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Estimation of distances and travel times between arbitrary addresses

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ABSTRACT

Methods to estimate travel distances and times in a region either relating addresses to zones or to the road network are presented.

Characteristics that zones should have and subset of road network that should be used, statistics and formulae that enable distances and times to be estimated are presented.

Relations between zone based models and network ones are discussed, each one being able to improve the other one.

An adaptable and dynamic model based on the previous ones is specified together with its data structures requirements; computationally efficient methods to estimate times and distances are developed and criteria to detect when and where changes are needed are introduced, resulting from validation procedures.
To
my mother and father
my brother Francisco
and to
Paula Alexandra

For all my Dreams
I thank you
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NOTATION

a  proportionality constant between straight line distance and actual distance
A  zone area
c  proportionality constant between expected travel time and square root of zone area
d  travel distance
d_e  euclidean distance (or straight line distance)
d_m  right angle distance (or manhattan distance)
d_r  radial and ring distance
D  equivalent delay per function
e  journey distance error
E  maximum distance error allowed for a certain percentage of journeys
ETD(I,J)  travel distance from zone I to zone J (E for External)
ETT(I,J)  Travel time from zone I to zone J
E[x]  expected value of variate x
I  zone number
ITD(I)  in-zone I travel distance
ITT(I)  in-zone I travel time
J  zone number
L_a  actual journey distance
L_e  estimated journey distance
N  number of junctions along link
P  percentage of journeys with estimated distance error greater than a given number E of Km
P_i  point in zone I
r  radius of a circle
R  Ratio of right angle to euclidean distance
s  travel speed
t  travel time
\[ x \]

- \( x_1 \): value of variate
- \( Z \): number of zones in a region
- \( \alpha \): proportionality constant between dimensions of a zone
- \( \sigma_x \): standard deviation of variate, \( x \)
- \( \sigma_{x^2} \): variance of variate, \( x \)
- \( \approx \): approximately equal to
CHAPTER ONE

INTRODUCTION

A computer aided planning system like the one that schedules outpatients in the non-urgent ambulance service relies on accurate knowledge about travel distances and times between patients addresses.

Estimation of travel distances and times between patient addresses is then an important subject of study. However, it is not a particular problem of an ambulance planning system. Similar situations arise for example when planning gas and electricity house booked services or collection and delivery of parcels.

The main problems came from the facts that:

1. Addresses are randomly distributed in time and space and it may be difficult to localize them precisely, for instance in long roads.

2. Distances between addresses are not precisely known as road network characteristics, even if known to the finest detail, such as one way streets, also change with time.

3. Average travel speed varies with day hour, kind of vehicle, driver and weather conditions, for example.

4. There are computational constraints to the maximum information stored and there is a maximum allowed reference time of the computer aided planning system.

Referring the last point, the planning algorithms will have to seek distances and travel times between addresses many thousands of times, before giving a first schedule. So it is very important that those parameters can be made available very fast each time.
Ideally, distance and travel time between any two addresses should be always available as soon as it is needed.

Two main models have been under study. The first one divides a geographic region in zones, each zone characterised by its area and boundaries. Addresses in the same zone might be seen as indistinguishable from each other. The second one considers addresses related to junctions of the road network. The geographical region is characterised by junctions and road segments. Addresses related to the same junction may or may not be distinguishable. Both models have associated to each address some uncertainty in localization.

What characteristics should have each zone, area and boundaries, and what junctions and road segments are necessary is the question to be answered.

In static model, once chosen those characteristics, this can only be changed in an overall way. So it was also developed a mixed dynamic model that is able to locally, and as necessary, refine itself to local and necessary changes. It will also be able to provide better distance and travel time estimation as information is gathered.

As with every problem that is not deterministic, the purpose is to have estimated parameters that are good enough most of the times. This requires that to "good enough" and "most of the times" be given some statistical significance. If, where and when, results are not within the established limits, then refinements to the model characteristics have to be made. This is the purpose of model validation, in this case, checking that zones or network models give distances and travel times between addresses that do not differ from actual distances and travel times between addresses more than allowed.

Good enough, most of the times is our actual optimum.
CHAPTER TWO
LITERATURE SURVEY

2.1 SUBJECTS OF RELEVANCE

The non-urgent ambulance service has its own peculiarities in what refers to estimation of distances and travel times. For instance, the particular kind of vehicles used and the numbers of patients that can be handled by each one, will be different from other handling services. When using some models this can have some implication. As an example, the expected travel distance in a zone will be different for a vehicle with capacity for two or three patients.

However, most of the problems involved when choosing a particular method of estimating distances and travel times, are common to a larger group of transportation problems. (see chapter one).

In this way, although some insight in ambulance related problems is important, general estimation techniques and information about distance and time in real world have been carefully surveyed. Statistics about speeds in different areas and day periods are important for derivation of actual travel times. Relations between road map and actual distances, according to statistical data and different models, give practical ways of estimating distances.

Some, network or mixed models, which deal with practical situations, give answers to the problem, each one with its weak and strong points. These have been the areas of literature survey.
2.2 REFERENCES OF MOST USEFULNESS

2.2.1 TRRL REPORTS AND OTHER STATISTICS

The Transport and Road Research Laboratory has published a number of useful statistics and reports about travelling speed in different areas of the U.K., different years, rural and urban areas, peak and off-peak hours, taking into account different kinds of roads. (Taylor, 1981; Marlow, 1978; Duncan 1974; TRRL, LF 779, 780, 923 - 925).

Some of the reports also give elaborated network based models of the road network, taking into account characteristics of junctions such as delay and possible turns, and road segments such as type, distance, amount of bends and hills from which speed can be estimated. (Taylor, 1981).

Wilson presents some useful statistics and references of travel distances, speeds and times, mainly for the Greater London region (Wilson, 1967).

2.2.2 MORRISON ROAD SPEED MAPS AND PAPERS

Morrison has several papers about improving the usefulness of maps for estimating travel times. In collaboration with the TRRL he has designed (1983) maps for the South East of England where roads are classified according to speed. Relevant information about traffic speed in different kinds of roads can be found in (Morrison, 1981) and accuracy of measurements and minimum segments that should be accurately represented in (Morrison, 1971). This last reference highlights some of the problems of measuring distances from maps, in different scales, directly from the apparent road line.
2.2.3 LARSON AND ONNI URBAN MODELS (Larson, 1981)

Expected travel times and distances in urban zones with different underlying models are derived. Manhattan like towns, circular and radial towns, with constraints of various kinds, like one-way streets are discussed. Sensitivity analysis of variations in expected travel distances and times due to variation in shape of zones and existence of barriers to traffic, like rivers, parks or lakes is done.

Also urban modelling based in network and graph theory are introduced and compared with actual situations. Some simple but relevant algorithms dealing with graph modelling of urban situations are explained, taking into account some actual constraints.

2.2.4 MANSOURPOUR AND TAWEEL ZONING MODELS ANALYSIS

(Mansourpour, 1982; Taweel, 1983)

Mansourpour studied the effects of a different number of zones, within a fixed area region, when estimating distances. The model was able to simulate in the same region urban and rural like sub-regions. A critical point was the internal travel time that should be considered, and that should impose a maximum size in the area of a zone.

Taweel investigated existing zoning patterns and made some recommendations about the shape of zones and their relation to road networks and locality of Hospitals, among others. Numerical data from a simulation model has shown the importance of the number of zones relate to errors when estimating travel distances and particularly internal travel distances. Problems of inconsistency arising from ill-defined zoning patterns were illustrated.
2.2.5 BABA BAASE GRAPH ALGORITHMS (Baase, 1978)

Baase presents the principles of design and analysis of efficient graph algorithms. Relevant implementations, data structures, memory space usage and efficiency are presented, and trade-offs between them are analysed.
CHAPTER 3
CHAPTER THREE

RELATIONS BETWEEN STRAIGHT LINE DISTANCES, REAL DISTANCES AND TRAVEL TIMES IN ZONE MODELS

3.1 INTRODUCTION

In certain situations it is rather difficult to know the travel distance between two arbitrary points, as was pointed out in chapter one. Sometimes we do not know precisely where the points are; given an address, it may be quite difficult to localize it. Also, there are often several paths from one to the other; in a town map, it may be even difficult to say if we are allowed to travel in some streets.

Actually, it is the amount of information about the road network that prevent us from estimating as accurately as we might want real distances. Usually costs in gathering that information will turn our minds to approximate models.

If distances are known, travel times can be estimated under considerations of travel speed. Due to statistical knowledge about speeds, most models only work with one or two average speeds, for instance peak and off-peak.

A useful model assumes that a region can be seen as a set of zones, each one with simplified characteristics. There are urban zones and rural zones; each one can be simplified in some different ways. What main characteristics should be preserved in each model is the problem, and the challenge.
3.2 ZONE MODELS

When dealing with a geographical region, urban zones and rural zones are quite different. Average speeds are different and road network characteristics, such as lay-out, are different.

So, when estimating travel distances and times in urban and rural zones, distinct models should be used.

3.2.1 URBAN ZONES

Urban zones can be classified according to street patterns. We may see a grid of parallel streets crossing at right angles. This kind of geometric pattern is sometimes referred to as having a discreet right-angle metric, or Manhattan metric. We may also see a central point with converging streets, and circular streets centred in that point. This time a radial and ring metric exists.

Real urban regions are usually a mixture of both.

Fig. 3.1 Urban Models
3.2.1.1. Manhattan Metric

If points are uniformly and independently distributed over a zone with an right-angle metric, the expected travel distance is minimized for a square zone, under constant area constraint. If Λ is the zone area, \( d_m \) the right-angle (Manhattan) distance,

\[
d_m = |x_i - x_j| + |y_i - y_j|,
\]

(3.1)

where \((x_i, y_i)\) and \((x_j, y_j)\) are the co-ordinates of two arbitrary points, then the expected value of \( d_m \) is:

\[
E[d_m] = \frac{2}{3} \sqrt[3]{\Lambda} \approx 0.67 \sqrt[3]{\Lambda}
\]

(3.2)

However, due to the discreet nature of streets and one-way systems, this result can go up to a third of the block average side (fig. 3.1) and to two block sides respectively. (Appendix B).

As can intuitively be seen, the larger the area, the smaller the error involved in the first approximation.

In this model the right angle distance, \( d_m \) is the actual distance travelled, \( d = d_m \). There is a strong relationship between \( d_m \) and \( d_e \), the euclidean distance. (Appendix A). This relationship can be used to estimate distances between zones in a Manhattan-like region:

\[
d_m \approx 1.27 \ d_e
\]

(3.3)

Statistical data support this conclusion if distances are not greater than 10 Km (Appendix D).
3.2.1.2 Radial and Ring Metric

Under equal point distribution as in the previous model, but a circular zone, if \( d_r \) is the distance,

\[
d_r = |r_i - r_j| + \min (r_i, r_j) |\theta_i - \theta_j| \tag{3.4}
\]

where \((r_i, \theta_i)\) and \((r_j, \theta_j)\) are the polar co-ordinates of two arbitrary points, and if travel crossing the central point is forbidden then (Appendix B):

\[
E[d_r] \doteq 0.62 \times \sqrt{A} \tag{3.5}
\]

if not, then:

\[
E[d_r] \doteq 0.56 \times \sqrt{A} \tag{3.6}
\]

3.2.1.3 Comparison of travel times

The expected travel distance decreases in the previous models. If expected speeds were equal the expected travel time would also decrease. However, it may be argued that travelling in the centre of a town would decrease the average speed. On the other way, traffic in a town like Coventry is similar to the one in a Radial and Ring model. In this town, traffic characteristics are quite good.

We might conclude that under equal average speed, expected travel times for a Manhattan town are greater than for a Radial and Ring town, if traffic crossing the centre is not allowed, or not encouraged.
3.2.2 RURAL ZONES

Rural regions have a much spread road network. Usually, they are crossed by several fast roads, linking urban regions. Between these fast roads there are usually slower ones.

![Diagram of rural region with urban regions, fast roads, and slow roads]

Fig 3.2 Rural Region

If we assume that distances over a rural region are euclidean the expected distance would be:

\[ \mathbb{E} [d_e] = 0.52 \times \sqrt{A}, \]  

(3.7)

for a fairly convex and compact zone, this is, an almost square or circular zone (see 3.3).

A correction factor of 1.30 taking account of the actual road network would give:

\[ \mathbb{E} [\hat{d}] = 0.68 \times \sqrt{A} \]  

(3.8)
Both relations are supported by statistical models and data available (Appendices B and D).

When expected distances between zones have to be evaluated they can be found by the relationship:

\[ d = a \times d_e \]  

(3.9)

where \( a \) goes down from 1.30, for distances smaller than 8 Km, to 1.15 for distances greater than 18 Km (Appendix D).

