLFM requires that the <return> button be pressed every time you have answered a question.

Entering "U" from this display will take you to a series of utilities for printing input data and results. They are discussed in Chapter 2. Entering "Q" will cause you to leave HLFM.

It is also possible to use a different graphics input device with HLFM, but HLFM must be properly reconfigured. Reconfiguration requires running programs that rewrite portions of HLFM. To do this, enter "M" (if you are converting to a mouse) or "P" (if you are converting to paddles) or "K" (if you are converting to keyboard). The disk drive will then run for about a minute, and HLFM will be restarted with the new option installed.

Once you have entered "H", a major portion of HLFM will be automatically loaded into the Apple II+/e/c. This process will take a few seconds. You will know that everything is working properly if the display shows a title and a very long question about previously created data files. At this point the computer is ready for you to start using HLFM.

It is a good idea to make a backup copy of the HLFM disk for yourself. To copy HLFM, use the program "COPYA", which is supplied on the "DOS 3.3 System Master" disk, or any other convenient disk copying utility.

If You Have Questions

If, after reading this manual, you still have questions about how HLFM operates or if you have problems getting HLFM to work properly, then you may get help by calling the Center for Urban Transportation Studies. Our phone number is (414)
963-5787. We are especially interested in hearing from you if you have used HLFM in a novel way or if you have suggestions on how HLFM can be improved.
CHAPTER 2

OPERATING THE
HIGHWAY LAND-USE FORECASTING MODEL

HLFM is interactive. That is, it asks you questions, and you answer them. Sometimes it asks for a number, other times it asks for permission to take certain action. HLFM generally needs to know many things, so it's best to familiarize yourself with the types of questions it will ask before you start to forecast land-use in your city. In the following pages, the various features of HLFM are described. By following the step-by-step instructions you will get a good hands-on feel of how the program operates.

The Grand Tour

You can see most of the inner workings of HLFM by loading a simple example called "FINCHBURG". Follow the instructions in the "Getting Started" section of Chapter 1. If you have done this properly you should see that HLFM is asking you to "Enter file name or 'N' for new network, ....". At this point HLFM allows you to do a variety of things. Right now, however, just enter a test network. Type "FINCHBURG" and hit the <return> button. If you make a mistake, HLFM will tell you so and let you try again. (FINCHBURG is on the "Master" disk that should now be in drive 1. If this copy of HLFM has been used by someone else, then the default data drive could have been reset to "D2". If so, change the default to "D1" by entering a "1" before entering the file name.)

The display soon shows the sketch pad and a small highway network. The network is made up of red squares, called nodes, and lines, called links. The links can be thought of as streets and the nodes can be thought of as intersections. The purpose of the sketch pad is to allow you to draw your highway network, add to it, and delete from it. Working the sketch pad requires moving the four arrows in the margins of the sketch pad so that they point to different places on the screen. The arrows are used to locate nodes, connect the nodes with links, and to perform other functions that will be described later. The arrows can be moved by using the keyboard, mouse or paddles. If you have previously selected the paddle option, then the top and bottom arrows can be moved by turning the "0" paddle. The right and left arrows can be moved by turning the "1" paddle. With the mouse option, the arrows will move in response to movement of the mouse across a flat surface.
Moving the arrows with the keyboard is less convenient but usually more precise. With the keyboard option, it is best to imagine that the arrows point to an invisible dot on the screen. If you want the invisible dot to rise, press the "I" key (or up-arrow key). Pressing the "M" (or down-arrow) will lower the invisible dot. Pressing the "J" (or left-arrow) and "K" (or right-arrow) will move the invisible dot left and right, respectively. Holding the "rept" key down while pressing these letters on the Apple II+ will cause the arrows to move faster. On the Apple IIe/c fast movement can be achieved by simply holding down the appropriate key. Try not to hit any other keys while moving the arrows. When the sketch pad is first displayed, each press of a letter will move the arrows a fixed distance on the screen, i.e. 4 "pixels". A pixel is the width of a link. Pressing any number from "1" to "9" or ":" will change that distance (from 1 to 10 "pixels"). Pressing the "0" key does nothing. You can point to any spot on the sketch pad by pressing these numbers and letters or arrows.

On the right hand side of the screen is a strip of symbols. These symbols represent the sketch pad menu. They allow you to connect nodes (the vertical line), add nodes (the square), print the sketch pad ("l"), shift and rotate the network ("2"), delete nodes and links ("D"), initiate a new network ("N"), or continue to the next step in HLFM ("C"). You will have a chance to modify FINCHBURG in a few minutes. For now, move the arrows so that they point to the "C". Press the button on paddle "1" or the mouse button or <return> if you are using the keyboard option. If you have trouble moving the arrows all the way to the right using the keys, try reducing the spacing by first pressing "1".

At this point the network is redrawn without the menu and three of the four arrows. The paddles are of no use here; HLFM expects you to enter data at this stage. However, on this grand tour of HLFM you won't be entering anything, just viewing what is already there. The arrow is pointing to a link, and at the bottom of the screen is the request: "Enter 1-way (1), 2-way (2), reverse (R), continue (C), or skip <cr>". At this point HLFM needs to know if automobiles can run both ways or one-way on the street represented by that link.

All information about this link has already been given to HLFM, so you can move to the next link by simply hitting the <return> button. Continue to hit <return> until the arrow points to the right-most, vertical link on the screen. It looks different from all the others. The hash mark in the middle of the link indicates that it has been designated as being one-way. Also, one of the nodes connected to the link has a hash mark, too. This is the origin node for the link. That is, all automobiles traveling on this link leave that node, but do not come back.
At this time, enter "R" for "reverse". Notice that you have gone backwards to the previous link. Enter "R" a few more times to see what happens, then hit <return> several times until the arrow disappears.

You will notice that one of the nodes has turned a frosted blue from its original red color. If you are using a monochrome monitor, the node will look like a Roman numeral three. At the bottom of the screen, HLFM is requesting, "Enter network node (N), zonal centroid (Z), reverse (R), continue (C) or skip <cr>". Since all node information has already been given to HLFM, this node can be skipped. You can do that by simply hitting <return>. Hit <return> a few more times until HLFM asks you about the "service to total ratio". Notice that all the nodes turned from red to frosted blue to some other color. The nodes that are still red are "network nodes" or simply intersections. The nodes that are orange are "zonal centroids", which represent areas of the city.

If you need to change the service employees to total employees ratio, or the service employees to population ratio, or the automobile costs per minute, you could do it now. However, they have already been fixed, so hit <return> several more times until the display doesn't change any more. HLFM is now making a rather complicated request: "Enter modify (M), view (V), new (N), save (S), quit (Q), execute (E), reverse (R) or data (D)". At this stage it might be useful to see all the data that you have skipped when you hit <return>. Press "V" and hit <return> again.

An arrow reappears and the travel time for the first link is displayed. Continue to hit <return> until the arrow disappears and the display below the network becomes crowded with words and numbers.

The information below the display refers to the frosted blue node. Shown are the intrazonal travel time, the amount of land that could possibly be developed for residential use, the amount of land that could possibly be developed for service use, the basic employment, the ratio of population to employment, and the average cost (in cents) of taking an automobile to this place. These numbers were generated by a process that will be described later. You can continue to display the data for the remaining nodes by hitting <return> until the service to total ratio, the service to population ratio and the automobile costs per minute are shown. Hitting <return> once more gets you back to the question about modifying, viewing, saving, quitting, etc. This time you should enter "E" and then "C" to calculate the employment and population in each zone.

After the disk drive stops running, HLFM displays the "Model Parameter Page 1" and says, "Enter choice or 'C' to continue or 'P' to see more parameters." It's not a good idea to tamper with
the model parameters unless you are sure you know what you are doing. Any change made in model parameters becomes permanent. So for now, enter "C" and hit <return>. HLFM does its heavy calculations at this time. For the network you have been displaying the calculations take about 3 minutes. But a typical 150-node network takes about 30 minutes to finish. HLFM produces three summary answers: total population, total employment, and total service employment. Also displayed are average travel costs for various trip purposes. These travel costs are used for calibrating HLFM.

The population and employment estimates for each zone can be seen by entering a "V" and then a "C" when prompted for a line number at the "Land-Use Results Display". Only the centroids are shown. The numbers at the bottom of the screen refer to the node that is highlighted (or colored frosted blue). These numbers represent estimates of the population, employment, service employment and intrazonal trips for this zone. You can advance through the centroids by hitting <return> and you can go back to a previous centroid by hitting "R". Hitting "C" will terminate this step and return you to the summary page.

Link loads can be viewed by entering "L" and then a "C" when prompted for a line number on the "Link Load Display". When viewing each link, the "A" node turns frosted blue to differentiate the direction of the load. These link loads could be for a single hour or for the whole day, depending on the trip rates that have been entered on the Model Parameter Pages.

If you wish to take a break, now is a good time. Progress to the question about viewing, modifying, etc., by hitting <return> a few times. Then tell the computer that you do not want to try again by entering "Q". If you say "M", the whole process will start over.

Up to this point, you have seen only a small part of HLFM. However, some of the procedures that you went through apply to other parts of HLFM, as well. For instance, you can almost always ignore a question by simply hitting <return>. HLFM will take no action -- leaving everything as it was. Also, by entering "C" for continue, you will almost always progress to the next major step in HLFM. Again, HLFM takes no action about things that are skipped. Entering "C" is especially helpful when editing a few items in a particularly large network. HLFM will not accept a <return> or "C" in only one instance: entering the beginning node of a newly designated one-way link. The ability to skip questions permits both piecemeal data entry and quick modification of a previously defined network. By entering "R" at any point, HLFM reverses itself by one step. If you have overshot the data item you wanted to change, "R" will allow you to get back to it. (The big exception to these rules is the "five-function calculator" discussed later in this chapter; a <return> or a "C" or an "R" response will be interpreted as a
zero.) With the "C", "R", and plain <return> you will be able to quickly edit data that has already been entered, as well as give HLFM new data.

**Using the Sketch Pad**

The sketch pad allows you to define, in a way HLFM can understand, how the roads are interconnected. As mentioned previously, a highway network can be represented by "nodes" and "links". A "node" can be thought of as a single important intersection. Ideally, every intersection should be explicitly shown, but this is impractical. Instead, nodes are usually separated by about 1/8 mile to 2 miles. Chapter 3 provides some guidance on how to effectively define nodes.

All nodes must connect to at least one "link". Links represent the streets in your city. A link must have a node at both ends. Together, nodes and links form a network that can be displayed and edited using the sketch pad.

In order to see how the sketch pad works, you should load HLFM in the manner described in Chapter 1. When HLFM asks for the name of a data file, just enter "N" to display a blank sketch pad.