3.3 ZONE AREA. ROBUSTNESS OF SHAPE VARIATION

From the previous points, expected travel distances are strongly related with zone area. The relation is almost the same for both urban and rural zones. The proportionality constant is also robust to variations in zone shape. It is valid for any shape as long as one of the dimensions is not much greater than the other dimension, and major barriers or boundary indentations do not exist in the zone. (Appendix B). Zones that satisfy both of the conditions will be called fairly compact and convex zones. It will be shown in Chapter four (4.6) that zones with these characteristics also help to build a consistent travel time matrix, i.e. internal (in-zone) travel times are smaller than external travel times (from the zone to the others).

The main difference between urban and rural zones will be the expected travel time. For equal expected in zone travel time, urban zones must be smaller, as expected speed is lower than in rural zones. The expected travel time is:

\[ E[t] = \frac{E[d]}{E[s]} \]  

(3.10)

(\#) The correct relationship is \( E[t] > E[d]/E[s] \), because \( E[1/s] \neq 1/E[s] \). See for example (Larson, 1961).
3.4 MINIMUM ZONE AREA

There is evidence that zones such that expected internal travel time is less than one minute, cannot be precisely defined. Also they wouldn't be either useful or manageable. (Morrison, 1980).

For urban average speed of 20 Km/h we get a 0.25 square Km urban zone. (From expressions (3.2) and (3.10)).

For rural average speed of 60 Km/h we get a 2.25 square Km rural zone (From expressions (3.8) and (3.10)).

![Diagram of urban and rural zones]

Fig 3.3 One minute square zones

The main reasons for this lower limit are:

1. It is statistically difficult to get accurate expected speed estimates for small regions due to overwhelming local characteristics such as traffic lights, or different speeds in different sections or ways of the same road. (Morrison, 1980).

2. Only a small percentage of ambulance non-stop journeys will be less than one minute and in those cases handling time will be the relevant one. (Hansourpour, 1982).
3. Difficult to say which zone belongs to which address as streets and roads will belong to different zones.

3.5 DEALING WITH NATURAL OR ARTIFICIAL CONSTRAINTS

When estimating distances between zones, a common procedure is to measure the straight line distance in a map, between the centre of the zones. If a uniform distribution of points is expected, the geometric centre, otherwise a probabilistic centre. The distance found is then corrected by expression (3.9).

However, there are quite a few situations where it would not be advisable to use this procedure. If the straight line crosses for example,

1. a river without bridges,
2. an estuary, a gulf, a lake or the sea,
3. a region without roads such as a park or a mountain,
4. a motorway or a railway without bridges.

These situations will be regarded as constraints if their extension is of the same size as the zoning pattern.

Fig. 3.4 Geographical Constraints
The solution is to consider the feasible straight line, i.e. the straight line distance will be the sum of a number of straight line sections taken over feasible travel regions (Fig. 3.3).

It is advisable to make some validation if these situations are frequent. One can measure road distance in a small scale map, compare them with the feasible straight line distance and find from such a sample the correction constant. Confidence limits can be considered.

Instead of making the approximation, measuring from a small scale map the road distance would be a more accurate procedure. However, it may be time consuming. Chapter 5 and 6 will deal with this kind of procedure.

3.6 CONCLUSIONS

Expected travel distances inside zones are directly related with the square root of the zone area. Travel times are inversely related with expected speed.

Travel distances between zones are strongly correlated to straight line distances, the relationship having to be corrected to the range of distance and adjusted to natural or artificial constraints.

Due to a more uniformly distributed population and road network in urban and suburban areas the urban models described can more easily reproduce actual characteristics of those regions. In rural regions, however, it will be seen in chapter five and six that network models alone or combined with zone ones will be more close to real environments and purposes of the study, this is, estimating distances and travel times.
CHAPTER 4
CHAPTER FOUR

GEOGRAPHIC ZONING PATTERNS, SIZES AND CHAIRMEN

4.1 INTRODUCTION

When zoning a region, two objectives must be in our minds; first, the zoning pattern must allow distances and travel times to be estimated between any two points; second, it must do it in such a way that the computer based planning system will give consistent and statistically accurate journeys. By this we mean for example that planned journeys will be close to actual short distance/time journeys and planned distances/times will be close to actual ones.

The closeness and variation will be checked against the deviation allowed by ambulance planning management from a sample of journeys according to confidence limits that are set up for a validation procedure.

Journeys will take place in an actual road network, under actual traffic conditions, and stop points eventually changing from day to day. The density of stopping points will be related to where population lives. Journeys will be oriented to Care Units such as Central Hospitals.

The size and shape of zones must take all this into account. Deviations not allowed, may give evidence that zone boundaries have to be changed or that some zones should be smaller. The size and shape of zones must follow considerations of actual road network configuration and intensity of traffic, of population distribution such as patients distribution and localization of care units. Special zones will improve the quality of computer planned journeys. Taweel has established some influence on zoning (Taweel 1983).
4.2 INFLUENCE OF POPULATION DENSITY

It is evident that places where more people live usually will have more patients to be picked-up. The distribution of these last ones is the important one as far as the ambulance service is concerned. However, as it may change, overall population densities will be a reference to where there is more chance of future patient distribution.

The urban region, with more people, will have more patients than rural regions, and the distribution of patients will be different in each situation.

Patients are not usually uniformly distributed over a region either it is urban or rural. In rural regions it is mainly in the villages or small rural towns. In urban and suburban regions certain blocks of houses or zones, such as where retired people live, will have higher concentration of patients than others. A practical way of finding, in a region like a county, the rural and urban regions, could be the following: wherever an urban region exists and should be seen as a separated one, a map with street names is published and available. The rural region is everywhere else, and the maps available will be for instance the 1:50000 Ordnance Survey or based upon them.

4.2.1 ZONE SIZE DERIVED FROM POPULATION DISTRIBUTION

We will consider the rural situation. However, the urban one is similar.

If patients were always closely grouped around points like villages, and in between there were none, the number and average area of zone could be found. In this case in-zone travel time could be set to zero.
Although this is not the actual pattern, it is a good image of it. Most of the time groups of patients can be reduced to a central point because they are clustered. (Haynes 1979 and Jarvis 1975).

This is sometimes referred to as a zone reporting centre (Jarvis 1975).

![Diagram](image)

Fig 4.1 Zone Reporting Centre

Even if a cluster is not evident, a reporting centre can be seen as a village or a road junction around which patients are uniformly distributed. Chapter 5 gives another model to deal with this situation. Taking into account these centres, the number and average area of zones can be estimated.

4.2.2. TRAVEL DISTANCES AND TIMES

Travel distances and times between zones will be estimated thinking of distances and travel times between zone reporting centres. Either by measuring road distance (for instance in a large scale map) and taking into account average speed in that road or by correlations between straight line distance and actual distance and travel time. (Both methods and statistics to do this are covered in appendices).

In-zone travel times and distances will not be zero. However, they can be calculated based in an effective zone area. This is the area in a zone where a uniform distribution of patients can be expected and where most of the patients will be found.
More detailed information on this subject can be found in Appendix F.

4.3 DEALING WITH HOSPITALS AND CARE UNITS

In the way the computer aided planning system works, zones where hospitals and care units are located, would be intensely used. Where delivering (or picking-up) patients the in-zone time would be added when necessary.

It is then necessary that they will be a set of special zones, point like zones, with zero in-zone travel distance and time. Travel times and distances to other zones (ETT, EDT) will be found as in 4.2.2.

However, to the zone where the care unit is, the values should be between the in-zone ones and zero, a reasonable value being half of the in-zone travel distance and time.

![Diagram of Zone Z with Ho point]

Ho: Hospital or care unit point zone
In zone parameter: IT (Z)
0 < EDT (Ho, Z) < ITD (Z)
0 < ETT (Ho, Z) < ITT (Z)

Care units will also influence where boundaries of zones should be drawn. This is a crossed influence with the road network. (4.4).

If there are a number of main roads or directions followed by ambulances when travelling to or from a hospital, then the zones where each one should be stopping must not be mixed. This concept is illustrated in figures 4.2 and 4.3. (Taweel 1983).
fig 4.2 three zone solution under usual ambulance flow

fig 4.3 two zone solution under usual ambulance flow

If in some place there is an address where ambulances usually stop to pick-up, say, 4 or more people, it may be a good idea to define this address as a point zone. This way in-zone travel parameters will be taken as zero, giving a more accurate overall planned journey.
4.4 INFLUENCE OF THE ROAD NETWORK

Roads are designed to allow easy traffic flow. However, they can also behave like barriers when we want to cross them. Only in special points motorways and carriageways can be crossed. Bridges, tunnels, roundabouts for example. Also jammed roads, in this sense, behave like barriers. Crossing points in this case can be traffic lights where it may be easier to cross them.

Zone boundaries will have to be drawn over these barriers. Distances between crossing points, compared with the average zone area (4.2.1) will be the main criteria to decide if and where boundaries will be. The following figures (4.4, 4.5, 4.6) show some examples with square zones. Appendix G gives other examples.

Legend for figures
4.4 to 4.7
- road that can be crossed
- road that cannot be crossed
- road with crossing point
- zone boundary

fig 4.4 Four zone region with barrier like road

fig 4.5 Six zone region with barrier like road
He should note that in a road with people living in both sides, the zone boundary should be drawn by its middle if and only if people cannot be picked-up from both sides at the same time. Otherwise, the boundary should be such that both sides are in the same zone. This is so because when relating addresses to zones it may prove extremely difficult to know to which side they belong.

However, where roads are not barriers to crossing traffic, they may be in the centre of the zones. It is a good criteria to draw boundaries parallel to the road and at equal distance from each side as in figure 4.7.

To follow the above criteria people with knowledge about the characteristics of roads and traffic flow should be asked to help when zoning a region.
4.5 INFLUENCE OF NATURAL AND ARTIFICIAL BARRIERS

Rivers, streams and railways have an identical influence to zoning as the one described in 4.4 for difficult to cross roads.

Lakes, parks and special zones like military fields, where no one can live may have to be taken into account. This is so if its size is comparable to the average zone size found to be advisable, for example by patient distribution. (4.2.1).

4.6 CONSISTENCY FOR THE PLANNING ALGORITHM

There is an important condition to allow good journeys to be planned. Patients within a zone must be picked up before the ambulance moves to another zone. The computer algorithm can only distinguish this if the in-zone travel time is smaller than any travel time to other zones. This may be achieved if the zone shape is fairly compact and convex, i.e. one dimension is not much greater than another (see chapter three, 3.3). Also zones of approximately the same size will help to achieve consistency. This is so because in-zone travel times will be always smaller than travel times to nearest zones (see appendix F).

---

Fig 4.8 Zone Shape

consistency.

Zones Z and W will have in-zone travel time greater than travel times to other zones.
4.7 CONCLUSIONS

Criteria for establishing zones must give particular attention to patient distribution. Clusters may help to define an average zone size both in urban and rural zones. From the road network characteristics and relations of it with patient clusters and hospital location, guidelines have been set to establish zone boundaries. Zone sizes will also be affected by those relations. Usual ambulance flow may enforce zone constraints on the previous guidelines. Criteria inferred by the actual planning system will be the source of point zones and the necessity of convex and compact zones, to prevent inconsistencies in planned journeys coming from inconsistencies in travel times.

A step procedure to zone a region, based on the principles given in this chapter and appendices F and G is outlined in appendix H.
CHAPTER 5
CHAPTER FIVE

ROAD NETWORK NODES AND LINKS

5.1 INTRODUCTION

As its name says, the road network is a network. It can be seen as a set of nodes connected by links. This justifies the introduction of network based models and analysis.

Any address can be seen as a node in the road network. With a simple model, if link lengths - road segment distances, and link times - road segment travel times, are known, graph theory will enable us to find distance and travel time between any two addresses (Saase 1978 and Larson 1981).

Actually road network characteristics and knowledge about it are not always easy to model and find with cost effectiveness.

In this chapter, models being used are introduced. Zoning models are seen as an approximation to network models. When estimating distances and travel times for a zoning model, network results can be most useful to provide an effective way of achieving consistency and building travel matrices.
5.2 TRANSPORT AND ROAD RESEARCH LABORATORY MODEL

TRRL model is a network based model. (Appendix I). It involves 7259 junctions and 46465 km of roads in England. Measured road segment distances and average speeds according to type of road are the main parameters of each link. Junctions influence travel times estimates since they introduce delay, and so nodes are classified according to delay.

Road distances are actual distances as measured in 1:50000 scale Ordnance Survey maps. Speeds and delays are based in statistical data collected by TRRL's Traffic Engineering Department (Taylor, 1981).

5.2.1 Travel Distance and Time estimation. Limitations.

In TRRL model average link length varies from 1000 metres in urban areas to 9000 metres in rural areas. (Morrison 1981). To estimate distance and travel time between two addresses, they need to be referred to a node and then a shortest path type algorithm could be used over TRRL data. However, for addresses close to each other, two kinds of error may arise due to the definition of the road network data in TRRL files.