The first step is to select an option from the menu. To do this, just point to the desired symbol with your arrows and press the button on the "1" paddle or press the mouse button or press <return>. Since you cannot add links to the network until nodes are first plotted, point the arrows at the square dot and press the button. You will know that you have done this correctly when the Apple makes a noise and a second square dot appears in the upper right corner of the screen. Move the arrows to a point in the work area and press the button. You have plotted your first node. Now plot a few more nodes at other places in the work area. You need not go back to the menu as long as you are only plotting nodes.

Now add some links. First, point your arrows at the vertical line (first symbol) and press the button. If you have done this correctly, the square dot in the upper right hand corner will change to a line. Then select one node to start the linking process. Point your arrows at it and press the button. It may take some practice to be able to consistently hit the node on the first try. If you have indeed hit the node, it will turn blue (on a color monitor) and it will chirp. This is now the first node in the link. Move the arrows to another node and again press the button. A line will appear between the two nodes, the first node will have regained its original color and the second node will have turned blue. The blue node is always the first node in the next link to be drawn. You can continue with this process until all the nodes have been connected. If
you are not using a color monitor, you must keep a mental note of
which node was last hit.

When using the keyboard to move the arrows, there is a
greater way to enter the node plotting mode or link plotting mode.
Pressing "H" will immediately place you into the node plotting
mode. Pressing "L" will immediately place you into the link
plotting mode. The other functions can only be reached from the
menu.

If you have put enough nodes on the screen, connecting them in
this fashion produces a drawing that more closely resembles a
cat's cradle than a highway network. Usually, each street looks
like a separate line, and all the nodes on each street are
connected separately from nodes on other street. You can begin
connecting up a new street by going back to the menu and
reselecting the vertical line or by simply pressing "L". Then a
new starting node can be chosen and the process repeated. There
is one restriction: HLFM will not let you select the blue node
to be the next starting node for a link. If you attempt to
select a blue node as the first node in a sequence of links, HLFM
will not respond. This restriction will probably cause some
minor aggravation, but it is necessary to prevent the possibility
of connecting a node with itself.

Nodes and links can be deleted by returning to the menu and
selecting "D". After you have done this, point the arrows at one
of your expendable nodes and press the button. The node and all
of its connecting links disappear. HLFM has marked the node and
links for deletion at the next time the network is saved. In
effect, HLFM will forget that the node had ever existed (once the
network is saved to disk). Deleting a node from a very large
network can take a few seconds, so be patient. By using the
three sketch pad functions discussed so far, it is possible to
edit an existing network or develop a new one from scratch.

If your Apple II+/e/c has a Grappler (or similar) graphics
printer interface, you can print a copy of the sketch pad. If
you select the "1" from the sketch pad menu, the "Sketch Pad
Options I" page will be displayed. Selecting a "1" from this
menu will ask a "Grappler" graphics interface to print a small
picture of the sketch pad. If you select the "2" from the menu,
the resulting picture will be double size. You should not select
either the "1" or "2" without having the proper hardware -- it
may hang the system and you could lose some valuable data.

The third menu item on the "Sketch Pad Options I" page will
tell HLFM to send a string of characters to the printer
interface. The string of characters is of your choosing. It
could be used to label drawings of the sketch pad produced by
menu items "1" or "2", although that is not its intended purpose.
Menu item "3" will allow other types of graphics interfaces to
dump a picture of the sketch pad. Graphics interfaces usually
require that a string of characters, starting with a "control I", be sent to it for a graphics dump to occur. An invisible "control I" is produced when the <control> key and the "I" key are pressed at the same time. Thus, when you are prompted for "something", enter the appropriate character string as specified by your graphics interface manual. (You may need to know that the sketch pad resides on high resolution graphics page 1.)

Apples have trouble accepting some special characters, especially the comma. If it is necessary to include one of the troublesome characters in the string that is sent to the printer interface, just enclose the string in quotation marks. The string will be faithfully (without the quotation marks) transmitted to the printer interface.

Networks need not be limited by the size of the sketch pad. It is possible to shift the network up, down, right or left, thereby opening new areas in which to draw. The sketch pad can be thought of as a window, with the drawing of the sketch pad being movable relative to that window. Networks can also be rotated through 90 degrees. Consequently, networks can be as large as necessary to maintain scale.

The shifting and rotating functions can be accessed by selecting "2" from the sketch pad menu. This action will display the "Sketch Pad Option II" page. There are six choices on this menu. The first choice will rotate the network counter-clockwise through 90 degrees. This choice can be repeated, so the network can assume four different orientations. The next four choices handle the shifting. After you have selected one of these choices, HLFM will prompt for a distance. The unit of distance is a pixel (the width of a link). The sketch pad is about 230 pixels wide by about 160 pixels high. Be careful when entering the distance. If you accidentally specify a large distance you could hide the network by shifting it completely off the screen, making it difficult to find again. After you have completed all necessary shifts and rotations, enter "C" to leave "Sketch Pad Options II" page.

A similar set of shifting and rotating functions is provided at the time that population and employment estimates at each zone are displayed.

There is a sixth item on the "Sketch Pad Options I" page that doesn't have anything to do with shifting. It is the "undelete" function. If this menu item is selected, the very last deleted node will be restored. (Remember, HLFM just marks nodes and links for deletion at the next time the network is saved, but HLFM doesn't actually destroy them.) Repeatedly exercising this function will restore every deleted node and link. Sometimes, a node is restored, but the display remains unchanged. This happens because the position of the deleted node had been previously shifted to outside the sketch pad. The
restored node can be observed when the network is shifted back to the position that existed when the node was deleted.

Networks that HLFM saves do not contain deleted nodes. Consequently, it is not possible to restore nodes and links that were deleted in a previous session.

Obviously, HLFM cannot display nodes that are outside the boundaries of the sketch pad. Links that are cut by the edges of the sketch pad are not shown, either. However, nodes within the sketch pad that are attached to these cut links are colored white (or solid on a monochrome monitor). The white nodes make it easy to see which portions of the network have not been plotted.

Networks can be of nearly any size, but HLFM will function best if most of the important parts of the network can be displayed at one time. There is one limit that relates to the length of links: because of the way links must be plotted, their lengths cannot be bigger than the width of the sketch pad.

If at least one node is not displayed, a plus sign will appear in the upper, left corner of the sketch pad. HLFM also alerts you to the number of unplotted nodes and links when you continue from the sketch pad. HLFM does not give data prompts for nodes and links that are off the sketch pad. Therefore, it is essential that you be aware of what has not been plotted, so that nodes and links are not mistakenly skipped.

To erase the currently displayed network, select "N" (for "new") from the menu. This will take you to the question about data files. Entering an "N" will clear the sketch pad and allow you to draw a new network. If you had selected "N" from the sketch pad menu by mistake, don't despair. Entering "C" at the question about data files will take you back to the sketch pad with your old network intact.

To leave the sketch pad, select "C" (for "continue").

Careful placement of nodes and links can produce a better looking network, as well as one that is easier to edit. It is also useful if the network on the sketch pad looks somewhat like a map of your city and is roughly to scale. A scale map makes it much easier to enter data and to spot errors.

HLFM allows plotting of up to 200 nodes and 320 links. At most 40 of these nodes may be designated as centroids. Unfortunately, deleted nodes and links are counted in this total. However, deleted nodes and links are always cleaned from the network when it is saved. So if you need to use all 200 nodes but have deleted some, you should save your data and restart. This procedure frees the deleted nodes for further use. Three methods of saving your data are discussed later in this chapter.
If you are familiar with other highway forecasting procedures, you know that there is usually a limit on the number of links that can be connected to a single node. HLFM does not impose such a limitation.

Example Networks. Examples of real networks are found on the "Master" disk and on the "Utilities" disk. WAUSAU is on the "Master" disk residing in drive 1. Get to the questions about data files and enter "WAUSAU". (Of course, make sure that the default data drive has been set to "D1".)

Wait for the network to load. This network uses 193 nodes, about a fifth of which represent areas of the city; the others simply represent intersections. If you have a color monitor, the centroids can be better seen by continuing to the data input step ("C") and hitting <return> many times until all the nodes have changed to their final color.

WAUSAU would be a large network for an urban area of 60,000 people. You should avoid using all 200 nodes simply because they are available. Too much detail increases data preparation time and greatly slows the calculations, but may not help the accuracy of estimates.

Entering a Small Network

Defining a whole new network requires both the sketch pad and the subsequent data input step. You are now familiar with operation of the sketch pad, so this section will concentrate on giving HLFM your data. First you need a network to play with. Clear the sketch pad ("N" on the sketch pad menu and then "N" at the question about old files) and draw the simple network that is illustrated in Figure 2.1. You won't be able to label the nodes on the screen the way they are labeled in the figure; however, you will soon be designating nodes A, B, C and D to be network nodes and nodes E, F and G to be zonal centroids. Links 1 and 8 are centroid connectors and links 2 through 7 are regular streets. Once you are satisfied that the network looks correct, select "C" from the menu in order to continue to the next step.

At the data input step, you need to describe the nodes and links to HLFM. Your data for the links are:

Link 1 -- Direction is two-way.
Travel time equals 8 minutes.

Link 2 -- Direction is one-way, B to A.
Travel time equals 5.2 minutes.

Link 3 -- Direction is two-way.
Travel time equals 10 minutes.
Figure 2.1. An Example Seven Node Network
Link 4 -- Direction is two-way.
   Travel time equals 5.6 minutes.

Link 5 -- Direction is two-way.
   Travel time equals 10.4 minutes.

Link 6 -- Direction is two-way.
   Travel time equals 9 minutes.

Link 7 -- Direction is one-way, C to D.
   Travel time equals 3 minutes.

Link 8 -- Direction is two-way.
   Travel time equals 3.6 minutes.

Nodes A, B, C and D are network nodes and do not require data entry. Here are the data for the three centroids.

Node E -- Intrazonal time equals 3.5 minutes.
   Population to employment ratio equals 2.3.
   Basic employment equals 250 employees.
   Net developable area equals 1.6 square miles.
   Service developable area equals 1.6 square miles.
   Automobile destination costs equals 0 cents.

Node F -- Intrazonal time equals 2.6 minutes.
   Population to employment ratio equals 2.1.
   Basic employment equals 720 employees.
   Net developable area equals 1.2 square miles.
   Service developable area equals 1.2 square miles.
   Automobile destination costs equals 50 cents.

Node G -- Intrazonal time equals 3.1 minutes.
   Population to employment ratio equals 2.4.
   Basic employment equals 15 employees.
   Net developable area equals 1.9 square miles.
   Service developable area equals 0.9 square miles.
   Automobile destination costs equals 0 cents.

The following whole network information should be entered.

Ratio of service employment to total employment equals 0.15.
Ratio of service employment to population equals 0.10.
Automobile costs per minute of travel equals 3 cents per minute.

One-way links may be specified by entering "1" for the link designation request. HLFM will respond by turning one node frosted blue and asking you if it is the origin node for the link. HLFM requires a yes "Y" or no "N" response to this question in order to fix the direction of travel. This is the only question in the data input step that HLFM won't let you skip by hitting <return>.
The order in which HLFM displays the links and nodes for data entry is the order in which they were originally created on the sketch pad. To be able to enter numerical data about links and nodes, the question about the type of link or node must be answered. Then you will be prompted for each piece of numerical data.

Enter the data by answering all the questions. Numbers can be entered as whole numbers (e.g., "134") or as decimal fractions (e.g., "-1.34") or in scientific notation (e.g., "1.34E3"). If you make a mistake; don't worry, you'll have a chance to correct it later. After you have finished, view the data to make sure you have entered it properly.

Changing the network is relatively easy. You can add nodes and links by drawing them on the sketch pad. Changing numbers is only slightly more difficult, if you keep in mind that hitting <return> without entering a number causes HLFM to advance, leaving everything as it was, while entering an "R" causes HLFM to back up one step. If you are changing link data, then you must answer at least the question about the link designation. Otherwise, HLFM will skip the link. If you are changing data for a node, then you must answer at least the question about the node designation. Otherwise, HLFM will skip the node.

It is often inconvenient to redesignate the links and nodes just so their numerical data can be edited. For this purpose it is easier to enter the wild card designation, "X". If an "X" is entered, the previous designation will be left as it was, and HLFM will let you change the numerical data. It is helpful to keep in mind the default data conditions for links and nodes. All numerical data is initially set to zero. Links are two-way. Nodes are network nodes.

After you have viewed your data, you can modify anything by entering "D" or "M" when HLFM gives you a chance. Entering an "M" will take you to the sketch pad. Entering a "D" will take you back to the first link for data input. Right now, change the basic employment for node "G" to 150, and fix anything else that may have been entered improperly.

When editing a large network, repeatedly hitting <return> to skip nodes and links can be slow and boring. There are two ways to speed up the process. First, holding the "rept" key down at the same time that the <return> key is pressed on the Apple II+ will speed things up considerably. Second, entering "C" anywhere will cause HLFM to continue to its next major step. The distance HLFM jumps when it encounters a "C" varies depending upon where it is at the time. For example, entering "C" at any link designation request will jump you to the first node designation request. Liberal use of both "C" and "R" will greatly speed editing of data.
Now execute the model by entering "E" at the end of the data input step. Don't modify the parameters. If your seven-node network has a population at node E of 2014, at node F of 1179 and at node G of 857, then all the data has been entered properly. If these are not the answers, there can be two reasons: someone might have previously changed the parameters or you might have made an error while typing the data.

**Saving a Network**

There are several reasons for saving a network. You may want to check your forecasts later, or you may want to slightly modify the network to see how population shifts, or you may be only partially finished defining the network and need to take a break. There are three ways to save the network that you are currently modifying. All of them involve the stage in HLFM that asks about viewing, modifying, saving your data, etc.

By entering "E" at this time, HLFM progresses to the calculation step, but first it gives you a chance to save your network. HLFM will prompt you for a file name. If you enter a "C" (for continue) at this prompt, HLFM assumes you are not interested in saving your data, but it temporarily stores the network in a file called "SCRATCH1". So, if you forget to formally save your data, all is not lost.

Entering "S" will allow you to save your data without continuing to the calculation step. Again, HLFM will prompt for a file name. But if a "C" is entered instead of a file name, nothing will be saved.

Entering "Q" will cause HLFM to terminate, but only after asking you for a file name. A "C" response to this prompt also will terminate the program without saving anything.

HLFM cleans deleted nodes and links from the network before it saves it to disk. This process can take one minute or more if several nodes have been deleted, so be patient.

Data may be stored on the same disk as HLFM. The disk has a fixed capacity, limiting storage to only a few networks. Therefore, it is good practice to clean up old files occasionally. There is a program on the "DOS 3.3 System Master" disk, called "FID", that is especially useful for file maintenance. It will allow you to delete any unwanted files, and it will let you move files to another disk.

There are a number of unlikely events that can make saving your data impossible. Some of these include: a disk that is full, an illegal file name, or a disk that is damaged. In these cases, HLFM will not let you save the network. HLFM will give you the option of trying to continue to the calculation step.
without formally saving the network. You may still be able to save it on another disk by following this simple procedure: when the error message appears, hit <return>. This will bring back the question about viewing, modifying, saving, etc. Before entering anything, insert a previously initialized disk into the disk drive. Then enter "S" or "Q". HLFM will save the network on the new disk and either terminate or come back to the question about viewing, modifying, saving, etc.

Using the Work Sheets

Several work sheets have been incorporated into HLFM to better handle many of the calculations. A work sheet is available anytime HLFM requests a number. The work sheets vary in complexity. Some work sheets just display a previously entered value and give you an opportunity to change it. Others perform mathematical procedures. Work sheets are easily found. By entering a "W" instead of a number, the work sheet will be displayed.

The next few paragraphs discuss the various work sheets. Reload "FINCHBURG" so that you can follow the discussion on the Apple. Continue to the data input step, and get ready to modify the first travel time by entering "X" for the request about the link designation.

Entering "W" instead of a number will display the "Auto Time Work Sheet". It is one of the more complicated work sheets. The current value of the travel time is displayed on line 4. This value can be changed by first entering "4" (hit <return>) and then entering the new value (hit <return>). The new value of the travel time replaces the old value on the display. Don't worry about the fact that you will be over-writing a formula that automatically appears.

This work sheet is designed to help you calculate travel time in minutes from the length of the link in miles and from the speed of the link in units of miles per hour. The first three lines of the work sheet are intended to facilitate this calculation. Line 1 has already been set to the number of minutes in an hour. You should enter the link length on line 2 and the speed on line 3. Then select line 4. An arithmetic expression will appear. To enter this expression, press the right-arrow key several times until the cursor is past the right side of the equation, and press <return>. The calculated travel time will be entered on line 4. If you fail to set either the speed or the link length before selecting line 4, the words "SPEED" or "MILES" could be imbedded in the arithmetic expression. If you completely replace these words, within the arithmetic expression, by numbers, the calculation will proceed normally.
Entering "C" advances HLDFM to the next link. Entering an "R" has no effect.

The next nine work sheets aid data entry for nodes and for the whole network. They are similar in how they work, so only the first one will be described here. Advance to the first node designation question, enter "X", and then enter "W".

You should now be looking at the "Intrazonal Travel Time Work Sheet". It has two lines. You can directly change the intrazonal time by selecting line 2 and entering the correct number. Line 1 will allow you to enter that same number at every zonal centroid. You can invoke this option by selecting line 1, and then entering "Y". When you "continue" from the work sheet, all intrazonal times will be set the number that is currently on line 2.

Entering a "W" for either the node designation or link designation will cause HLDFM to display designation pages. These pages are not work sheets, as there is nothing on them to change. Hitting any key will return you to the link designation request or the node designation request, depending on where you started.

The Five Function Calculator

It is permissible to use arithmetic expressions in place of numbers when entering data on the work sheets (and only on the work sheets). For instance, you could approximate the intrazonal travel time as a function of the gross area of the zone and an assumed travel speed. Arithmetic expressions can have up to 200 characters and can multiply (*), divide (/), add (+), subtract (-), and exponentiate (^). The calculator follows the BASIC rules for evaluating expressions. Exponentiation is always carried out first. Multiplication and division follow. Addition and subtraction are done last. Parentheses can be used to separate and combine terms. If the entered arithmetic expression has a syntax error (e. g., parentheses not balancing), a zero instead of the desired answer will be produced. So if an unexpected zero appears, check your expression and enter it again. All of the following expressions evaluate to 12.

\[
\begin{align*}
4+8 &= 12 \\
3*4 &= 12 \\
100/5-8 &= 12 \\
(9-5)^*5*6 &= 12 \\
2*(4*(6-4)-2) &= 12
\end{align*}
\]

HLDFM redefines the keyboard when in the calculator mode. Illegal characters cannot be entered. Shifting is not required to produce a "*", "^" or "~" on the Apple II+. Pressing an "A" will produce a "(" and pressing an "S" will produce a ")".
When a work sheet is first displayed, HLFM sets the variable "E" equal to the bottom line entry. This can be an especially useful feature when making constant multiple changes in data items. For example, to test the effect of a 10% reduction in basic employment at several zones, the new basic employment can be determined by entering "E* .9" for each bottom line.

The five-function calculator will not permit entry of a "C" or an "R". If the calculator is invoked by mistake, the bottom line entry may be destroyed. It can be restored by reselecting the bottom line and entering an "E" instead of an arithmetic expression.

One feature of HLFM, which can be invoked to give extraordinary power to the five-function calculator, is the definition and use of "keyboard macros". Any character on the Apple keyboard can be redefined to be any sequence of characters. For instance, the sequence of characters can be a previously defined arithmetic expression. These arithmetic expressions may contain any variable or parameter within HLFM. Keyboard macros are discussed later in this chapter.

**Maintaining Data Files**

HLFM has a number of features that facilitate file maintenance. These are available at the time HLFM requests the name of an old data file, just after loading or when "N" is selected from the sketch pad menu. It is possible to lock (protect the file from being over-written), unlock, and delete files. The catalog of a data disk can be displayed. And it is possible to tell HLFM to look for data on either disk drive of a two-drive system.

**Drive Designation.** HLFM normally looks for data on the HLFM disk that is in drive 1. This can be changed to drive 2 by entering a "2" instead of a file name. It can be changed back by entering a "1". The HLFM disk should always be in drive 1. HLFM remembers the data drive designation, and it expects to see data on this drive in all subsequent sessions (even if the computer has been turned off). A network may be moved from one disk to another by changing the drive designation once the data has been loaded into memory.

**Catalog.** Entering "CATALOG" instead of a file name will tell HLFM to list the files that are stored on the data disk. The amount of free space (in sectors) on the data disk will also be displayed. Hit <escape> to abort a long catalog listing.

**Delete, Lock and Unlock.** These functions will help you clean up old networks and protect the ones worth keeping. Locked files cannot be deleted. The syntax for these commands is illustrated by this example: "LOCK FINCHBURG".
File Naming Conventions. HLFM follows DOS 3.3 file naming conventions. Names must be shorter than 30 characters. They must start with a letter and they cannot contain commas.

Error Messages. If problems develop when saving or maintaining data files, HLFM will produce appropriate error messages. Some of them are self-explanatory. Others are referenced by number. The following list should help you determine the nature of the problem.