Fig 5.1
Addresses referred to nodes
The first one is a problem of error when approximating an address by its nearest road junction. The second arises because there are roads that are not in the TRRL files. The example in fig 5.1 shows that TRRL journeys between P₁ and P₂ are mainly on a motorway, so taking a given travel time. However, actual journeys would take place by another road, the actual quickest, but taking more time than planned as travel times from addresses to junctions are not included in the first method.

Several actions could be taken to overtake this problem. Travel matrices built without motorway links could provide the short time elements for the actual travel matrices, or an address should never be referred to a motorway node. However, these procedures are also subject to errors of the same kind as the previous ones.

However, another more subtle problem is present. The node an address is referred to should depend on where the journey is going. In figure 5.1 if travelling from P₁ to P₂, P₁ should be referred to other node. The problem will turn out as an erroneous estimation of distance and time. The relative error is increased for nearby addresses.

Only including in the network links all road links from the address to the nearby nodes and applying a shortest path algorithm would solve the problem. However, due to the characteristics of the computer aided planning system it is not a time effective procedure. It would be equivalent to having each address an individual node (or a zone, in zone model terminology). We are left with the first approach of relating an address to the nearest node if we want to keep a manageable network model, like TRRL.

5.3 RELATIONS OF NETWORK AND ZONING MODELS

Due to the limitation of a network model in this application it can be seen as a zoning model. If each node is assimilated to the zone reporting centre (Chapter 4, 4.2.1) and given parameters
similar to in-zone ones, we get a zoning model.

However, the approach is much more efficient to estimate travel distances and times between any two zones and in-zone, than using one of them separately.

5.3.1 Advantages of a mixed model approach

Let us think of a region with 50 nodes or 50 zones. To build a travel matrix in a zoning model 1225 elements will be needed, each one being evaluated separately. In a TRM model for 50 nodes there will be no more than 100 road links (average 85, appendix I).

With these 100 links it is possible to build the 50 x 50 travel matrix applying a shortest path type algorithm. It is much easier to make errors compiling 1225 elements than 100 and these ones are already available if necessary, and will give consistent estimators.

On the other side for nearby zones and in-zone parameters, network based measures will give large errors. (5.2.1). Zoning based methods such as those of correlation between straight line distance and actual distance that takes into account the patient distribution will be better. (Chapters 3 and 4).
Fig 5.2 Node covering zones

If nodes are too close or too far away, related with the distribution of zone reporting centres, it may be necessary to aggregate or create nodes. This is necessary to keep consistent travel parameters, as in-zone parameters must be smaller than parameters from that zone to another one.

5.4 CONCLUSION

Utilization of a network model like TRRL one, gives a straightforward way of estimating travel distances and times. It has the advantage of giving consistent results, and having been tested.

However, unsufficient number of nodes and links in certain regions may impose refinements for parameter estimation in close zones. It is also possible to build a TRRL like model for the region under study. It might include TRRL data and other important nodes and links under consideration of local patient, road and care units distribution. Then standard graph theory or a similar to TRRL would be used. This would give a better error proof way of building travel matrices and assure consistency. For in-zone (or in-node) parameter estimation, relations as in chapter 3 must
be used.

A network model has also the advantage that changes in road network are easily reflected when it is necessary to change the travel matrix, as this might be built automatically from a graph where only relevant links are changed. The relationship to actual road configuration is always important.
CHAPTER 6
CHAPTER SIX

ADAPTATIVE DYNAMIC ZONING

6.1 INTRODUCTION

The main characteristic of an adaptative dynamic zoning system is its ability to change when and where necessary, so dynamic and adaptative.

A static zoning system could only be changed as a whole. As it is based in a travel matrix for estimation of all distances and travel times, all the matrix would need to be changed each time the zones were changed. A dynamic and adaptative, on the contrary, should be able to develop only in the areas where necessary and to the correct extent. From an initial zone pattern with a travel matrix, refinements should be able to proceed in a tree like structure for each zone.

In the initial zone pattern, travel distances and times are known from any zone to a particular one. However, it may be necessary to estimate travel distances and times to different points or sub-zones in this particular zone, from any zone.

The static zoning system would solve the problem dividing the zone into smaller zones and building a new matrix with all the new zones and all travel parameters. Ideally, a dynamic system only with knowledge of the particular zone would be able to locally estimate the travel parameters from any other zone, for example as a correction to the initial zone to zone parameters. It should be able to go dividing zones into sub-zones and wherever necessary sub-zones also. The final level would be to set address to address estimation. Each level should be transparent to the upper ones in the sense that only local level information should be necessary.
6.2 MAIN CONSTRAINTS

The main problems with a dynamic and adaptative system are related to computer efficiency and transparency of levels.

Distances and travel times are useful to the computer aided planning system if they can be estimated very fast.

Due to different zone boundaries and barriers to travel in some places or directions, the specification of level transparency must be to some degree changed. In effect it is not possible to estimate travel distance from an arbitrary zone to a particular point in a particular zone only with information about:

1. zone to zone travel distance,
2. localization within zone of particular point

The travel distance will depend also from what external zone. So some kind of information about the relative spatial or geographical orientation is necessary, and then some transparency may be lost.

6.3 NECESSARY LEVELS OF DIVISION

If the primary zoning pattern is chosen according to the criteria that is explained below it will be shown that only a two level dynamic system is necessary.

Primary zones are built around nodes of road network, using TRRL or alike model (chapter five). The minimum zone size is that one where internal travel time is not less than one minute (chapter four). The conclusions will be based on average zone area, with square zones. For urban regions a Manhattan metric will be used and for rural ones euclidean metric with a correction factor to take into consideration actual road network. (chapter three).
Rural average speed of 60 Km/h and urban of 30 Km/h will be considered.

Average straight-line distance between junctions in TRRL PYMF maps compiled by Morrison is 5 Km in rural regions and 2 Km in urban regions. If square zones with these side lengths are utilized then expected average internal travel distances and times will be:

Rural Regions

\[ d = 1.25 \times 0.52 \times \sqrt{A} \]

(expressions 3.7 and 3.9 with \( a = 1.25 \))

\[ d = 1.25 \times 0.52 \times 5 \]

\[ d = 3.3 \text{ Km} \]

\[ t = 3.3 \text{ minutes} \]

Urban Regions

\[ d = 0.67 \times \sqrt{A} \]

(expression 3.2)

\[ d = 0.67 \times 2 \]

\[ d = 1.34 \text{ Km} \]

\[ t = 2.7 \text{ minutes} \]

If zones are divided into 6 and 9 equal area sub-zones, the expected internal travel times will be divided by the square root of 6 and 9:
Rural Regions

6 sub-zones for each zone  \( E[t] = 1.3 \text{ min.} \)
9  \( E[t] = 1.1 \text{ min.} \)

Urban Regions

6  \( E[t] = 1.1 \text{ min.} \)
9  \( E[t] = 0.9 \text{ min.} \)

The primary zoning for a county like Cornwall, about 3500 squared KM would have 140 zones of 5 x 5 = 25 square KM and also a number of smaller urban zones. This is comparable to TRRL number of nodes for Cornwall, 246, as has been explained in chapter five some of the nodes are too close to be necessary. (Chapter 5). Subsequent divisions would allow up to 1260 rural zones.

6.4 MODEL SPECIFICATIONS

Under consideration of 6.2 main constraints, the specified dynamic system is based on travel matrices for computational efficiency. There is a principal one that deals with the primary zoning, and local matrices that give parameters for the divided zone and neighbouring zones.

Whenever addresses are in nearby zones and a local travel matrix exists, this one gives the parameters instead of the principal. For addresses in distant zones the travel distance and time is estimated adding both principal and local travel matrix elements. Figure 6.1 exemplifies the procedure. In appendix J a complete description of the model is given.
Fig 6.1 Travel estimation in a dynamic zoning system

6.4.1 Advantages of local matrices

If a zoning system goes from, for example, 70 to 78 zones the travel matrix will grow from 2415 to 3003 elements (triangular matrices), 24 per cent increase in memory space utilization. The adoption of a local travel matrix, however, only increases the number by 6 per cent. These conclusions are based on a zone pattern such that each zone is surrounded by eight zones and is divided into 9 sub-zones. (appendix K).

It is also much more reliable to compile a small matrix, for example from local road network characteristics or relations between local metric and road distance/travel time.

6.5 LEVEL REFINEMENT AS A RESULT OF VALIDATION PROCEDURES

It was stated that the principal zoning system may have to suffer subsequent division of several zones. What will be the criteria followed to find that need?
As none of the models used to estimate travel distances and times give actual address to address values, some kind of limits have to be set to the maximum error and associated probability. As it is discussed in appendix I, errors in estimating distance are much more related with the chosen zone area and shape than estimated travel time. Variation in travel time comes also from factors such as day hour, weather, driver and vehicle. Although travel times will be more important in the overall planning system, distances can check better the effectiveness and errors introduced by the zoning pattern chosen, instead of point like zones.

It is necessary to set objectives for the estimated distance error of the following type:

No more than P per cent of the journeys will have a distance error greater than E Km.

Choosing values for P and E may be a hard task, because they must reflect the relation from distance to travel time and must be such that the planning algorithm gives acceptable journeys. They may be also different for long and short journeys, as a way of deciding when to divide a zone.

The choice of P and E will need in some way an explicit statement of objectives. Either in estimating distances, travel times or planning journeys. To test the zoning model, time or planning objectives have to be translated into distance objectives.

6.6 CONCLUSION

Allowing for changes in local zones, an adaptable system may prove to be the best way to correct variations from first estimated travel distances and times to observed ones.

The utilization of local travel information also gives the possibility of checking inconsistencies much more efficiently.
Compilation of matrix elements is done as necessity arises and to provide more accurate and less inconsistent results in the planning procedure.

The main problem with a dynamic system is that the time necessary to estimate travel parameters is greater than the time to do the same in a static zoning system. An automatic generation of an overall unique travel matrix from the principal and local travel matrices, might be a more reliable procedure than just building it directly, if computer memory constraints are not important. This would have the advantages of keeping the reliability and advantages of dynamic system and giving a much faster answer.
CHAPTER 7
CHAPTER SEVEN

RECOMMENDATIONS AND CONCLUSIONS

7.1 RECOMMENDATIONS FOR FURTHER STUDY

7.1.1 STATIC AND DYNAMIC METHODS

Implementation of the dynamic method will require further study on how to build the local matrix updating interface for the user. Also the introduction of point zones at level two will pose no problem for the method as was described. However, it will increase estimation time. If point zones are to be considered in the principal matrix, codification problems will arise that may bring important changes to the method of estimating travel parameters.

Although mainly qualitative comparisons between static matrix method and dynamic ones has been done, some kind of quantitative comparative study should be pursued.

This study may fall upon comparison of errors between two equivalent static and dynamic systems, where the static is kept unchanged and the dynamic suffers successive refinements. Overall journey distance error may be the criterion for evaluation of performance. Also time efficiency of the dynamic method should be studied to check if it is acceptable for the computer aided planning system.

7.1.2 LOCALIZATION OF ADDRESSES AND VALIDATION

Almost as important as defining correct zone shape and area, according to the various influencing factors, is to be able to localize addresses in the correct zone. As zones become smaller this problem is magnified, and it will turn down any effort of reducing errors by reducing zones and changing its shape.
So we think that studies on how to locate more precisely addresses are important. When it is necessary to localize addresses in long roads or roads with sections in different zones, or when having to decide in what side of the road the address is. The only practical way of doing this may be a road file up-dated as knowledge becomes available.

Validation of zone or network model according to time variation is more difficult to do than according to distance. However, time variation is more important for qualifying or setting service level characteristics.

Travel time variation exists for constant travel distance. What should be the allowed travel distance error variation, that will not reflect in not allowed travel time variation? (If the distance error variation is only due to estimating model actually being used).

Further study which allows distance error variation limits to be set according to travel time service level should be done. This way, validation procedures could be followed to decide if the model is the origin of problems, if, of course, there are problems in the planned journeys.

7.2 CONCLUSIONS

Two different approaches to estimate travel distances and times have been discussed and characterized.

Geographic zoning of a region enables addresses to be related to zones, and zone to zone and in-zone values to be estimated, this being the certified address to address parameter.

Relating addresses to road network junctions and with knowledge about inter junctions road distance and travel time, graph theory enables address to address parameters to be estimated.
Zone to zone parameters may be derived from road network graph models and methods for in-zone parameter estimation may be applied to estimate distances and times for addresses related to the same junction. So, although each method has its own characteristics, there are direct relationships that can be used to enhance each other.

With whatever, zoning or road network method, a dynamic and adaptative may be used to allow for refinements where validation procedures detect that the estimated parameters depart from actual distances and times more than previous established limits or to cope with new limits.