<table>
<thead>
<tr>
<th>ERROR NUMBER</th>
<th>CAUSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Disk is write protected, remove tab.</td>
</tr>
<tr>
<td>8</td>
<td>Read/write error, may be a damaged</td>
</tr>
<tr>
<td></td>
<td>or uninitialized disk or the door</td>
</tr>
<tr>
<td></td>
<td>may be open.</td>
</tr>
<tr>
<td>9</td>
<td>Disk full, use another disk.</td>
</tr>
<tr>
<td>10</td>
<td>File locked, use another file name</td>
</tr>
<tr>
<td></td>
<td>or unlock it.</td>
</tr>
<tr>
<td>11</td>
<td>Syntax error, probably an illegal</td>
</tr>
<tr>
<td></td>
<td>file name.</td>
</tr>
</tbody>
</table>

Wild Cards in File Names. It is possible to specify only the first part of a file name. If the rest of the file name is replaced by an "="", then HLFM will process the first file it encounters that matches the beginning of the file name. For example, entering "FIN=" will tell HLFM to load FINCHBURG, because it is the first file on the disk having the same beginning three letters. It is best to type enough of the name so that the request is unambiguous. The use of the "=" can be especially hazardous when deleting files.

A "?" may be specified instead of a "=". If this is done, then HLFM will prompt you for the file to be processed. When prompted, just hit the "Y" or the "N" to select the correct file. HLFM will not allow the use of the "?" when specifying the name of the file to be executed (e.g., at the "E" option at the end of the data input step.)

Space on Master Disk. About 130 sectors have been left as free space on the Master disk for scratch files. If you are using an Apple with only 64 Kbytes of memory, HLFM will want to create as many as four additional scratch files on the Master disk. These scratch files vary in size but can, at times, fully occupy this free space. If you have a 64K Apple, it is important to reserve this free space. There is still room on the Master disk for a few network files, but if the free space drops below 130 sectors, you should move unnecessary files to another disk. If disk space problems are going to develop, they will usually first become apparent during the calculation step. Fortunately, you would have already saved your network at this point. Just delete some network files and try again.
Keyboard Macros

A "macro" is a single keystroke that produces the effect of multiple keystrokes. Macros are user definable. For example, the "#" could be defined to be "FINCHBURG". Then each time the "#" is pressed, the character string, "FINCHBURG", will appear. Macros may be invoked anywhere within HLFM, except on the sketch pad. Any character may be defined as a macro and any character may appear in a macro string. Obviously, many characters should not be redefined as macros. All upper case letters are needed for either file names or HLFM commands, and all numbers and arithmetic operators are needed for data input. "Control M" is the same as a <return>; "control P" is the "insert mode" toggle; "control H" (also the left-arrow) is the backspace; "control U" (also the right-arrow) is the forward space; "control I" is the printer interface lead-in character; and "control S" is the printed output pause character. Most symbols are permissible (including <tab>, <delete>, and the up-arrow) as are all lower case characters and the remaining control characters (those invisible characters that are produced when <control> and a letter are pressed at the same time).

Macros can make data preparation a lot simpler. For example, if it were necessary to change the automobile time on many links, "X" <return> "W" <return> "4" <return> could be defined as "control W". Then, hitting "control W" at the link designation question would quickly display the "Auto Time Work Sheet" with the five-function calculator ready to accept a number.

A few macros have already been defined. "Control F" (for "fast") will produce five <returns> to advance through the data. "Control V" (for "very fast") will produce ten <returns>. "Control R" will produce five sets of "R" and <return>. "Control Q" will produce ten sets of "R" and <return>. And "Control C" will produce four sets of "C" and <return>. Try these macros at various places in the data input step to see what happens. Of course, any of them can be altered.

Macros may be defined at almost any place within HLFM, but it is best for several reasons to do it at the question about old data files. Hitting "control P" and then "control @" (i. e., hitting <shift>, <control> and "@" all at the same time) will put HLFM into the macro definition mode. The existing macros will be displayed. Any character typed immediately after a "control @" will become the next macro. Subsequent characters become the macro string. The macro string is terminated by typing another "control @". Hitting the left-arrow will erase a character. The macro definition mode is terminated by hitting "control P". Then hit <return> to restore the screen to its original condition. The new macro may be saved to disk by entering "M" (after leaving
the macro definition mode, of course). The combined length of all macros and macro strings must be less than 256 characters.

Macros can considerably increase the power of the five-function calculator. Normally, the five-function calculator will accept only eighteen different characters from the keyboard; everything else is ignored. However, the five-function calculator will accept any character that is included in a macro string. Since all eighteen characters should be preserved as they are, it is usually necessary set up the macro so that it first invokes the five-function calculator and then issues the character string to be calculated. For example, assume that you want to test the effect of a 10% speed improvement on several links. You could define "control W" to be the following macro:

"X"<return>"W"<return>"4"<return>"E*+.9"<return>"C"<return>. Hitting "control W" at the link designation question would then cause HLFM to enter the "Auto Time Work Sheet", lower the existing time by 10%, and then advance to the next link. All this would occur in a fraction of a second.

The five-function calculator will accept variables and parameters, if they are generated by a macro. By using variables, it is possible to enhance or completely override the formulas that are at the basis of the work sheets. For example, it would be feasible to use the scale of the sketch pad to calculate automobile time as a function of the coordinates of the nodes at each end of the link. The screen length of each link has the variable name "SL", and is displayed above the first line in the "Auto Time Work Sheet". "SL" could be used instead of a number in any arithmetic expression. Assume that the network has been drawn at a scale of 20 pixels per mile and that the average speed of automobiles is 20 miles per hour. The following macro will calculate an approximate automobile travel time:

"X"<return>"W"<return>"4"<return>"SL*.15"<return>"C"<return>.

Efficient use of macros requires some practice. You should try the examples that are described above on your seven-node network or on FINCHBURG. Then define a few of your own and see how they work. Macros can greatly reduce the tedium of data preparation on large networks.

Printer Utilities

Included with the HLFM "Master Disk" is a "Utility Disk". It contains the original source version of the calculation step and a few sample networks. It also contains four utility programs: a program for printing input data; a program for printing results; a program for printing a labeled drawing of the network; and a program for rescaling a network. These utility programs may be accessed from the very first menu that appears after HLFM is started. If "U" is chosen, then HLFM displays a
menu of utilities. If one of the printer utilities is selected, HLFM prompts you to insert the "Utility Disk" into either drive 1 or drive 2 (whichever is most practical) and to enter the drive number. Then HLFM loads the selected utility.

The program for printing input data and the program for printing results operate similarly. First, the name of the file containing the appropriate data should be entered. Then, HLFM prompts for a comment to be printed at the beginning of the data listing. The listing may be made to an 80-column display in "slot 3" or to a printer attached to "slot 1". Nodes are referred to by an arbitrary, but unique, two-letter code. Links are referred to by the nodes at either end.

Results may only be printed from a file that has been explicitly saved. An option for saving the results in a file on your data disk is provided at the end of the calculation step. You may choose to save your results to a temporary scratch file at this time. When prompted for a file name, just enter "C" to continue. A file called "SCRATCH8" will be created on your current data disk. This scratch file may be printed by entering "D" (for default) when prompted for a file name in the results printer utility.

The utility for printing a picture of the network has been designed to work with a graphics printer and graphics printer interface. As in the case of printing a picture of the sketch pad, it is assumed that the interface is Grappler compatible. The "print something" option is also available. You also can "view" the screen image without printing it, or you can "put" (i.e., record) the image to a disk file for later processing.

Only the portion of the network that is displayed in the small window will be printed. This portion is doubled in size and has its nodes labeled before printing. All link segments within this window are accurately reproduced. By repeatedly moving the network relative to this window, a complete drawing of the network can be created. A labeled drawing of the network is essential for understanding the printed results.

The utility for rescaling the network is most useful for producing different sized drawings. Excessive use of this utility should be avoided, because repeated rounding of node coordinates can eventually destroy your network. When the original file name is entered, HLFM prompts for the rescaled file name and the rescaling factor, and asks whether the rescaling should be horizontal, vertical or both.

Install Feature

It is possible to have HLFM modify itself for specialized or advanced applications. Modifications can be performed by
entering an "I" at the title screen, right after HLFM is started. In response, HLFM will prompt for an "install" file name that contains the modifications. After the modification is completed, HLFM is restarted.

The writing of an install file requires considerable knowledge of the inner workings of HLFM. However, two install files are provided on the Master disk, FORMULAS and ORIGINAL. Installing FORMULAS will change the Travel Time and Intrazonal Time Work Sheets. The Travel Time Work Sheet will subsequently calculate link times using the FHWA capacity restraint formula. The Intrazonal Time Work Sheet will subsequently approximate intrazonal time as a function of gross area of zones. Installing ORIGINAL will restore HLFM back to its original condition.

HLFM now supports three different graphics input devices. Each graphics input device has an associated text file, having the structure of an install file, on the Master disk. These files are MOUSE, PADDLES, and KEY. It is possible to modify one or more of these files, using a text editor, to support other graphics input devices. This new install file should be placed on the Master disk.

Play Time

Now that you a familiar with how HLFM functions, you should try using it for a few minutes. FINCHBURG is a good test network because it's small. Change something and recalculate population and employment distribution. Change the automobile times on several links, or redistribute basic employment or increase parking charges in the CBD. The effect on population of one of your changes should be intuitively correct. Continue to change different parts of FINCHBURG until you are comfortable with the way HLFM works.

What's Missing

The only portions of HLFM that haven't been discussed are the parameter pages. If you do not intend to customize HLFM to your city, then you now have all the information you need. However, the parameter pages are the heart of HLFM, with the accuracy of forecasts depending upon how well the parameters are selected. Unfortunately, deriving new values for many of the parameters requires more effort than many people are willing to spend. But with some time and care, it is possible to adjust the parameters provided with HLFM so that it will produce consistently better forecasts. More will be said about the parameter pages in the next chapter.
CHAPTER 3
DEVELOPING NETWORKS FOR THE
HIGHWAY LAND-USE FORECASTING MODEL

As seen in Chapter 2, HLFM requires an abstract representation of the city. Streets must be shown as links, intersections shown as nodes, and areas of the city shown as centroids. Each zone of the city is described in terms of land area available for various types of development, the ratio of population to employment, the intrazonal travel time, the amount of basic employment, and monetary costs of taking an automobile there. All inputs to HLFM must be developed by a unified procedure that is discussed in this chapter. Also discussed in this chapter are the meanings of many of the parameters and the implications of changing them.