As either utilizing zoning or network methods, the source of distance and travel time data will be a travel matrix, necessary refinements imposed by exceeding error limits, will have to be translated in overall matrix changes. In the adaptative methods, however, by utilizing local matrices as sources of data, only local matrix adjustments will reflect necessary refinements.
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APPENDIX A

Ratio of Right Angle to Euclidean Distance Metrics

The problem deals with the penalty in travel distance incurred by a mobile unit while travelling a grid of streets, compared to a helicopter or other unit that could travel "as the crow flies". If the mobile unit is located at \((x_i, y_i)\) and is travelling along a shortest distance path to \((x_j, y_j)\), then the right-angle distance, \(d_m\), between the points is:

\[
d_m = |x_i - x_j| + |y_i - y_j| \tag{1}
\]

A.1 If street directions are parallel to the co-ordinate axis, the right-angle distance (also called Manhattan, metropolitan or rectangular distance) is a good approximation for the actual travel distance covered.

The ratio, \(R\), of the right angle to Euclidean distance,

\[
d_e = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \tag{2}
\]

provides insight as to the extra distance travelled because of the requirement of driving on streets.

\[
R = \frac{d_m}{d_e} \tag{3}
\]

Fig a.1 Euclidean and Right-Angle Distances
It can be shown (Larson, 1981) that in a large, uniform city, or under an isotropy assumption the mean and variance of $R$ are:

$$E[R] = \frac{4}{\pi}$$  \hspace{1cm} (4)  \hspace{1cm} E[R] \approx 1.273

$$\sigma^2_R = 1 + \frac{2}{\pi} - \frac{16}{\pi^2}$$  \hspace{1cm} (5)  \hspace{1cm} \sigma^2_R \approx 0.0155

Thus, on average the mobile unit travels about 1.273 times the Euclidean distance (given the model assumption). The coefficient of variation $\sigma^2_R / E[R]$ is only 0.098, meaning that the estimate of $4/\pi$ for $E[R]$ is quite robust.

A reasonable test of the right-angle distance metric would be to compare the empirical distribution of ratios of recorded travel distances and corresponding Euclidean distances to the distribution junction of $R$ and to compare the empirically found average to 1.273. Another way would be to simulate different realistic city layouts and compare the results.

A.2 If we consider a square zone of unit area in which travel is right angle and direction of travel is parallel to the sides of the square, the expected value of $R$ increases (Larson, 1981). In this case:

$$E[R] = \frac{1}{3} \times \left[ 5 \log (1 + \sqrt{2}) + \sqrt{2} - 2 \right]$$  \hspace{1cm} (6)

$$E[R] \approx 1.274$$

fig a.2 same as a.1 but in a square zone
A.3 If street direction is rotated at a $45^\circ$ angle to the co-ordinate axis, intuition might lead one to think that $E[R]$ would be less than $4/\pi$. However, it can be shown that:

$$E[R] = \frac{1}{3} \times \left[ 4 \sqrt{2} \log (1 + \sqrt{2}) + 2 \sqrt{2} - 4 \right]$$  \hspace{1cm} (7)

$$E[R] \approx 1.271$$

that is much closer to $4/\pi$ than might otherwise have been expected.

fig a.3 same as a.1 with right-angle travel at $45^\circ$ angle
APPENDIX B
APPENDIX B

Expected Travel Distances in Rectangular, Square and Circular Zones with Right-angle, Euclidean and Other Metrics

B.1.1 Rectangular zone, right-angle metric parallel to sides of the zone.

With points \( P_i, (X_i, Y_i) \) and \( P_j, (X_j, Y_j) \) independently and uniformly distributed over the zone, and travel distance according to the right-angle metric:

\[
d_m = |X_i - X_j| + |Y_i - Y_j| \quad (1)
\]

Fig. b.1

then (Larson 1981):

\[
E[d_m] = \frac{1}{3} \times (X_o + Y_o) \quad (2)
\]

\[
\sigma^2_{d_m} = \frac{1}{18} \times (X_o^2 + Y_o^2) \quad (3)
\]

B.1.2 Optimum shape

Keeping the area constant, \( A = X_o \times Y_o \), the minimization of (2) turn out to be \( X_o = Y_o = \sqrt{A} \), not surprisingly a square zone, then:

\[
E[d_m] = \frac{2}{3} \times \sqrt{A} \quad (4)
\]
Intuitively speaking, the optimal shape of the zone is the one for which it takes as much time to traverse the zone from "east to west" as from "north to south". (This takes into account possible different travel speeds in different directions).

B.1.3 Robustness of expected travel distances

Let us examine the case where:

\[ x_0 = \alpha y_0 \quad , \quad \alpha \geq 1 \quad (5) \]

Then (4) can be written as:

\[ E[d_m] = \frac{(\alpha + 1) \sqrt{A}}{3\sqrt{\alpha}} = \frac{2}{3} \sqrt{A} + \frac{(\sqrt{\alpha} - 1)^2}{3\sqrt{\alpha}} \quad (6) \]

The second term is the amount by which \( E[d_m] \) deviates from its minimum value in (4). For \( \alpha = 1.5 \) the expected distance is only about 2 per cent greater than its minimum value. Even for \( \alpha = 4 \), the expected distance is only 25 per cent more than its minimum value.

An entirely similar analysis can demonstrate the robustness of expected travel times.

B.2 Square zone, euclidean metric.

Taking \( x_0 = x_0 = A \), the expected right-angle distance will be:

\[ E[d_m] = \frac{2}{3} \sqrt{A} \quad (7) \]
With the results of Appendix A, \( R = \frac{d_m}{d_e} \) equals \( \frac{4}{\pi} \). However, only an approximate constant can be devised for this case, because the conditions underlying that value of \( R \) are not exactly the same but we do know that it is also a robust constant. Then we can say that:

\[
\mathbb{E}[d_e] = \frac{2}{3} \frac{\pi}{4} \sqrt{A} \\
\approx 0.524 \sqrt{A}
\]

(8)

We note that this constant is within one percent of the one found by simulation by Tawel (Tawel, 1983). Tawel's result was:

\[
\mathbb{E}[d_e] \approx 0.517 \sqrt{A}
\]

(9)

3. Rectangular zone, right-angle discrete metric parallel to sides of zone.

![Fig 3.2](image)

Considering an \( n \times m \) rectangular grid of two-way streets as in the figure. Points distributed uniformly over the grid, independently.

The minimum expected travel distance will be a function of the relation between \( n \) and \( m \), but it can be shown (Larson, 1981) that:

\[
\frac{1}{2} \ (n + m) \leq \mathbb{E}[d] \leq \frac{1}{3} \ (n + m + 1)
\]

(10)
The left-hand inequality becomes an equality when \( n \) or \( m \) is zero and the right-hand inequality becomes an equality when \( n = m \).

Thus, the continuous approximation, (2), is never in error by more than \( \frac{1}{3} \) block length.

**B.4 Rectangular zone, right-angle one-way discrete metric, parallel to sides of zone.**

![Diagram of a grid with points P_i and P_j](image)

**Fig. b.3**

Consider a very large grid of equally spaced one-way streets, with the direction of travel alternating from street to adjacent parallel street. Assume points are independent and uniformly distributed over the grid. Assuming that the distance from point \( P_i \) to \( P_j \) is a shortest path that remains on the streets of the grid and obeys the one-way constraints. The expected travel distance is two blocks greater than the right-angle distance. (Larson, 1981).

**B.5.1 Circular zone, euclidean metric.**

![Diagram of a circle with points P_i and P_j](image)

**fig b.4**
The points \( P_i \) and \( P_j \) are uniformly and independently distributed over a circle of radius \( r \).

If:

\[
    d_e = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}, \tag{11}
\]

then the expected value of \( d_e \) is (Larson, 1981):

\[
    \mathbb{E}[d_e] = \frac{128}{45\pi} r \tag{12}
\]

\[
    = \frac{128}{45\pi} \sqrt{A} \tag{13}
\]

\[
    \mathbb{E}[d_e] \approx 0.511 \sqrt{A}
\]

where \( A = \pi \times r^2 \) is the area of the circle.

### B.5.2 Circular zone, right-angle metric

![Diagram](image)

Fig. b.5

In this case, with the same argument of 3.2,

\[
    \mathbb{E}[d_m] \approx \frac{4}{\pi} \frac{128}{45\pi \sqrt{\pi}} \times \sqrt{A} \tag{14}
\]

\[
    \mathbb{E}[d_m] \approx 0.650 \times \sqrt{A}
\]
B.5.3 Circular zone, radial and ring metric. No zone centre travel.

Suppose two points $P_i (R_i, \phi_i)$ and $P_j (R_j, \phi_j)$ are independent and uniformly distributed over a circular zone of radius $r$. That zone has a large number of radial routes and circular ring routes so that the travel distance can be approximated as,

$$d_r = |R_1 - R_2| + \min (R_1, R_2) |\phi_1 - \phi_2|$$  \((15)\)

if it is not allowed traffic through the zone centre.

Then (Larson 1981),

$$\mathbb{E}[d_r] = \frac{4}{15} \frac{(1 + \pi)}{\sqrt{n}} \sqrt{A}$$  \((16)\)

$$\mathbb{E}[d_r] \approx 0.623 \sqrt{A}$$

B.5.4 Circular zone, radial and ring metric
In this case,

\[ E[dx] = 4 \left( \frac{5\pi - \frac{4}{15}}{15\pi} \right) x \]  

(17)

\[ = 4 \left( \frac{5\pi - \frac{4}{15}}{15\pi} \right) \times \frac{1}{\sqrt{\pi}} \sqrt{A} \]  

(16) \[ E[dx] = 0.561 \sqrt{A} \]

B.6 Proportionality constants

The expected distance can then be calculated by the following general expression:

\[ E[d] = c \sqrt{A} \]  

(19)

Value of c:

<table>
<thead>
<tr>
<th>Shape of zone</th>
<th>Metric</th>
<th>Square</th>
<th>$45^\circ$ rotated square</th>
<th>circle</th>
<th>Fairly compact and convex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform and Independent points in the zone</td>
<td>Euclidean</td>
<td>0.52</td>
<td>0.52</td>
<td>0.51</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>Right-angle</td>
<td>0.67</td>
<td>0.66</td>
<td>0.65</td>
<td>0.67</td>
</tr>
</tbody>
</table>

NOTE: A fairly compact and convex zone is one for which one of the dimensions is not much greater than the other dimension, and major barriers or boundary indentations do not exist. According to B.1.2 expected parameters are robust to variations in shape much more than in area.
APPENDIX C
APPENDIX C

Transport and Road Research Laboratory Statistics of Traffic Speeds for Urban Areas

The statistics shown were collected from a survey organised by the Department of Transport and reported in TRRL SR 438 (Marlow, 1978).

C.1.1 Results for Weekday Periods in Five Conurbations, 1976

<table>
<thead>
<tr>
<th>Average Traffic Speed (Km/h)</th>
<th>Central</th>
<th>Non-Central</th>
<th>All-Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Peak</td>
<td>Off-P</td>
<td>Peak</td>
</tr>
<tr>
<td>Birmingham</td>
<td>25.4</td>
<td>20.5</td>
<td>39.1</td>
</tr>
<tr>
<td>Leeds</td>
<td>23.6</td>
<td>23.4</td>
<td>39.1</td>
</tr>
<tr>
<td>Liverpool</td>
<td>19.1</td>
<td>19.4</td>
<td>29.4</td>
</tr>
<tr>
<td>Manchester</td>
<td>16.4</td>
<td>17.7</td>
<td>31.4</td>
</tr>
<tr>
<td>Newcastle</td>
<td>17.6</td>
<td>17.8</td>
<td>35.2</td>
</tr>
<tr>
<td>Mean Value</td>
<td>20.4</td>
<td>21.4</td>
<td>35.5</td>
</tr>
</tbody>
</table>

C.1.2 Weekday Speeds, Averaged Over All Five Conurbations, 1967, 1971 and 1976

<table>
<thead>
<tr>
<th>Average Traffic Speed (Km/h)</th>
<th>Peak Periods</th>
<th>Off-Peak Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Sections</td>
<td>27.6</td>
<td>27.8</td>
</tr>
<tr>
<td>Central Area</td>
<td>14.9</td>
<td>17.6</td>
</tr>
</tbody>
</table>
### C.2.1 Results for Weekday Periods in Eight Towns, 1976

<table>
<thead>
<tr>
<th>Speed (Km/h)</th>
<th>Central</th>
<th>Non-Central</th>
<th>All Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
<td>Off-P</td>
<td>Peak</td>
</tr>
<tr>
<td>Sheffield</td>
<td>21.9</td>
<td>28.3</td>
<td>36.7</td>
</tr>
<tr>
<td>Bristol</td>
<td>19.9</td>
<td>27.8</td>
<td>29.5</td>
</tr>
<tr>
<td>Leicester</td>
<td>17.5</td>
<td>20.0</td>
<td>28.1</td>
</tr>
<tr>
<td>Luton</td>
<td>20.9</td>
<td>24.5</td>
<td>30.9</td>
</tr>
<tr>
<td>Reading</td>
<td>24.1</td>
<td>30.6</td>
<td>26.7</td>
</tr>
<tr>
<td>Preston</td>
<td>19.3</td>
<td>25.3</td>
<td>29.7</td>
</tr>
<tr>
<td>Chesterfield</td>
<td>17.6</td>
<td>18.3</td>
<td>38.6</td>
</tr>
<tr>
<td>Watford</td>
<td>25.1</td>
<td>25.6</td>
<td>29.0</td>
</tr>
<tr>
<td>Mean Value</td>
<td>20.8</td>
<td>25.0</td>
<td>31.4</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Average Traffic</th>
<th>Peak Periods</th>
<th>Off-Peak Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Towns</td>
<td>24.3 29.8 29.4 29.5</td>
<td>33.1 32.0 33.3 34.0</td>
</tr>
<tr>
<td>Central Area</td>
<td>15.1 18.2 19.6 20.8</td>
<td>20.7 19.6 23.4 25.0</td>
</tr>
</tbody>
</table>

### Notes
1. Peak periods include measurements in the morning peak (7.45 - 9.15 am) and evening peak (4.45 - 6.15 pm) adjusted where necessary to allow for local variations. Off-peak periods include measurements taken in the late morning and early afternoon periods.

2. Central section in towns were selected based on the main shopping and business area of the towns.
3. The average speeds take into account traffic delays such as junction ones, and measurements came from a sample where drivers were asked to drive at the average speed of the traffic, overtaking the same number of vehicles as overtook the survey cars.

4. Population and Areas

<table>
<thead>
<tr>
<th>Conurbation</th>
<th>Pop. (1000)</th>
<th>Area (sq.Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birmingham</td>
<td>1061.8</td>
<td>264.3</td>
</tr>
<tr>
<td>Leeds</td>
<td>744.5</td>
<td>562.2</td>
</tr>
<tr>
<td>Liverpool</td>
<td>542.1</td>
<td>112.9</td>
</tr>
<tr>
<td>Manchester</td>
<td>496.1</td>
<td>116.2</td>
</tr>
<tr>
<td>Newcastle</td>
<td>253.8</td>
<td>111.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Town</th>
<th>Pop. (1000)</th>
<th>Area (sq.Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheffield</td>
<td>555.4</td>
<td>367.6</td>
</tr>
<tr>
<td>Bristol</td>
<td>413.3</td>
<td>109.5</td>
</tr>
<tr>
<td>Leicester</td>
<td>286.6</td>
<td>73.4</td>
</tr>
<tr>
<td>Luton</td>
<td>162.9</td>
<td>43.4</td>
</tr>
<tr>
<td>Reading</td>
<td>131.4</td>
<td>36.8</td>
</tr>
<tr>
<td>Preston</td>
<td>130.4</td>
<td>142.4</td>
</tr>
<tr>
<td>Chesterfield</td>
<td>95.2</td>
<td>65.8</td>
</tr>
<tr>
<td>Watford</td>
<td>76.5</td>
<td>21.4</td>
</tr>
</tbody>
</table>

5. The measurements indicate that speed should be increasing by about 1½ Km for every subsequent year since 1967 onwards. It was found, however, (Taylor, 1981) that the speeds so obtained are too high to account for travel times measured by other TRRL surveys. The conclusion that speeds have increased since 1968 but have subsequently decreased is also supported by other sources. (TRRL, LF 925).
APPENDIX D
APPENDIX D

Statistics relating to euclidean map distances and actual road distances. Average speeds.

The different statistics presented here are all based on straight-line (euclidean) map distances, measured road map distance and actual milemeter readings taken during validation in field work. For more precise definition of the design of the data collection the sources are acknowledged.

Actual road distance, $d$, is obtained by multiplying straight-line distance, $d_e$, by a constant $a$. $E[s]$ is the expected travel speed under actual road distance.

Studies in the Birmingham ambulance services have shown that the constant $a$ changes significantly with the order of distances involved:

\[
\begin{align*}
0 & \ldots \ 8 \text{ Km} & : & a \neq 1.30 \\
6 & \ldots \ 18 \text{ Km} & : & a \neq 1.20 \\
18 & \ldots \ 25 \text{ Km} & : & a \neq 1.17
\end{align*}
\]

(type I) (type II) (type III)

These conclusions are supported by a number of other studies.

1. Haynes and Bentham (Haynes, 1979) in a rural hospital accessibility study established that:

\[
\begin{align*}
d & = 1.15 d_e \\
E[s] & = 53 \text{ Km/h (33 mph)}, \text{ rural area}
\end{align*}
\]

The distances involved in their study were type III.
2. Wilson (Wilson, 1967) established that when travelling to London:

\[ d = 1.18 \, d_e \] , correlation = 0.99

\[ \bar{E} [s] = 26 \text{ Km/h (16 mph)} \] , Greater London

\[ \bar{E} [s] = 21 \text{ Km/h (13 mph)} \] , Central London

the distances involved in his study were type III

3. Battilana (Battilana, 1976), in a study of town-centre deliveries used:

\[ d = 1.33 \, d_e \]

However, he made no distinction based on in-town and inter-town travelling.

\[ \bar{E} [s] = 56 \text{ Km/h (35 mph)} \] , Rural area

\[ \bar{E} [s] = 32 \text{ Km/h (20 mph)} \] , Urban area

4. Cooper and Jessop (Cooper, 1983) arrived at:

\[ d = 1.25 \, d_e \]

mainly for type III distances.
APPENDIX E

Minimum Zone Area. Local Variations and Number of Stop Points Influence

E.1 Travel time constraint in an urban region. Memory space constraint.

The elementary travel time should be in the minute order of magnitude. For urban areas where both population and road network are dense, one minute in zone travel time is seen as reasonable minimum.

As average speeds are low and are a function of day hours, there is evidence that in smaller zones travel times cannot be measured with more than 10% accuracy (Morrison 1971). Local variations could only be measured with excessive cost and time effort.

Also, for a computer based system with a triangular matrix for looking up distances and travel times, the memory space available might be the actual limiting factor on number of zones or zone area and in zone travel time. As will be seen for a conurbation like central Birmingham (367.6 sq Km) mainly urban, one minute zones (speed = 30 Km/h) would need about 700 zones. This gives two 250000 element triangular matrix system. If each element takes 2 byte (integer) then almost one Megabyte of fast memory would be needed for the computer aided planning system.

E.2 One Minute Zone

Let us find the area, A, of a zone in the following conditions:
1. Central town region
2. Peak period, expected speed, $E[S] = 20$ Km/h (Appendix C)
3. Manhattan model (Appendix A)
4. One minute in zone travel time, \( E[t] = 1 \)

We know that:

\[
E[t] = \frac{E[d]}{E[s]}
\]

where \( E[d] \) is the expected in zone travel distance given by \( E[d] = 0.67 \sqrt{A} \) (Appendix B).

(The correct expression is \( E[t] \geq E[1]/E[s] \). This is so because \( E[1/s] \neq 1/E[s] \). However, in most cases the approximation is valid. (Larson, 1981).)

Then:

\[
A = \left( \frac{E[t] \times E[s]}{0.67} \right)^2
\]

\[
A = 0.25 \text{ (sq. Km)}
\]

This would give a square zone of 500 m by side. This area is still valid for a Manhattan model. However, the expected travel time will be greater than one minute due to the actual discreet road network, possibly with some one-way streets. This could increase it up by 20%. (Appendix B).

However, the same zone, when in non-peak period, would have again the approximate one minute in zone expected travel time as speed increases.

Travel times may have strong variations in central urban zones and not in other zones. From the computational point of view, different travel time matrix should be used, according to the hour of day. There is also evidence that the boundaries of zones should be different according to the hour of day. (Chapter 4). However, this might put difficult problems when it is needed to localise addresses within zones.
3. Number of intermediate journeys within a one minute zone

Mansourpour gives some statistics from the Cornwall Ambulance Services. Although referring to a mixed rural and urban region, he shows the distribution of intermediate distance segments for 38 individual ambulance journeys. Only 17 out of 207 are less than 0.8 km. Even at 25 km/h only 7 per cent would take less than 2 minutes. (Mansourpour, 1982, Appendix D).

4. Influence of more than two stopping points upon expected in-zone travel time

What would happen to the expected in-zone travel time (between two arbitrary points) if instead of estimating it based only in two stop points each time (fig. e.1), it had to be evaluated for more than two stop points (fig. e.2)? (The in-zone time would be anyway the expected travel time between any two points inside the zone).

fig e.1: 6 times two point journeys

fig e.2: 2 times six point journeys
Taweel has shown by simulation that in a square zone euclidean metric model, with a shortest route algorithm the expected travel distance decreases when increasing the stopping points. (Taweel, 1983).

Assuming:

1. Direct relationship between distance and travel time (constant speed).
2. Direct relationship between an euclidean and Manhattan metric (Appendix A).

Then, the expected travel times would be for the one minute zone:

<table>
<thead>
<tr>
<th>Numbers of stop points</th>
<th>Expected travel time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The simplification that whatever numbers of stopping points are necessary in this zone, the time between them is 1.0 minute may be accepted if we think that in-journey patient handling times must also be added. (See table i) from DHSS. We will have problems when several points are coincident. (Same address). However, this situation can usually be foreseen and there are ways of dealing with it, for example, creating a point zone. (Chapter 4).

E.5 Other evidence for a minimum one minute zone

In actual conditions, variations between drivers and vehicles (misuse of ambulance warning devices also) could be investigated to see what influence they had upon the minimum size zone. It might happen that it would be a non-realistic smallest zone.
Recent surveys (Armstrong, 1977) have shown that drivers choosing routes between addresses take an average 10 to 14% excess time and distance over the optimum. In small regions this can go up to 200%, i.e. taking 3 times as much as the minimum necessary. However, this may not be an important factor once drivers get used to the zones where they travel, and as most addresses become familiar.
<table>
<thead>
<tr>
<th></th>
<th>W0</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>W7</th>
<th>W8</th>
<th>W9</th>
<th>W10</th>
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</thead>
<tbody>
<tr>
<td><strong>INWARD</strong></td>
<td></td>
<td></td>
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<tr>
<td>DH0</td>
<td>-</td>
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<td>7</td>
<td>9</td>
<td>12</td>
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<td>DH2</td>
<td>13</td>
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<td>20</td>
<td>22</td>
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<td>28</td>
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<td>DH8</td>
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<td>DH9</td>
<td>56</td>
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</tr>
<tr>
<td>DH10</td>
<td>61</td>
<td>66</td>
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</tr>
<tr>
<td><strong>STRETCHER CASE = 14 MIN</strong></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th>W1</th>
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</tbody>
</table>

Table 1) Patient handling times (minutes)
Fig. e.3 Square zones in urban region (manhattan model)
APPENDIX F
APPENDIX F

Sizes of zones, Relations Between Population Distribution, Zone Areas and Travel Times

The relations below between expected in-zone travel times \( E[t] \) and distances \( E[d] \), and area \( A \), of zone are valid if the zone population or better, stopping points in the zone, are uniformly distributed.

\[
E[d] = c \times \sqrt{A}, \quad \text{value of } c \text{ change with shape and metric used, euclidean or Manhattan, (in Appendix B).}
\]

\[
d = a \times d_e, \quad \text{values of } a \text{ depend on metric used (in Appendix A for Manhattan) and range of distance (in appendix D).}
\]

\[
E[d] = a \times E[d_e] \quad \text{(in Appendix A for Manhattan) and range of distance (in appendix D).}
\]

\[
d_e \text{ stands for euclidean or straight-line distance.}
\]

\[
E[t] = E[d]/E[s], \quad \text{only approximated because distribution of speed, } s, \text{ is unknown. (Appendix E).}
\]

Tables i), ii) and iii) each one for different average speeds, show for several in-zone travel times, the zone area and also the expected travel time to the closest zones. This last time was obtained based on the following model:

A square grid of zones, each one with area \( A \). The expected euclidean distance is the average of distances between central points, i.e.

\[
E[d_e] = \frac{1 + \sqrt{2}}{2} \sqrt{A}
\]

Fig f.1 Grid of square zones
The results shown are valid for zones other than squares, with a minimum error if zones are compact and convex. (Appendix B, B.6).

We might think of what would happen if population is not uniformly distributed. For instance, if outpatients all came from various points. (Fig. 22). The in-zone travel model would not be valid if zones were centres in those points and covering the region, because in-zone travel time and distance would be zero.

![Fig. 2](image)

Measuring the distances from each point to the nearest ones and calculating the average, would allow the estimation of an average travel time to the nearby zones. If this was a real model we could then, based on tables like i), ii) or iii) evaluate zone areas $A$ and just have in-zone parameters equal to zero.