Network Nodes, Centroids and Links

Networks for HLFM have only two types of elements: nodes and links. Nodes can be as complicated as "centroids" in order to represent characteristics of an area of a city, or nodes can simply be intersections. Of course, centroids can be intersections, too. Links can be either two-way or one-way. (If you are wondering, HLFM does not make special provision for "centroid connectors" that are found in many other transportation models. If a centroid needs to be connected to the rest of the network, a regular two-way link should be used instead.)

It is not difficult to produce a complete HLFM network, but the task can be time consuming. Therefore, it is a good idea to assemble all necessary materials before a single node is plotted on the sketch pad. This practice will help eliminate the possibility having to make a major revision of the network at a later time.

The construction of an HLFM network is more of an art than a science. Enough detail has to be included so that the results are sufficiently accurate, but too much detail can greatly increase the time it takes to prepare the data and to run the model. Furthermore, too much detail can unreasonably suggest that the model can reliably forecast impacts on very small parcels of land. This manual can provide general guidelines, but you should be willing to vary the procedures to suit your particular application and data.

Defining Zones. HLFM gives you considerable latitude in how
you define your zones. Consequently, it is possible to draw the zones so that their boundaries correspond to those of U.S. Census tracts or to traffic analysis zones (TAZs) of more traditional transportation studies. It is also possible to vary the size of zones to fit your application. Zones can be as small as a quarter square mile and as large as 10 square miles.

Before drawing the HLFM zone system, you should get maps of the highway network and maps of any other zones that you wish to respect. It is usually easiest to overlay zone boundaries on the highway network map, because zone boundaries typically follow major streets. The normal situation in small cities is that Census tracts are too large to be HLFM zones and TAZs are too small. Thus, it is necessary to subdivide Census tracts and to aggregate TAZs. If your city is like most of the rest of the world, you will soon discover that it is not possible to produce HLFM zones that are compatible with both Census tracts and TAZs.

When developing TAZs, transportation planners size their zones so that the number of "trip ends" are roughly constant. TAZs are smaller in areas of high activity (e.g., the central business district, CBD) and larger in areas of low activity (e.g., urban fringe areas). This, too, is a good procedure for sizing HLFM zones, but there are other considerations. First, zones should be smallest in places where the impact is expected to be the largest. Because HLFM can work with zones that vary greatly in size (e.g., by a factor of 40) it is possible to use HLFM for corridor analysis or small-area analysis within some rather large cities. Second, try to center each zone on a major intersection. The node representing the intersection can then do double duty as a zonal centroid. Third, when subdividing Census tracts and TAZs, avoid splitting Census block groups. This is not an especially difficult task, because block group boundaries run along nearly every street in a city. Fourth, avoid using major arterials, particularly those with substantial retail or other commercial activity, for zone boundaries. It is far easier to interpret results if major commercial areas are not split between two or more zones. Fifth, observe HLFM's limit of 40 zones.

Zonal centroids, exactly one for each zone, should be located near the center of each zone. Preferably, centroids should be at major intersections. If a centroid cannot be located on an intersection, you should try to put it somewhere else on a major street. As a last resort, a centroid can be located in a open area. In this case, a single two-way link (acting as a centroid connector) is necessary to attach the centroid to the rest of the network.

Draw your zone map in a manner that can be easily reproduced. During data preparation, you will find it useful to have several clear copies.
Representing Streets as Links. The primary purpose of the highway network is to permit accurate determination of the most efficient travel times from any zone to any other zone. Streets that detract from this purpose, particularly locals and collectors, should not be included in the network. Even some major arterials can be discarded if it is clear that they will never be on a shortest path between any pair of centroids. A drawing of the remaining streets in the network should be produced at the same scale as the zone map.

Nodes should be drawn at all intersections. Every road segment between two nodes is a link. There may be at most 320 links (less the number reserved for centroid connectors); and there may be at most 200 nodes (less the number of centroids that were not placed at intersections). Check to make sure that the number of nodes and number of links fall within these limits. Then add the centroids and centroid connectors to the network drawing. You may want to assign temporary identifiers to the links and nodes to aid data preparation; however, once the network is entered into the computer, HLFM will assign its own designations to the nodes and links.

Before drawing the network on the sketch pad, some thought should be given to the scale of the drawing and the order in which the nodes and links are to be entered. Select the smallest scale that looks good on the sketch pad. The minimum convenient spacing between nodes is eight pixels (two key-presses at the default spacing under the keyboard option). Define blocks of the network that should be plotted as a single unit. It is most convenient if the blocks are rectangular, about 200 pixels wide and 140 pixels high.

When plotting the network on the sketch pad, enter all the nodes of a block before entering any links. The order in which the nodes and links are plotted is not critical, but it is best to develop some personally satisfying procedure. A haphazard ordering can be quite inconvenient, even frustrating, when entering data and retrieving results. Separately complete each block; then tie the blocks together with links, as necessary. Save the network to disk.

If you have a graphics printer and the appropriate interface card (or graphics software), then use the network printing utility to produce a complete picture of the network. Check to see that everything has been correctly plotted. You should not attempt to enter numerical data until satisfied that the drawing of the network is final.
Determining Automobile Times

The only piece of numerical data for links is travel time. It may be determined in many different ways (e.g., floating car techniques, capacity-restraint formulas, comparisons with streets of similar characteristics). It is assumed here that you already know the length of each link. The only real problem is determining the average speed. This average speed must include all traffic delays, because HLFM does not provide for delays due to signals, stop signs, or turning movements at intersections.

One method of determining average speeds is to sample several links of each type; then drive them, record the time and distance traveled, and calculate average speed. (Traffic engineers prefer to calculate average speed by dividing the total distance by the total travel time.) The variety of link types need not be large. Links should be selected from a few different road capacities (e.g., two-lane arterial, four-lane arterial, freeway) and from a few different parts of the city (e.g., CBD, remaining fully developed areas, fringe areas). Additionally, any links that will be affected by the highway project and any links that are known to be particularly congested should be individually timed. If possible, links should be driven during the evening peak hour.

A second method involves determination of "free speed" for each link. The free speed is the speed at which a single car would travel if it were the only car on the road. Free speeds can be converted to estimated "actual" speeds by using the FHWA capacity-restraint formula. The FHWA capacity-restraint formula computes actual speeds from the free speed, the volume, and the design capacity of the road. The design capacity is less than the ultimate capacity; the design capacity most closely corresponds to the "service volume" at level of service B as defined in the 1965 Highway Capacity Manual. A more practical definition of design capacity is the amount of volume that would degrade speed by 15% from the free speed. The FHWA capacity-restraint formula is not presented here, but it is included in the "install" file, called FORMULAS. Installing FORMULAS converts the Travel Time Work Sheet into the FHWA capacity-restraint formula (see Chapter 2).

Free speeds are determined in much the same way as actual average speeds. Links of several types are sampled. Then they are driven during a period of time when traffic is very light, but the signalization is identical to the evening peak hour. For most cities, a good time for ascertaining free speeds is the mid-evening period (e.g., 8:00 to 10:00 p.m.)

The use of the FHWA capacity-restraint formula requires more work than determining links times directly from actual speeds. However, this formula can be quite helpful when determining additional traffic delays that might occur because of shifts in
development. When the project is so large that major impacts are expected or when substantial growth in population is expected, the predicted volumes should be used to recalculate link times. If the link times change appreciably, then HLFM should be run again, with the new link times substituted for the old.

**Zonal Centroid Data**

Each zone requires six pieces of data: Intrazonal Time; Population to Employment Ratio; Basic Employment; Net Developable Area; Service Developable Area; and Automobile Destination Costs. The following paragraphs explain each of these data items.

**Intrazonal Time.** Trip times between different centroids are calculated by tracing the shortest path across the network, but HLFM cannot automatically determine times for trips that occur entirely within a single zone. An intrazonal time depends upon the size of zone and on the average speed of traffic within that zone. One method of approximating intrazonal times is to assume that the zone is square and that the length of an average intrazonal trip is one-half the length of a side. This trip length can be divided by the average speed to yield intrazonal trip time. If FORMULAS is installed, the Intrazonal Time Work Sheet facilitates this calculation.

**Population to Employment Ratio.** The Population to Employment Ratio can be easily calculated from Census data. Since the ratio varies little from zone to zone, it is usually sufficient to calculate it for whole Census tracts and then enter the same number for all zones within each tract. The "employment" part of this ratio requires further clarification. It is the number of full-time equivalent employees in the zone of residence (not the workplace). The ratio is related to family size, typically being larger in suburban areas and smaller near the core of the city.

**Basic Employment.** Basic Employment is the number of employees (at the workplace) that cannot move in response to improvements in a highway. Basic employees generally work for firms that sell their products to persons or other firms that are outside the study area. Manufacturers and some service industries (e.g., insurance company headquarters) distribute their products to geographically large markets — so all their employees would be considered to be basic employees. Some other service industries (e.g., grocery stores and restaurants) can be classified as being strictly nonbasic. Inconveniently, there are service industries that sell their products both to local markets and to markets outside of the urban area (e.g., hospitals, banks, and large department stores). The employees in these service industries must be split between basic and nonbasic categories. The fraction of service employees that can be classified as being basic varies from city to city.
A simple example will help clarify how to split services into basic and nonbasic categories. Finchburg has a population of 30,000, and it is the county seat of Foghorn county. Foghorn county has a population of 90,000. There are 300 hospital beds in Foghorn county, 250 of them in the city of Finchburg. Here is how to allocate hospital employees as basic and nonbasic. In Foghorn county, there are 300 people per hospital bed. If hospital bed usage is constant across the county, then the people of Finchburg only use 100 beds. The remaining 150 beds in Finchburg are serving other parts of the county. So for every 10 hospital employees, four are classified as basic and 6 are classified as nonbasic.

Net Developable Area. Net Developable Area is the amount of land that is currently being used or could possibly be used for residential development. The way in which Net Developable Area is calculated depends on the assumed strength of zoning or farmland preservation regulations, the degree of local access, and the availability of sewer and water service. However, net developable area definitely excludes areas that are covered by water, marshes, environmentally sensitive areas, quarries, present and former landfills, parks and other public lands, institutionally held property, industrial parks, and land currently occupied by basic industries. Net Developable Area can be expressed in any units of area, but these units must be compatible with those used in the Service Employee per Area Parameter.

Service Developable Area. Service Developable Area is the amount of land that is currently devoted to local services (i.e., nonbasic businesses) or could possibly be developed for local services. All of the exclusions for Net Developable Area apply to Service Developable Area. In addition, land should be excluded that does not have direct access to a major arterial street. Service Developable may be expressed in any units of area.