Actually, what usually happens is shown in figure f.3:

![Fig. 3](image)
If we find central points related with the actual distribution we may find average zone areas following the above procedure. However, in-zone travel time will be greater than zero. If the distribution in any area is uniform the value of the table will be valid. However, it may happen that points are concentrated within the zone in a smaller area. As far as in-zone travel time estimation is concerned, this area should be the one to look up on the tables. It may be called effective area. (figure f.5).

![Figure f.4](image)

![Figure f.5](image)
For the ambulance service, if outpatients distribution for several days is plotted on maps (rural and urban ones), patterns such as clusters will emerge. (Jarvis, 1975; Haynes, 1979). The distance between central points of groups could give a first value for the number and size of zones needed to zone the region. This more or less scattered group will be usually related to villages or special urban places.

If it cannot be possible in certain areas to find groups of points, but they are uniformly distributed, zone areas should be such that each day and each journey it should not be necessary to pick up more than two or three patients (Mansourpour, 1982; Tawel, 1983) or should not be smaller than one minute in-zone travel time (Appendix E).

If regions do not have any patients, but they are potential places for patients (i.e. it is not a lake, a natural park, a reserved region or similar) it should be zoned anyway according to the size found. This will protect the computer planning system to avoid future possible inconsistencies.

In some places a zone may have to include two or more clusters of points, otherwise the zone size might have to be too small (figure f.6) violating the one minute zone criteria (Appendix E).

![fig f.6](image)

Most of the time, boundaries will have to be drawn according to road network and other constraints. Sometimes road network may influence shifts or divisions in zones found by this process. (Appendix H).
<table>
<thead>
<tr>
<th>In-zone travel time (min)</th>
<th>Zone area A (sq. Km)</th>
<th>A (Km)</th>
<th>close zone travel time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.56</td>
<td>0.74</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>2.23</td>
<td>1.49</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>5.01</td>
<td>2.24</td>
<td>6.9</td>
</tr>
<tr>
<td>4</td>
<td>8.91</td>
<td>2.99</td>
<td>9.2</td>
</tr>
<tr>
<td>5</td>
<td>13.92</td>
<td>3.73</td>
<td>11.4</td>
</tr>
<tr>
<td>6</td>
<td>20.10</td>
<td>4.47</td>
<td>13.7</td>
</tr>
<tr>
<td>7</td>
<td>27.30</td>
<td>5.22</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Table i) Urban region, average speed: $E[s] = 30 \text{ Km/h}$

$c = 0.67$

$a = 1.27$

<table>
<thead>
<tr>
<th>In-zone travel time (min)</th>
<th>Zone area A (sq. Km)</th>
<th>A (Km)</th>
<th>close zone travel time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.50</td>
<td>1.82</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
<td>1.00</td>
<td>3.62</td>
</tr>
<tr>
<td>3</td>
<td>3.23</td>
<td>1.49</td>
<td>5.43</td>
</tr>
<tr>
<td>4</td>
<td>3.96</td>
<td>2.00</td>
<td>7.24</td>
</tr>
<tr>
<td>5</td>
<td>6.18</td>
<td>2.49</td>
<td>9.05</td>
</tr>
<tr>
<td>6</td>
<td>8.01</td>
<td>2.98</td>
<td>10.87</td>
</tr>
<tr>
<td>7</td>
<td>12.13</td>
<td>3.48</td>
<td>12.68</td>
</tr>
</tbody>
</table>

Table ii) Urban region, average speed: $E[s] = 20 \text{ Km/h}$

$c = 0.67$

$a = 1.27$
<table>
<thead>
<tr>
<th>in zone travel time (min)</th>
<th>Zone area A (sq. Km)</th>
<th>A (Km)</th>
<th>close zone travel time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.19</td>
<td>1.48</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>8.75</td>
<td>2.96</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>19.69</td>
<td>4.43</td>
<td>7.0</td>
</tr>
<tr>
<td>4</td>
<td>35.01</td>
<td>5.92</td>
<td>9.3</td>
</tr>
<tr>
<td>5</td>
<td>54.71</td>
<td>7.40</td>
<td>11.6</td>
</tr>
<tr>
<td>6</td>
<td>78.78 *</td>
<td>8.88</td>
<td>13.9 *</td>
</tr>
<tr>
<td>7</td>
<td>107.22 *</td>
<td>10.36</td>
<td>16.3 *</td>
</tr>
</tbody>
</table>

Table iii) Rural region, average speed: \( E[s] = 60 \text{ Km/h} \)

\[
c = 0.52
\]

\[
a = 1.30
\]

\[
\hat{a} = 1.20
\]

**NOTE:** For a rural zone an euclidean metric was used.

\[
E[d_o] = c \times \sqrt{A}, \text{ corrected by factor } a,
\]

\[
E[d] = a \times E[d_o]
\]
APPENDIX G

ZONES UNDER BATTLE AREA. POPULATION, HOSPITALS AND AMBULANCE
FLow INFLUENCES. EXAMPLES

In Chapter 4, 4.3, a Hospital in the converging point of
several roads influenced the boundaries of zones. When other
constraints are added other boundaries may prove necessary.

Let us suppose that according to patient distribution an
average zone area A, has been found as a first approximation.
(Appendix F).

Legend for the following figures:

| ——— road that can be crossed |
| ——— road that cannot be crossed |
| ——— road with a crossing point |
| Ho Hospital |
| © cluster of patients |
| —— zone boundary |
| \[\[ Zone |

1.1 EXAMPLE ONE

Let us reproduce the situation described in fig 4.2 (chapter 4)

Fig g.1.Roads converging
to Hospital
The direction of the flow of ambulances through the three main roads indicate that these three zones should be differentiated.

An ambulance approaching from one direction should not go to other zones if any other is coming. A central zone would allow any patient in that zone to be picked up by any ambulance approaching the Hospital. If this central zone was not very small, journeys would not be optimum.

Let us think that the approaching main roads are either motorways or usually jammed roads so that it is difficult to cross from one side to the other, as the next figure (fig.g.2) shows. Then zone boundaries should be as indicated. We note that zone areas are approximately equal to A.

Fig.g.2 As g.1 but motorways or jammed roads.
With patient distribution as shown in figure 3 the boundaries might need to be changed again. We write for instance that zones Z and Y were before a unique one. However, patients in that zone are distributed in two clustered groups.

They are sufficiently separated to create two zones which areas are not very different from A. On the contrary, the clusters in zone W are so close that a unique zone remains. In other cases, the clusters are so distant, that zones without them have to be defined to keep a uniform zone pattern. This way travel time consistency is kept (Chapter 4, 4.6).
1.2 EXAMPLE TWO

Even when there is no hospital nearby, ambulance flow may influence the zone boundaries. Figure 4.4 and 4.5 show a junction with arrows indicating a possible ambulance flow.

Zone boundaries are then drawn with similar criteria as before.

Fig 4.4

or

Fig 4.5

Similar changes will be needed to take into account road network and population characteristics.
APPENDIX H

ZONING A REGION. GENERAL PROCEDURE

1. In a small scale map, for instance Ordnance Survey 1:50000 define the boundaries of the region.
Define urban and rural regions, according for instance to principles in 4.2. Define the boundaries of the urban regions in very large scale maps (1:20000 - 1:10000) which have road and street names.

2. Identify Hospitals, care units and ambulance stations.

3. Identify important junctions, for instance those shown in a small scale map (1:250000) between M, A and B roads or in Morrison PYNF maps (appendix I, I.1).

4. With patient addresses locate them in the rural and urban zones.
Data from randomly chosen days should be used until clusters begin to emerge. Transparent overlaid sheets should be used, one for each day. The numbers of clusters will give an approximate number of zones needed for both urban and rural areas (appendix F).
Circles may be drawn centred in each cluster.
Whenever clusters are not evident take important junction as cluster-like centres. Transparent sheets for each day are another way of defining average zone area when clusters do not turn out, as day to day similar patterns may arise.

5. Taking into account road network, hospital locations and ambulance flows (4.3, 4.4, appendix G), natural barriers (4.5), and always having in mind that zones should be compact and convex (4.6) draw the boundaries.

6. Estimate travel distances and travel times, in-zone and to other zones. Note that in-zone travel time must be smaller
than any other travel time from that zone to other. Methods to do this are covered in chapters 3 and 5.
APPENDIX I

TRANSPORT AND ROAD RESEARCH LABORATORY’S PRESENT YEAR NETWORK FILE

I.1 ROAD NETWORK MODEL. THE PYNF

The Transport and Road Research Laboratory, TRRL, developed a computer simulation of the road network, involving 7259 junctions and 46465 km of classified and unclassified roads (as by the end of March 1984). It allows minimum cost, distance and time journeys between any two junctions to be found.

The road network file is known as Present Year Network File, PYNF. It has data about junction and road sections connecting junctions. As a graph model, junctions are called nodes, and road sections, links.

Nodes are numbered and each one has a name related to its localization. Links are classified according to official type of road. Each link length is a true length of the road section (not crow-fly lengths). Link speeds are car speeds based on an average annual week-day flow, and have been calculated with TRRL formulae (Taylor 1981).

Conventional and road speed maps of South East England showing the PYNF in Autumn 1982 have been published. Compiled by A. Morrison and produced by M.C. Shand under contract with TRRL. They have been designed following studies by Morrison about road speed maps. (Morrison 1971 and Morrison 1980).

I.2 ESTIMATING DISTANCES AND TRAVEL TIMES

All distances are measured using a map measuring wheel on 1:50000 scale Ordnance Survey maps. This technique allows average road sections to be defined to better than 100 metres.
Speeds are estimated according to the following criteria. Roads are classified as restricted and unrestricted.

1. Unrestricted Roads

<table>
<thead>
<tr>
<th>type</th>
<th>speed</th>
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</thead>
<tbody>
<tr>
<td>2½ and 3 lane single carriageways</td>
<td>75 Km/h (*)</td>
</tr>
<tr>
<td>2½ and 3 lane dual carriageways</td>
<td>85 Km/h (*)</td>
</tr>
<tr>
<td>2½ and 3 lane motorways</td>
<td>100 Km/h</td>
</tr>
</tbody>
</table>

(*) Actually TRRL formulae take into account bendiness and hilliness. This is an approximation.

2. Restricted Roads

Locations of 30 and 40 mile/h restriction roads are obtained from County Council records.

2.1 Rural and Sub-urban Regions

Speed is taken to be a proportion of the speed restriction.

<table>
<thead>
<tr>
<th>Speed restriction (mile/h)</th>
<th>factor</th>
<th>speed (Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.925</td>
<td>44.6</td>
</tr>
<tr>
<td>40</td>
<td>0.925</td>
<td>59.5</td>
</tr>
</tbody>
</table>

2.2 Urban Regions

Roads in urban regions can be seen as restricted ones but with speed reduced.

<table>
<thead>
<tr>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 Km/h</td>
</tr>
</tbody>
</table>

Travel times are then calculated for each road section. To find the travel time between any two nodes a delay for each junction
must be added:

\[ t = \frac{d}{z} + ND \]

t = total travel time  \hspace{1cm} d = \text{length of link}

z = free speed  \hspace{1cm} N = \text{number of significant}

\hspace{1cm} \text{junctions along link}

D = \text{equivalent delay}
\hspace{1cm} \text{per junction}

For rural and sub-urban regions junction delay is taken as
15 seconds and for urban regions 25 seconds. The speeds above are
so called free speeds.

To build a travel matrix it is necessary to calculate the
distances and times between all pairs of nodes. It is therefore
important to have available efficient methods for obtaining shortest
and quickest paths, as this is usually the objective. An elegant
and simple-to-program approach is generally attributed to Floyd.
Although his algorithm is simple to describe its logic is not
particularly easy to grasp. (Larson 1981).

I.3 AVAILABILITY AND COST OF PYNF DATA

Marketing of PYNF is done by a computer services company,
SIA, Service in Information & Analysis Limited. (Ebury Gate,
23 Lower Belgrave Street, London SW1W ONW, Tel: 01-730 4544).

SIA cells either the data or a service such as the provision
of travel time matrices.

Although SIA does not take any responsibility for the accuracy
of the data, it has carried out validation checks on many items to
check for logically inconsistent errors.
Prices for the sale of PYNF data are the following (x):

(a) PYNF Link Data File
   Cover Charge  £25.00
   Cost per link £0.50

(b) PYNF Node Data File
   Cover Charge  £25.00
   Cost per node £0.25

As examples, PYNF data for Bedfordshire and West Midlands is the following: (as in the end of this appendix).

<table>
<thead>
<tr>
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So the cost would be (x):

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(x) As at 31 December 1983, exclusive VAT

I.4 SIMILAR PYNF DATA

Scicon, another computer services company, has developed for its vehicle routing and scheduling system a road file similar to TRL's PYNF. (Scicon Ltd., 49 Berners Street, London W1P 4AQ, Tel: 01-580-5599).
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<td>MERSEYSIDE</td>
<td>159</td>
<td>28</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>SOUTH YORKSHIRE</td>
<td>177</td>
<td>36</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>TYNE &amp; WEAR</td>
<td>132</td>
<td>22</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>WEST MIDLANDS</td>
<td>401</td>
<td>73</td>
<td>249</td>
<td></td>
</tr>
<tr>
<td>WEST YORKSHIRE</td>
<td>318</td>
<td>38</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>GREATER LONDON</td>
<td>1032</td>
<td>111</td>
<td>603</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL NUMBER OF PYNF LINKS IN ENGLAND | 12025 |
| TOTAL NUMBER OF PYNF NODES IN ENGLAND | 7259  |
| TOTAL LENGTH OF PYNF TRUNK ROAD IN ENGLAND | 10189 KM |
| TOTAL LENGTH OF PYNF PRINCIPAL ROAD IN ENGLAND | 24029 KM |
| TOTAL LENGTH OF PYNF OTHER ROADS IN ENGLAND | 12247 KM |
| TOTAL LENGTH OF PYNF PRIMARY ROUTE IN ENGLAND | 18817 KM |
| TOTAL NUMBER OF PYNF LINKS OUTSIDE ENGLAND | 513 |
| TOTAL NUMBER OF PYNF NODES OUTSIDE ENGLAND | 332 |
Present Year Network File

The Link File Format

1. The format of the data is given in Section 1.

2. All of the data held in the link file is right justified unless otherwise stated.

3. Class-Index (cols 3 and 4) defines the general standard of the road, the number of lanes and the environment through which the road passes; see Section 2.

4. Jurisdiction Code (col 7) defines the road status; see Section 3.

5. The A node number (cols 9 to 16) and the B node number (cols 18 to 25) define the end points of a length of road or link. The A node is normally the lower of the two nodes numerically, except that on one way links the ordering of the nodes is in the direction of the traffic flow regardless of the numerical value of the nodes.

6. Length (cols 26-29) is defined in 1/10 kilometre units eg 11.7 km equals 117 (remember this is right justified).

7. Speed-Time indicator (col 31) defines whether the data in cols 32 to 35 is in units of speed or time. "S" defines speed and "T" defines time. In PYNF only "S" is used.

8. Speed or Time (cols 32 to 35) units. Speed is in 1/10 kph units eg 88kph equals 880. Time is in minutes. In PYNF only speed is used as many of the links are very short and a minimum time of one minute would be far too long. See Section 4.

9. A to B direction (cols 36 and 37) defines the direction that the link leaves the A node to get to the B node. B to A direction (cols 47 and 48) define the direction that the link leaves the B node to get to the A node. See note 1 below.

10. Toll charge for cars (cols 38 to 40) defines the charge in pence for cars using the link or ferry.

11. Direction Indicator (col 42) defines whether the road is a one way or a two way link. A value of "2" is used on a two way link but on a one way link the column is left blank, (see 5 above for a description of 1 way links).

12. The OSGR's of the nodes, A node easting (cols 43 to 46), A node northing (cols 49 to 52), B node easting (cols 73 to 76), B node northing (cols 77 to 80). Each node location is defined by an eight digit OSGR, this locates the node to within 100 metres accuracy.

13. Road type (col 53) defines the road number prefix, M, A or B. All other roads are defined as a blank except A(M) roads which are given an A definition.

14. Road number (cols 54 to 57) is always greater than zero except for unnumbered roads which are defined as "0".
15. Road classification (col 58) is the same as the Jurisdiction Code.

16. Bendiness (cols 64 to 66) is measured in degrees/km. Default values are given in Section 5.

17. Hilliness (cols 67 and 68) is measured in m/km. Default values are given in Section 5.

18. Percentage Heavy Goods Vehicles (cols 69 and 70), the default value is 15%.

19. Date of Amendment (cols 81 to 86) is the date at which the link was last amended, in the form DDMyyy.

Note 1: The nearest of the 8 compass points N, NE, E, SE etc are used at present. There are proposals to change this to a radian measure of the angle to obtain greater accuracy. Users will be notified before the change takes place.
### PYNF - Link File Format

<table>
<thead>
<tr>
<th>Cols</th>
<th>Description</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>Blank</td>
<td>211</td>
</tr>
<tr>
<td>3 and 4</td>
<td>Class-Index</td>
<td>I1</td>
</tr>
<tr>
<td>5 and 6</td>
<td>Blank</td>
<td>I18</td>
</tr>
<tr>
<td>7</td>
<td>Jurisdiction Code</td>
<td>I1</td>
</tr>
<tr>
<td>8</td>
<td>Blank</td>
<td>I8</td>
</tr>
<tr>
<td>9 to 16</td>
<td>A Node number</td>
<td>I18</td>
</tr>
<tr>
<td>17</td>
<td>Blank</td>
<td>I8</td>
</tr>
<tr>
<td>18 to 25</td>
<td>B node number</td>
<td>I4</td>
</tr>
<tr>
<td>26 to 29</td>
<td>Length (km x 10)</td>
<td>I4</td>
</tr>
<tr>
<td>30</td>
<td>Blank</td>
<td>A1</td>
</tr>
<tr>
<td>31</td>
<td>Speed Indicator (S)</td>
<td>I4</td>
</tr>
<tr>
<td>32 to 35</td>
<td>Speed (kph x 10)</td>
<td>A2</td>
</tr>
<tr>
<td>36 and 37</td>
<td>A to B Direction</td>
<td>I3</td>
</tr>
<tr>
<td>38 to 40</td>
<td>Toll Charge Cars (pence)</td>
<td>I1</td>
</tr>
<tr>
<td>41</td>
<td>Blank</td>
<td>I1</td>
</tr>
<tr>
<td>42</td>
<td>Direction Indicator (1 way = 1, 2 way = 2)</td>
<td>I1</td>
</tr>
<tr>
<td>43 to 46</td>
<td>A node OSGR, easting</td>
<td>I4</td>
</tr>
<tr>
<td>47 and 48</td>
<td>B to A Direction</td>
<td>A2</td>
</tr>
<tr>
<td>49 to 52</td>
<td>A node OSGR, northing</td>
<td>I4</td>
</tr>
<tr>
<td>53</td>
<td>Road type (M,A,B or blank)</td>
<td>A1</td>
</tr>
<tr>
<td>54 to 57</td>
<td>Road number (right justified)</td>
<td>I4</td>
</tr>
<tr>
<td>58</td>
<td>Road classification</td>
<td>I1</td>
</tr>
<tr>
<td>59 to 63</td>
<td>Blank</td>
<td>I3</td>
</tr>
<tr>
<td>64 to 66</td>
<td>Bendiness</td>
<td>I2</td>
</tr>
<tr>
<td>67 and 68</td>
<td>Hilliness</td>
<td>I2</td>
</tr>
<tr>
<td>69 and 70</td>
<td>%age HGV's</td>
<td>I2</td>
</tr>
<tr>
<td>71 and 72</td>
<td>Blank</td>
<td>I2</td>
</tr>
<tr>
<td>73 to 76</td>
<td>B node OSGR, easting</td>
<td>I4</td>
</tr>
<tr>
<td>77 to 80</td>
<td>B node OSGR, northing</td>
<td>I4</td>
</tr>
<tr>
<td>81 to 86</td>
<td>Date of last amendment</td>
<td>312</td>
</tr>
</tbody>
</table>

* See over for comments on the above
Class/Index - These are in general fairly accurate except that the number of lanes is suspect. An effort has been made to get the data about Dual/Single carriageway and Urban/Suburban/Rural correct though when detailed accuracy is important a further check is advisable.

Jurisdiction Code - An expanded range of codes has now been adopted, these are given in section 3. Work is currently going on to improve all of the jurisdiction codes. The codes for Trunk and higher roads are likely to be correct but the Principal Road codes, in particular the separation into Primary Routes, still needs some work before it can be considered adequate.

Node Numbers - The first two characters of the node numbers indicate the County in which the node is situated. Recent checking has revealed that there are some errors and corrections are being carried out.

Length - Originally these link lengths were measured as the straight line distance between the nodes and were later improved using a map wheel. The change to the use of the digitizer has meant that much more accurate results can be obtained. In addition, link lengths derived by STCG, which have been well checked, have been merged into PYNF, hence at least the Trunk and other A Road elements of PYNF should be accurate for most purposes.

Speed - Speed data has been estimated on the basis of the considerations given in Section 5 sometimes adjusted for local knowledge. In the future when we have better estimates of hilliness and bendiness Speed values will be generated using TRRL formulae. For applications where local detail is important the user should consider verification.

A-B and B-A Direction - Originally these were the compass bearing of one node to another. Recent work using the digitizer has meant that these directions are now the direction that the road leaves the node to get to the next node. Over the next few months it is expected that all Trunk Road links will be digitized, then, these directions will be as accurate as the 1:50000 maps being digitized will allow.

Toll Charge - This field is generally zero or blank. Users should insert current values when necessary.

Direction Indicator - There are very few one way links in PYNF the majority of these will be correct.

OSGR's - A program of digitization of node OSGR's has been recently completed using 1:50000 OS maps. Errors will be very few.

Road Numbers - Most Road Numbers are correct. Errors are likely to be in Urban areas where the Ordnance Survey 1:50000 maps do not give clear information.

Bendiness - Most current values of bendiness are default values. Use of the digitizer is enabling more accurate values of bendiness to be inserted. Values other than the default ones are measured from the 1:50000 OS maps.

Hilliness - These cannot be obtained from any current sources with accuracy all values shown are either estimates or a default of 15%.
### Description of items and their values included in the Link data records are as follows:

<table>
<thead>
<tr>
<th>Class</th>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Dual 4 Lane Motorway Rural</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Dual 4 Lane Motorway Urban</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Dual 4 Lane Motorway Suburban</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Dual 3 Lane Motorway Rural</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Dual 3 Lane Motorway Urban</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Dual 3 Lane Motorway Suburban</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>Dual 2 Lane Motorway Rural</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Dual 2 Lane Motorway Urban</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Dual 2 Lane Motorway Suburban</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>Dual 4 Lane All Purpose Rural</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Dual 4 Lane All Purpose Urban</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Dual 4 Lane All Purpose Suburban</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Dual 3 Lane All Purpose Rural</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Dual 3 Lane All Purpose Urban</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Dual 3 Lane All Purpose Suburban</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>Dual 2 Lane All Purpose Rural</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Dual 2 Lane All Purpose Urban</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Dual 2 Lane All Purpose Suburban</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
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</tr>
<tr>
<td></td>
<td>1</td>
<td>Single 4 Lane All Purpose Urban</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Single 4 Lane All Purpose Suburban</td>
</tr>
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<td></td>
<td>3</td>
<td>Single 3 Lane All Purpose Rural</td>
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<td></td>
<td>4</td>
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<td></td>
<td>2</td>
<td>Single 2 Lane All Purpose Suburban</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>Ferries</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Single 1 Lane All Purpose</td>
</tr>
</tbody>
</table>
Jurisdiction Codes

1. Motorways.
3. Trunk Roads.
5. Principle Roads - Primary Routes.
7. Classified Roads - Primary Routes.
8. Other Classified Roads.
10. Ferries.
Each link in the Present Year Network File is allocated an average 24 hour speed in kilometres per hour, based on TRRL LF170. If local knowledge indicates that a different speed is appropriate then this is used, though normally the speeds will be expected to fall into the ranges indicated below:

<table>
<thead>
<tr>
<th>Type</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>89</td>
<td>105</td>
</tr>
<tr>
<td>Rural Dual carriageways</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Suburban Dual carriageways</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Rural single 4-lane</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>Rural single 3-lane low bendiness</td>
<td>75</td>
<td>89</td>
</tr>
<tr>
<td>medium bendiness</td>
<td>72</td>
<td>85</td>
</tr>
<tr>
<td>high bendiness</td>
<td>67</td>
<td>80</td>
</tr>
<tr>
<td>Rural single 2-lane low bendiness</td>
<td>72</td>
<td>86</td>
</tr>
<tr>
<td>medium bendiness</td>
<td>64</td>
<td>81</td>
</tr>
<tr>
<td>high bendiness</td>
<td>56</td>
<td>71</td>
</tr>
<tr>
<td>All suburban single carriageways</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>All urban links</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>
Bendiness

Bendiness is a factor used in determining the speed/flow characteristics of a single carriageway rural road. It is expressed in degrees per kilometre and is the sum of the magnitudes of the angular changes in direction over the length of the link, divided by the link length. Default values are:

<table>
<thead>
<tr>
<th>Category</th>
<th>Very straight</th>
<th>Average bendiness</th>
<th>Very bendy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single carriageway</td>
<td>40 deg/km</td>
<td>40 to 100 deg/km</td>
<td>100 deg/km</td>
</tr>
<tr>
<td>2-lane roads.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single carriageway</td>
<td>20 deg/km</td>
<td>20 to 60 deg/km</td>
<td>60 deg/km</td>
</tr>
<tr>
<td>3-lane roads.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average bendiness is used for all dual carriageways and for all urban and suburban single and dual carriageway links.