Automobile Destination Costs. These costs, such as parking charges and tolls, are associated with taking a car to a specific location. HLFM deals with only one-way trips. Consequently, costs associated with a complete round trip must be divided in half. For example, parking in Finchburg's CBD costs 10 cents per hour. The average time people spend in the CBD is 4 hours, so the total parking cost for a round trip is 40 cents. Therefore, the Automobile Destination Costs are one-half of 40 cents, i.e., 20 cents. The units of Automobile Destination Costs are cents.
Whole Urban Area Data

Three pieces of data relate to the whole urban area. Two of these are "base multipliers": the Ratio of Service Employees to Total Employees and the Ratio of Service Employees to Population. The third data item is Automobile Costs per Minute of Travel.

Base Multipliers. The two base multipliers, Ratio of Service Employees to Total Employees and the Ratio of Service Employees to Population, should be calculated by a consistent procedure. "Service employees", as used here, requires further definition. These employees are nonbasic; in other words, they sell their services only to local customers. The "service employees" in the Ratio of Service Employees to Total Employees include only those employees that serve businesses (e.g., accountants, advertising agents, workers in industrial laundries). The "service employees" in the Ratio of Service Employees to Population include only those employees that serve people (e.g., grocery store checkers, gas station attendants, doctors, criminal lawyers). Of course, employees who are in ambiguous trades must be split among the two types of services. Figure 3.1 is an example of how Census data are used to determine the base multipliers for Finchburg.

Automobile Costs per Minute. Automobile Costs per Minute are typically gasoline costs. These costs have units of cents/minute.

Meanings of Parameters

HLMF has several parameters which control the operation of the model and help determine the distribution of activities across zones. A list of parameters and initial values, as supplied with HLMF, is shown on Table 3.1.

Trip Distribution Parameters. Three of the parameters (Residential Location, Residence Serving, and Employee Serving) control the density of activities in the city. In general, the forecasted city will be denser if the parameters are small and it will more spread out if the parameters are large. Results are most sensitive to the Residential Location Parameter and are least sensitive to the Employee Serving Parameter. There is an intrinsic relationship between the magnitude of these parameters and the average length of trips. This relationship provides a means of quickly calibrating HLMF. Calibration is discussed later in this Chapter. A rule of thumb can be used to determine if the three trip distribution parameters are approximately correct. For most cities, the trip distribution parameters will be slightly larger than the reciprocal of the average trip length, expressed in minutes.

Service Area per Employee. HLMF can be directed to reduce
## FINCHBURG:
Total Population = 30,000

<table>
<thead>
<tr>
<th>Industrial Category</th>
<th>Total</th>
<th>Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Basic</td>
</tr>
<tr>
<td>Agriculture, mining</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Construction</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>3900</td>
<td>3900</td>
</tr>
<tr>
<td>Transportation</td>
<td>550</td>
<td>50</td>
</tr>
<tr>
<td>Utilities</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>Wholesale trade</td>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>Food stores</td>
<td>450</td>
<td>0</td>
</tr>
<tr>
<td>Restaurants</td>
<td>700</td>
<td>100</td>
</tr>
<tr>
<td>General Retail</td>
<td>450</td>
<td>150</td>
</tr>
<tr>
<td>Auto sales &amp; service</td>
<td>300</td>
<td>50</td>
</tr>
<tr>
<td>Other Retail</td>
<td>700</td>
<td>200</td>
</tr>
<tr>
<td>Banking</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>FIRE</td>
<td>250</td>
<td>50</td>
</tr>
<tr>
<td>Repair</td>
<td>450</td>
<td>100</td>
</tr>
<tr>
<td>Private household</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Other personal</td>
<td>350</td>
<td>0</td>
</tr>
<tr>
<td>Entertainment</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Hospital</td>
<td>700</td>
<td>420</td>
</tr>
<tr>
<td>Other health</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Education</td>
<td>900</td>
<td>200</td>
</tr>
<tr>
<td>Welfare, Nonprofit</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>Professional</td>
<td>200</td>
<td>50</td>
</tr>
<tr>
<td>Public Administration</td>
<td>600</td>
<td>300</td>
</tr>
</tbody>
</table>

Totals                      | 13100 | 6150 | 4780 | 2170 |

Ratio of Service Empl. to Total Empl. = 2170/13100 = 0.166
Ratio of Service Empl. to Population = 4780/30000 = 0.159

---

Figure 3.1. Example of a Base Multiplier Calculation
**Table 3.1**
Initial Values of Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Location</td>
<td>0.163 per minute</td>
</tr>
<tr>
<td>Employee Serving</td>
<td>0.170 per minute</td>
</tr>
<tr>
<td>Residence Serving</td>
<td>0.170 per minute</td>
</tr>
<tr>
<td>Service Area per Employee</td>
<td>0.0004 square mile</td>
</tr>
<tr>
<td>Value of Time</td>
<td>8 cents/minute</td>
</tr>
<tr>
<td>Work to Home Trip Rate</td>
<td>0.36 trips/employee</td>
</tr>
<tr>
<td>Home to Work Trip Rate</td>
<td>0.04 trips/employee</td>
</tr>
<tr>
<td>Home to Service Trip Rate</td>
<td>0.18 trips/person</td>
</tr>
<tr>
<td>Service to Home Trip Rate</td>
<td>0.18 trips/person</td>
</tr>
<tr>
<td>Work to Service Trip Rate</td>
<td>0 trips/employee</td>
</tr>
<tr>
<td>Service to Work Trip Rate</td>
<td>0 trips/employee</td>
</tr>
<tr>
<td>Adjust Service Attractions?</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjust Residential Attractions?</td>
<td>Yes</td>
</tr>
<tr>
<td>Scratch Slot</td>
<td>3</td>
</tr>
<tr>
<td>Central Tendency</td>
<td>3</td>
</tr>
</tbody>
</table>
the amount of land available in a zone for residential development in order to account for the amount of land taken up by service development. The amount of land deducted from Net Developable Area depends upon the number of service employees in a zone and the Service Area per Employee Parameter. The Service Area per Employee Parameter can be calculated by dividing the total amount of land used for services by the total number of service employees. The units of area should be the same as the units used for Net Developable Area. This adjustment in land area will occur only if the Adjust Residential Attraction Parameter is set to "Y", and the Maximum Iterations Parameter is set to a number greater than 1.

Value of Time. The Value of Time Parameter allows HLFM to simultaneously consider both the time and monetary costs of trips. Numerous research studies have shown that the value of time for commuting trips is about half the wage rate. The Value of Time Parameter has units of cents/minute.

Central Tendency. The Central Tendency Parameter controls the amount of concentration of services. A large value of this parameter (e.g., 4.0 or more) will cause services to be concentrated in the more central areas of the city. A zero value will spread services roughly in proportion to market sizes (population and employment). The Central Tendency Parameter will have no effect on forecasts unless the Adjust Service Attraction Parameter is set to "Y". It is essential, when invoking the Central Tendency Parameter, to run the model through at least two iterations. The Central Tendency Parameter may be determined by a calibration procedure discussed later in this Chapter.

Trip Rates. Trip rates are used to estimate the volume of traffic on the roads in the city. In themselves, they do affect the distribution of employment and population. The trip rates can be set so that the volumes are for a single hour or for a whole day or for any other convenient period of time. A single peak hour is preferred, so that points of congestion can be readily spotted. There are six trip rates: one each for the work-to-home and reverse trip; one each for the home-to-service and reverse trip; and one each for the work-to-service and reverse trip.

The work-to-home and work-to-service (and reverse) trip rates are the average number of automobile driver trips of this purpose that an employee makes during the particular period of time. The home-to-shop (and reverse) trip rate is the average number of automobile driver trips of this type that a person makes during the particular period of time. Some examples will clarify how these parameters are calculated. Consider a city with the following characteristics: number of employees equals 18,000; number of work trips by automobile drivers made each day equals 16,000; fraction of work-to-home trips made during the evening peak hour is 0.36; and the fraction of home-to-work trips
made during the evening peak hour is 0.04. The work-to-home trip rate for the evening peak hour is, therefore, 0.32 trips/employee (0.36 trips/trips x 16,000 automobile driver trips / 18,000 employees). Similarly, the home-to-work trip rate for the evening peak hour is 0.03556 trips/employee (0.04 trips/trips x 16,000 automobile driver trips/employee x 18,000 employees). This same city has 40,000 people who make a total of 64,000 automobile driver, home-to-service (includes shopping, personal business, school, and recreation) trips and a similar number of service-to-home trips. It is found that 10% of both trip types are made during the evening peak hour, so both trip rates equal 0.16 trips/person (0.1 trips/trips x 64,000 automobile driver trips / 40,000 persons).

It is sometimes desirable to use the predicted volumes to determine which roads will be particularly congested. If the predicted volumes are to be reasonably accurate, all trip purposes must somehow be shoehorned into the six trip rates.

**Maximum Iterations.** The number of iterations is controlled by the Maximum Iteration Parameter. Normally, the model should be run through only one iteration. However, a minimum of two iterations are required if adjustments are to be made in either net developable area (to account for land taken up by services) or service developable area (to account for agglomeration). Experience has shown that three iterations are sufficient for small urban areas.

**Scratch Slot.** This parameter has meaning only if you are running HLFM on an Apple with 128 Kbytes of memory. During the calculation step, HLFM needs to create three large scratch files. One file contains the "back node" table, and two other files contain various results. When the Scratch Slot is "3", these scratch files are stored in the computer's memory. When the Scratch Slot is "6", scratch files are stored on the Master disk. You should only change the Scratch Slot to "6", if you need to save the back node table for other purposes.

**Brute Force Calibration and Sensitivity Analysis**

It is good practice, when using any mathematical model, to check if possible errors in parameters will significantly affect estimates. Such a check is called "sensitivity analysis." With sensitivity analysis, a single parameter is varied by a fixed percentage (e.g., 10%) and the percentage change in the estimate is noted. The "sensitivity" is the percentage change in the estimate divided by the percentage change in the parameter. HLFM facilitates sensitivity analysis by allowing the calculation step to be rerun without having to go back to the sketch pad or data input step. When HLFM completes its calculation, it asks if you want to try again. Entering "P" displays "Model Parameter Page I". Any parameter can then be changed, and HLFM again forecasts
population and employment when you continue from the page. You
should note that HLFM saves some intermediate results as it
calculates, so subsequent computations will go faster.

As you become more familiar with HLFM, you may find that the
default parameters are not sufficiently accurate for your city.
They can be easily changed, but shouldn't be without some basis.
It is possible to refine the parameters (calibrate the model) by
repeatedly running the program. To do this you will need to have
a network prepared for a base year. It is also helpful if you
have base-year population, total employment and service
employment for each zone and the average trip time for each major
trip purpose. It is preferable that recent home interview survey
data be used to determine the average trip times. Otherwise,
they can be approximated. For instance, average work-to-home
times are compiled by the U.S. Census, and average trip times
from other trip purposes may be transferred from other cities of
similar size and geography.

Three of the parameters are called "trip distribution
parameters" (Residential Location, Residence Serving, and
Employee Serving). They control how concentrated the forecasted
city will be. These parameters are set so that the average
aggregate trip costs (both time and money) as determined by the
model agrees with the base-year data. Determining the base-year
average aggregate trip costs requires only a small amount of hand
calculation.

An aggregate average trips cost, as reported on the Results
Summary Page, is a sum of two terms: (1) average
over-the-network driving time; and (2) average monetary costs,
converted to units of time. This conversion of monetary costs
to time units is performed by dividing them by the Value of Time
Parameter. The following is an example of how aggregate average
trip costs may be calculated for the base year. Surveys
invariably ask respondents for door-to-door time. This
doors-to-door time contains, what is called, "excess time" or the
amount of time spent walking to the car and pulling out to the
street. Excess time must be subtracted from door-to-door time to
got over-the-network time. In Finchburg the Census has reported
that home-to-work time was 12 minutes in 1980. Excess time
averages about 2 minutes at each end of the trip. Consequently,
over-the-network time is 8 minutes (12 minutes - 2 minutes - 2
minutes = 8 minutes). Gasoline costs in Finchburg are 3
cents/minute and the value of time is 8 cents/minute. The
average gasoline cost for a trip is 24 cents (8 minutes x 3
cents/minute). This is equivalent to 3 minutes of travel (24
cents / 8 cents/minute). There are not significant destination
costs in Finchburg, so the aggregate average trip cost is 11
minutes (8 minutes + 3 minutes).

The three average aggregate trip costs that are reported on
the Results Summary Page (work-to-home, home-to-service, and
work-to-service) correspond, respectively, to the first three parameters on Model Parameter Page I (Residential Location, Residence Serving, and Employee Serving). For instance, a 10% increase in the Residential Parameter will produce about a 10% decrease in the work-to-home average aggregate trip cost. This inverse relationship also holds for the other two sets of costs and parameters. Consequently, the trip distribution parameters can be systematically varied until the average aggregate trips costs are correct for the base-year. It is not necessary to determine the parameters to more than three significant digits (e.g., 0.163), so the model needs to be run only a few times for calibration purposes.

One other parameter that could require some attention is Central Tendency. This parameter controls how must agglomeration (i.e., the tendency for businesses to locate near each other) will occur in the service sector. The Central Tendency parameter should be set so that the density of service activities, as predicted by the model, corresponds to actuality. A good measure of density is the ratio of service employment to Service Developable Area. It is typical that this ratio will be larger near the center of the city and smaller near the outskirts. You should start with a Central Tendency Parameter of zero, and then increase it gradually until the model is showing the same pattern of service density. Scatter diagrams (i.e., a graphs where the actual values are plotted on the X axis and the predicted values are plotted on the Y axis) are helpful in determining where to stop. When the Central Tendency Parameter is properly selected, the points on the scatter diagram should approximate a 45 degree line, passing through the origin.

Land-use models predict equilibrium conditions for a city, but it is unlikely that your base-year data represents an equilibrium situation. Cities are always changing -- moving to another stage of development. Consequently, it would be surprising if any land-use model accurately predicted the base-year case. Instead, we would expect the model to over-estimate the amount of development in zones that are growing and to under-estimate the amount of development in zones that are declining. These differences between actual and estimated levels of development can be quite pronounced if the city has recently undergone a major change in its transportation system or a major change in its land-use policy. It is imperative that you resist the temptation to change the base-year data (particularly, the two developable areas) so that you can get an exact match between actual and estimated levels of development. Otherwise, you could build a substantial amount of error into your forecasts. It is simply not appropriate to "calibrate" your data.

Parameters should only be modified when data is available to verify that the modification is reasonable. HLEFM can produce accurate forecasts at selected zones in the base year using a complete set of false parameters. Then problems will develop
when the bad parameters are used to forecast population and employment for a future year. The laws of statistics state that there must be many more pieces of base-year data than parameters to be determined. Unless your base year population and employment data are dependable, limit calibration to the trip distribution parameters using average trip times from similar cities.
CHAPTER 4

INSIDE THE
HIGHWAY LAND-USE FORECASTING MODEL

HLFM is built around the the Lowry-Garin land-use model (Lowry, 1964; Garin, 1966). Essentially, the Lowry-Garin model predicts the amount of employment and the amount of population in each zone that is within an urban area. To do this, the model requires information about the highway system, information about demographic and socioeconomic characteristics of the population, and information about existing and proposed land uses. HLFM extends the Lowry-Garin model by permitting constraints on the total amount of land that may be allocated to various activities and by allowing for the possibility for agglomeration in services. HLFM also enables the planner to maintain consistency between projected land use and the volume of traffic that occurs on the streets in the city.

HLFM is designed to produce a forecast that is consistent with the original description of the physical transportation network. Operationally, this means that congestion (and travel delays) that are predicted by the model should be fully represented in the forecast. This condition will not be satisfied when the initial travel times for the streets in the network are chosen arbitrarily. Instead, an iterative procedure (shown in Figure 4.1) is required to modify initial travel times until this condition holds. This iterative procedure is called an "equilibrium land-use model".

In an equilibrium land-use model, like HLFM, network characteristics and land use characteristics are specified by the planner. The model first calculates time and cost of travel between all pairs of zones on the basis of only the given network description. Then spatial distributions of population and employment are calculated using trip distribution equations and the Lowry-Garin model. These population and employment distributions are used by HLFM to predict travel patterns in the urban area, which includes traffic volumes on each street. The planner can then observe where congestion has developed, recalculate travel times for those particular streets, and rerun the Lowry-Garin model. When the travel patterns are unchanged over two successive iterations, the planner can terminate the procedure.

The allocation phase of the equilibrium model in Figure 4.1 is expanded in Figure 4.2. Three trip distribution equations (work-to-home, home-to-service, and work-to-service) are used to
Input: Transportation Network

Calculate smallest generalized cost between zones

Allocate Employment and Residences (Figure 4.2)

Compute Peak-hour Trip Distribution

Assign trips to Network

Manual review if traffic volumes

Manual adjustment of network travel times

Yes

Road segments in excess of capacity?

No

Stop

Figure 4.1. Major Steps in the Use of HLFM as an Equilibrium Land Use Model
construct the employment conservation equation that is at the heart of the Lowry-Garin model. This employment conservation equation, derived later in this chapter, is solved for the spatial distribution of total employment. Once the spatial distribution of total employment has been found, then the spatial distribution of population can be calculated from the same work-to-home trip distribution equation.

Garin Version of the Lowry Model

The Garin version of the Lowry model is a series of matrix equations that forecasts the distribution of population and employment in an urban area. The Lowry-Garin model recognizes only four land-use activities: residential, basic industries, service industries for population and service industries for businesses. Basic industries (i.e., industries that receive their income from outside the urban area) are assumed to be fixed at known locations. The Lowry-Garin model attempts to maintain proximity of workers' residences to their workplaces and to maintain proximity of service industries to their respective markets (either residences or other business, depending on the type of service activities).

The Lowry-Garin model is derived here by constructing an employment conservation equation. Let E be a vector of total employment (each element, \( e_i \), of E being the total employment of the \( i \)th zone), \( E_B \) be a vector of basic employment, \( E_R \) be a vector of service employment required by residences, and \( E_W \) be a vector of service employment required by workers (i.e., businesses). Total employment is thus the sum of its three components:

\[
E = E_B + E_R + E_W \quad (4.1)
\]

Each of the three vectors on the right hand side of Equation 4.1 represent the spatial distribution of a sector of employment in the urban area. Basic employment, \( E_B \), is the only exogenous variable in the Lowry-Garin model. Employment serving residences, \( E_R \), and employment serving workers, \( E_W \), are dependent upon trip making patterns, the transportation system, and existing land use. Essentially, Equation 4.1 states the obvious condition that total employment in each zone must be equal to the sum of that zone's employment over all sectors.

Employment in industries that serve workers, \( E_W \), is calculated by distributing service employees around all employment locations as given by the vector E. Define \( h_{ij} \) as the conditional probability that an employee in zone \( j \) is served by another employee in zone \( i \). Denote this matrix of conditional probabilities as \( H \). Also define \( f \) as the number of service employees required for each employee, averaged across the whole
Figure 4.2. Allocation of Employment and Residences
urban area. The matrix $H$ is used to distribute service employees to zones according to the location of total employment. That is,

$$E_W = f H E$$  \hspace{1cm} (4.2)  

A similar relation can be constructed for employees serving the entire population. Define $b_{ij}$ as the conditional probability that an individual who lives in $j$ is served by an employee in $i$. This conditional probability matrix is $B$. Also define $g$ as the number of employees that serve each individual, averaged across the whole urban area. Then, as in Equation 2,

$$E_R = g B P$$  \hspace{1cm} (4.3)  

where $P$ is the population vector, containing elements, $p_i$, each of which is the population in zone $i$.

Population distribution is computed from total employment. Define $a_{ij}$ as the conditional probability that an individual working in $j$ lives in $i$. Let $A$ be the matrix of these conditional probabilities. Also define $q_i$ as the ratio of population to employees in residential zone $i$. Furthermore, let

$$Q = [K_{ij} \ q_i]$$  \hspace{1cm} (4.4)  

where $K_{ij}$ is the Kronecker delta. That is,

$$K_{ij} = 1 \text{ if } i = j$$  

or

$$K_{ij} = 0 \text{ if } i \neq j$$  

Note that $Q$ is a diagonal matrix. Populations of all the zones are found from:

$$P = A Q E$$  \hspace{1cm} (4.5)  

Consequently, from Equations 3 and 5,

$$E_R = g B A Q E$$  \hspace{1cm} (4.6)
Substituting Equations 2, 3, and 6 into Equation 1 reduces the employment conservation equation to one with terms for only total employment, \( E \), and, basic employment \( E_B \), i.e.,

\[
E = E_B + g B A Q E + f H E
\]  
(4.7)

Equation 7 can be solved for the spatial distribution of total employment, \( E \), in terms of basic employment. Specifically,

\[
E = (I - g B A Q - f H)^{-1} E_B
\]  
(4.8)

The spatial distribution of population can be computed from Equation 5, and the spatial distributions of employment in the two service sectors, \( E_W \) and \( E_R \), are directly computed from Equations 2 and 6.

The base multipliers (\( g, f \) and \( q_i \)) should be prepared by the planner from existing data sources. The three conditional probability matrices (\( A, B \) and \( H \)) are computed from trip distribution equations that are discussed in the next section.

**Trip Distribution**

The trip distribution equation most often encountered in recent literature and the one used in HLFM has an exponential deterrence function. Specifically for work-to-home trips, the \( A \) matrix can be found by

\[
a_{ij} = w_i \exp \left\{ -u^a c_{ij} \right\} / \sum_i w_i \exp \left\{ -u^a c_{ij} \right\}
\]  
(4.9)

where \( c_{ij} \) is the generalized cost of travel between zones \( i \) and \( j \), \( w_i \) is the "attractiveness" for residential zone \( i \), and \( u^a \) is the work-to-home parameter. HLFM uses net developable area for \( w_i \). This trip distribution equation implies that modal choice decisions do not enter into the location process, and \( c_{ij} \) can apply to all travelers regardless of chosen mode.

The generalized cost of travel is computed as if trips followed the shortest path between pairs of zones in the urban area. That is,

\[
c_{ij} = (1 + y/v) t_{ij} + d_j/v
\]  
(4.10)
where $t_{ij}$ is the shortest travel time, $y$ is the cost per minute, $v$ is the value of time parameter, and $d_j$ is the automobile destination cost.

An efficient calibration technique has been developed for the case where all constants of the generalized cost function are known -- as is the normal situation with HLFM (I. Williams, 1976; Hyman, 1969; Hathaway, 1975; and Evans, 1971). The maximum likelihood estimate of $u^a$ (or, in fact, any trip distribution parameter) satisfies the condition that predicted average cost of travel over all trips, $c(u^a)$, equals observed average cost of travel, $c^*$:

$$c(u^a) = c^* \quad . \quad (4.11)$$

Here the computed generalized cost of travel is shown as a function of $u^a$. HLFM calculates $c(u^a)$ each time it is run. So if the planner has independent knowledge of $c^*$, the average network generalized cost, then HLFM can be used to calibrate itself.

The $B$ and $H$ matrices for home-to-service and work-to-service trips, respectively, in the Lowry-Garin model are constructed similarly to the $A$ matrix. Again, singly constrained trip distribution models of the exponential type are used. Generalized cost functions are constructed for trips to each service sector; and service attractiveness, $s_i$, is used in place of the residential attractiveness, $w_i$. Again, mode distinctions are ignored, resulting in two equations:

$$b_{ij} = s_i \exp\{-u^b c_{ij}\} \Big/ \sum_i s_i \exp\{-u^b c_{ij}\} \quad , \quad (4.12)$$

and

$$h_{ij} = s_i \exp\{-u^h c_{ij}\} \Big/ \sum_i s_i \exp\{-u^h c_{ij}\} \quad . \quad (4.13)$$

In these equations $u^b$ is the home-to-service parameter and $u^h$ is the work-to-service parameter. The service attractiveness, $s_i$, should be chosen to reflect the size of the $i$th zone. The data input step of HLFM requests that $s_i$ be the "nonbasic developable area"; or, in other words, the total amount of land in a zone, less land that is either unusable for development or devoted to basic industry.
Adjustments to Residential Attractiveness

Land area does not formally appear in either the Lowry-Garin model or in the trip distribution equations. Nonetheless, land area has been introduced into HLFM by making residential attractiveness, wᵢ, equal to net developable area and by making service attractiveness, sᵢ, equal to service developable area. The trip distribution equations will assign activities to zones roughly in proportion to these developable areas. If, for instance, it is found that HLFM is assigning too much population to a given zone, the population can be reduced on subsequent runs by decreasing net developable area.

One reason why activities can be over-assigned to a zone is that the Lowry-Garin model disregards land capacity. If a zone is almost fully occupied by service activities, then only a few people should be able to live there. But the Lowry-Garin model will assign people to the zone as if the service activity did not exist at all.

HLFM can be instructed to reduce residential trip attractiveness in response to large allocations of service employees to a zone. This is an iterative procedure as indicated in Figure 4.2. In order to use this feature three parameters must be changed. The "adjust residential attractiveness?" question must be answered "Y"; "maximum iterations" must be set to a number greater than 1; and "service/area per employee" must be set to a number greater than zero. When HLFM is run, the residential attractiveness on iteration n (after the first iteration) are based on the amount of service allocated at iteration n - 1. Specifically,

\[ W^n = W^1 - z (E^n_{R} + E^n_{W}) \]

where

- \( W^n \) = the vector of residential attractiveness at iteration n;
- \( W^1 \) = the vector of residential attractiveness at the first iteration as specified in the data input step;
- \( z \) = service area/employee;
- \( E^n_{R} \) = the vector of the number of employees that serve residences as calculated on iteration n-1; and
- \( E^n_{W} \) = the vector of the number of employees that serve other employees as calculated in iteration n-1.

Residential attractiveness at any iteration, \( W^n \), is constrained
to be greater than or equal to zero. This procedure for adjusting residential attractiveness effectively incorporates the notion of land capacity into the forecasts.

Adjustments to Service Attractiveness

Even in small cities, significant agglomeration in the service sector can occur. The Lowry-Garin model does not provide for agglomeration even though Lowry did recognize that certain zones would attain high levels of service activities. The original Lowry model permitted the planner to set the minimum amount of service employment that could occur in a zone.

HLFM handles agglomeration by making upward adjustments of service attractiveness from those set by the planner. The underlying assumption in HLFM is as follows: agglomeration will occur in zones which have the highest potential to attract a disproportionately large share of customers. These zones will tend to be central to the region or near large concentrations of population. A minimum of two iterations of HLFM are required -- the first iteration establishes the "potential" and the second iteration actually distributes the home-to-service and work-to-service trips according to this potential. The measure of potential is continually updated as the number of iterations is increased.

Here is a summary of how each iteration is handled.

Iteration 1:

a. Guess the population in each zone for the first iteration as a multiple of basic employment in the same zone using this equation:

\[ p_i^1 = e_{Bi} \left( \frac{q_i}{1 - q_i g - f} \right) \]  \hspace{1cm} (4.15)

where \( e_{Bi} \) is the basic employment in zone \( i \).

b. Run the Lowry-Garin model using service developable area, \( S_1 \), as specified by the planner for the measure of service attractiveness. At the same time calculate service potential, \( M^1 \):

\[ M^1 = g B^1 p^1 \]  \hspace{1cm} (4.16)

Notice that \( M^1 \) would have been the same as \( E_r \) if \( p^1 \) had been gotten from the Lowry model instead by just guessing it through Equation 15. Calculate a new population vector, \( p^2 \), in the
normal way with Equation 5.

c. Recalculate the measure of service attractiveness, \( s_i^2 \),
for the second iteration.)

\[
s_i^2 = s_i^2 \left( \frac{m_i^1}{s_i^1} \right)^k
\]

(4.17)

where \( k \) is the central tendency parameter. Then continue to the
next iteration.

Subsequent iterations:

a. Estimate service potential, \( M \), while the Lowry-Garin
model is being run

\[
M^n = g B^1 p^n
\]

(4.18)

where \( p^n \) had been calculated on the previous iteration and \( B^1 \) is
from the first iteration.

b. Recalculate service attractiveness,

\[
s_{i}^{n+1} = s_i^1 \left( \frac{m_i^n}{s_i^1} \right)^k
\]

(4.19)

For this procedure to work well, the term \( \left( \frac{m_i^n}{s_i^1} \right) \) should be a
measure of concentration, so \( s_i^1 \) should be a measure of the size
of the zone. It can be seen from Equation 19 that when \( k \) equals
zero the results will be identical to the case of no
agglomeration. As \( k \) is increased, service employment will
increase in the more central zones and decrease in outlying
zones. A large value of \( k \) can force HLFM to forecast that all
service employment will be located in a single zone.

Traffic Assignment

Traffic is loaded on the network using all-or-nothing
assignment. There are a total of six trip purposes, and the
amount of traffic is governed by the six corresponding trip rate
parameters. The number of work-to-home trips between zones \( i \) and
\( j \) are found from:

\[
T_{ij}^{wh} = r_{wh} e_{i} a_{ij}
\]

(4.20)

where \( r_{wh} \) is the work-to-home trip rate parameter. For the
reverse trip:
Inside HLFM

\[ T_{ji}^{hw} = r_{ji}^{hw} e_i a_{ij}, \]

(4.21)

where \( r_{ji}^{hw} \) is the home-to-work trip rate parameter. Similarly, the home-to-service trips can be found from:

\[ T_{ji}^{hs} = r_{ji}^{hs} p_i b_{ij}, \]

(4.22)

and the service-to-home trips are found from:

\[ T_{ji}^{sh} = r_{ji}^{sh} p_i b_{ij}, \]

(4.23)

where \( r_{ji}^{hs} \) is the home-to-service trip rate and \( r_{ji}^{sh} \) is the service-to-home trip rate. Finally, work-to-service trips are computed by:

\[ T_{ij}^{ws} = r_{ij}^{ws} e_i h_{ij}, \]

(4.24)

and service-to-work trips are computed by:

\[ T_{ji}^{sw} = r_{ji}^{sw} e_i h_{ij}, \]

(4.25)

where \( r_{ij}^{ws} \) is the work-to-service trip rate and \( r_{ji}^{sw} \) is the service-to-work trip rate.

It should be noted that the work-to-home, the work-to-service, and the corresponding reverse trip rates are based upon total employment in zones. The home-to-service and service-to-home trip rates are based upon population in zones.

Other Computational Considerations

Computation Time. If you are dealing with a large network, be prepared to wait a few minutes for HLFM's ridership estimates. You may estimate computation time for the first iteration in minutes by the following formula:

\[ \text{Computation time} = 0.03 \text{ (centroids)}^2. \]

Calculations will take a little less time if there are relatively
few network nodes. Expect calculation time to increase by as much as 50 percent for each iteration beyond the first.

**Error Handling.** HLFM is designed to check for many common errors. However, a particularly creative user can find ways to abort computation in the middle of the calculation step. The causes of most errors are improper specification of the network or improper setting of parameters.

During the sketch pad and data input steps, HLFM's usual response to an obvious error is to not do anything. If you find that HLFM is repeating a question, it is because it didn't like your previous answer. On the sketch pad HLFM will not let you plot the 201st node, it will not let you plot a node in the menu area, it will not let you select an already blue node as the starting node for a link, it will not let you continue from the sketch pad if nothing has been plotted, and it will not let you plot the 321st link. If the sketch pad is not responding in other situations, it is probably because you have missed with the arrows. In the data input step HLFM will not let you designate more than 40 centroids.

It is impossible for HLFM to check whether the data you have entered has been typed correctly. Therefore, you should be very careful when entering data and you should always view any new data you have entered. HLFM's response to erroneous data is an erroneous forecast of ridership.

**For Further Reading**