Hilliness

Hilliness is also used in determining the speed/flow characteristics of a road. It is expressed in metres per kilometres and is calculated as the sum of the magnitudes of the changes in height over the length of the link, divided by the length of the link. Default values are:

- 0 - Level road.
- 15 - Mildly hilly - normal value used.
- 30 - Hilly.

In practice the default values are always used as it is very difficult to measure hilliness.
APPENDIX J

DYNAMIC ZONING MODEL

J.1 BASIC PRINCIPLES AND CONSTRAINTS

The basic idea behind a dynamic zoning model is that we have some consistent way of refining the zoning pattern as it is needed in a simple way.

We want to divide a region in several zones. Then if a zone is too big to get accurate travel estimators we want to sub-divide it. This must be done in such a way that consistent results are achieved with little effort. It must have only local effects on the travel matrix. If each time a zone is divided all matrix has to be changed it is not a dynamic system.

Although the division of a zone may seem straightforward, the methods to deal with distance and time estimators have to take into account boundary problems such as natural or artificial barriers and utilize computational efficient algorithms.

As an illustration let us have a region with nine square zones as in figure j.1

![Diagram of nine zone region]

**fig j.1** Nine zone region
Zone 5 has to be sub-divided into 9 smaller zones. If we know the distance from zone 3 to 5 how to know distance from 3 to sub zone 5.9? We could imagine that zone 5.9 was related to the centre of zone 5 using rectangular or polar coordinates, or road distance. Then, by triangulation, distance from 3 to 5.9 was easy to estimate. This would mean that distance from 3 to 5.9 was the straight line from one to the other (with a correction for reality of road network, for example). However, this method does not take into account barriers. It may happen that to go from 3 to 5.9 it may be necessary to go to the centre of 5. In each case each sub-zone would have to have an information of accessibility from the other zones, as travel can come from any zone.

fig 1.2 Boundary Constraint

When a zone is subdivided, the purpose is to get better estimators. For smaller zones barriers such as motorways, rivers, lakes and parks become important. The introduction of accessibility from zone to zone may be a very difficult parameter to quantify and so, better estimation will rely on an uncertain parameter, which goes against the objective.

Also as distances must be very quickly available for the computer aided planning system, the overhead in computation may not be admissible. Even knowing that calculations would be carried out in the central processing unit, (CPU) at least four values (x) must be taken out from memory, as opposed to one, in a simple zone system with a
travel matrix. Also the calculation will involve multiplications
and other similar slow CPU operations such as sine and cosine.

(*) Zone to zone distance, two co-ordinates and accessibility
information.

J.2 DEVELOPTED DYNAMIC MODEL

Mainly with the problems outlined above, barriers and computa-
tional efficiency in mind, a dynamic methodology, requirement and
specification was developed. It is based in the concept of zone level
and requires the existence of local travel matrices. It has some
implementation advantages over a static system of equal number of
zones, in addition to its dynamic characteristics. It requires also
a principal travel matrix for the first set of zones.

J.2.1 LOCAL TRAVEL MATRICES AND ZONE LEVEL

In the first place a region is divided into zones. They do not
need to have an optimal size but they should obey the shapes as
discussed in chapter 4, for example, although this is not so critical.
These are level one zones. Once a zone is divided the resulting
ones are level two zones.

There is a principal travel matrix for level one zones and each
time a zone is divided, a local matrix is created. It contains all
travel parameters of nearby zones to the ones that resulted from
divisions and between all sub-zones created, as well as for the
zones created, in-zone distances and travel times.

For the sake of simplicity suppose that zone 5 of figure j.1 was
divided into three zones. Then the local travel matrix for zone 5
will contain all link parameters drawn in fig j.3 and in-zone
parameters for the three sub-zones. (Not necessarily straight
line distances!)
Fig. 3: Zone Division

If a nearby zone was already divided all those sub-zones behave as nearby zones, and the other local matrix must be corrected for this. This procedure may be subject to optimization such as automatic correction of the other matrix and avoidance of redundancy.

Fig. 4: Nearby Divided zones. New links.

We must remember that patient addresses first classified according to level one zones must be classified accordingly to level two, when a division is made.
J.2.2 JUSTIFICATION OF METHOD

Once the overall region travel matrices and local matrices are compiled using methods already referred in chapter three, four and five, we must devise a method to estimate travel distances and times between any two points or addresses. As previously every address is referred to a zone, level one or two.

Basically if the two addresses are in nearby zones and if in at least one, a local matrix exists, the values are those ones; if no local matrix exists, then the values are the ones in the principal matrix. If the addresses are not in nearby zones then we can do two things: (1) just take the principal matrix values, or if local matrices exist add two or three values. This last method is now explained by an analogy. If someone wants to go from somewhere near London to somewhere near Edinburgh he has to go first to the North of London and then to the South of Edinburgh. The method is similar. Once identified the travel direction, local matrix values are added to principal values. The method must anyway be easy and fast as required by the computer system. An adequate choice of data structures and codification of zones will be seen to give a fast answer from a computational point of view.

J.2.3 DATA STRUCTURES AND ZONE CODIFICATION

We will base our specification in a zone system composed of a regular grid of square zones. Each zone will only be able to be divided in nine sub-zones. As was seen in chapter 6 this is sufficient but there is nothing that prevents this number being changed. The squared regular grid although artifical is only a simple way of explaining the problem and the method can cope with other kinds of zoning patterns with minor modifications.

As had already been said, an orientation is necessary. Then for each zone we need to know the orientation of nearby zones. In the regular square grid each zone is surrounded by eight zones.
Clockwise from top we could refer to North, North-East, East, South-West, South, South-West, West and North-West. In figure j.5 zone 24 has zone 14 at its North, zone 15 at its North-East and so on.

<table>
<thead>
<tr>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
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<td>26</td>
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<td>63</td>
<td>64</td>
<td>65</td>
<td>66</td>
<td>67</td>
</tr>
</tbody>
</table>

fig j.5 Zone numbering

For general purpose this information can be stored in records, where for each zone is also stated if it has or has not a local travel matrix (LTM)

<table>
<thead>
<tr>
<th>Zone No:</th>
<th>LTM</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
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</table>

fig j.6 Zone information records
As is seen, zones in the same row are codified with the same second digit number and zones in the same column with the same first digit number. This will enable a fast search for orientation. If more than 99 zones are necessary or the region is too long in one direction a similar codification can be used. This allows a very efficient way of finding the zone orientation.

Addresses must also have the indication of which zone they belong to and which sub-zone. An address in zone 24, that has been divided in 9 zones will have a zone and sub zone number identification:

<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>ZONE</th>
<th>SUB-ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIT</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>

If the original zone is not divided, sub-zone number will be zero. In this case sub-zone parameter can go from 0 to 9.

J.2.4 ESTIMATING TRAVEL TIMES AND DISTANCES

Based on the data structures described before a Pascal like notation, sometimes referred to as Structured English will help to explain the algorithm to be used.

IF both addresses belong to level one zone
THEN travel times and distances came from principal travel matrix
ELSE (at least one address is in a level two zone)
IF addresses are in nearby level one zones
THEN Travel times and distances came from local travel matrix. Only the address in a level two zone will have a local matrix.
ELSE (addresses are not in nearby zones)
IF only one address, Z, is in a level two zone
THEN
Travel times and distances are the sum of local travel matrix and principal travel matrix elements (see fig. 7, route A).

ELSE (both addresses are in level two zones)
Travel times and distances are the sum of local travel matrix, principal travel matrix and again local travel matrix elements (see fig. 7, route B).

An efficient way of deciding if two addresses are in nearby zones is to look up in the zone information record (fig j.5). If the orientation is rearranged to NW, N, NE, W, SE, S, SW nearby number zones will be in order and it is possible to know very quickly if two zones are near, using binary search for example (Mirth, 1976).

--- route A
--- route B

Fig j.7 Travel estimates for not nearby zones
The codification of zones according to North-South and West-East is useful to find the intermediate zones as in fig. 1.7. These are zones 34 for route A and zones 52 and 43 for route B.

A more realistic example based on figure 1.8 will show how a procedure to find these zones could work.

Finding intermediate zones when addresses are in zone 11 and 63 is done in the following way. For simplicity of explanation we only consider the case where one of the zones is divided, in this case zone 63.

Zone 63 is two units east and 5 units south of zone 11. So the intermediate zone should be to the north (factor 5) and to the west (factor 2). The zone that better satisfies is the north one (5 is greater than twice 2; if it was equal, both north and north-east would be in the same position and a random one might be chosen; or taking both and choosing the shortest overall result).
Fig 3.8: Finding Intermediate Zones

However, after looking up in 63 zone information record, North zone does not exist. The following step is to look for zones to West and East until one is found. In this case it is zone 54. Then travel estimation should be based upon local travel matrix from address in zone 63 to zone 54 and from principal travel matrix from zone 54 to zone 11.

The same procedure applied to zones 7 and 47 would give intermediate zones 17 and 37. Travel time and distance between zone 17 and 37 will take into account if the gap in between is a non travelling region, like the sea or just another region (other county for example).
Comparison between both examples show that dummy zones may have to be created. If zone 53 belongs to a travelling region, although in another county, the result of first example would be erroneous. In fact, it is possible to go from zone 11 to zone 63 crossing zone 53 if it exists.

J.2.5 COMPUTATIONAL EFFICIENCY

All the steps followed previously require looking up from one to three times in travel matrices and several operations by the central processor. However, all of these operations are very fast ones, as only comparisons and additions are required, and integer division. Direct implementation in machine code of the procedures specified would enable even faster response, as the integer divisions could be done simply by elementary rotations in the accumulator of the central processing unit.

Deciding on nearby zone will take an average three comparisons (base 2 logarithm, of eight) and three memory cycles. For nearby zones this is the overhead over just looking up a matrix element. For separate zone addresses, estimation time, of distance and travel time, will increase.

The overall increase is difficult to estimate as it depends on the distribution of one and two level zones and the zone distance between addresses. More work would be needed to get a significant value.

However, the adaptability of the method, the memory space usage and the reliability when building the travel matrices discussed in chapter 6 may prove to give an overall advantage, although overall speed is decreased.
APPENDIX K

MEMORY SPACE WITH STATIC AND DYNAMIC ZONING SYSTEMS

In a zoning pattern where each zone is surrounded by eight zones as in fig K.1, Z is the overall number of zones for the region under consideration.

![Zone Diagram](image)

fig K.1 Zone with eight neighbour zones (Z)

If a zone is divided into nine sub-zones and an overall new travel matrix is built it will have \((Z + 8) \times (Z + 8 - 1)/2\) elements (triangular), compared with \(3 \times (Z - 1)/2\) initially.

However, if we keep the first matrix and build a local new one with the nine sub-zones plus the eight neighbouring ones, this one will have \((8 + 9) \times (8 + 9 - 1)/2\) elements. This is the extra number of elements in memory.

If \(Z\) equals 70 the first case will have one increase of 24 per cent and the second only 6 per cent. For a large number of zones this may be a very important consideration.
APPENDIX L
APPENDIX L

Validation

Once a zone or network model is established, either with dynamic characteristics or not, there must be some way of knowing if it is adequate.

The last criterion is that planned journeys are acceptable, or good enough. However, what is acceptable and good enough?

From the point of view of the model utilized to give estimated travel distances and times, acceptable can be translated into probabilistic confidence limits for the error between estimated and actual values. This is to quantify "good enough, most of the time".

Whatever method used, estimated distances and travel times will be added to give overall ambulance journeys.

Estimated journey distance is the sum of estimated distances between addresses. Estimated journey time is the sum of estimated travel times between addresses and patient handling times.

Errors between estimated distance between addresses and actual distances came from the fact that several addresses are related to a point or a zone. Estimated distances are then point to point or zone to zone distances, and so the estimation errors arise.

Errors between estimated travel times and actual travel times have the same origin but also have other sources such as that travel speed varies with day hour, weather, driver and vehicle, for example.

To check the validity of the model used to estimate distances and travel times, two things are necessary:
1. A practical validation experiment,
2. Setting acceptable confidence limits for distances and travel times.

As has been said, time error variation has several sources. However, distance error is closely related to the model used to localize addresses and will reflect its weaknesses. Large variation will indicate too large zones or insufficient numbers of junctions or links used for instance.

On the other hand, from the patient point of view, travel time variations are more important. If limits for the variation of journey time are set, it may be possible to set related journey distance limits. So that distance variation together with other sources of time variation will not result in exceeding the set journey time variation limits.

Let $L_a$ be the actual total distance travelled in a journey and $L_e$ the estimated value. For example, using a zoning model $L_e$ is the sum of several in-zone and zone-to-zone travel distances. $L_a$ can be measured from a large scale map. Against this last procedure we can see problems of precisely identifying addresses, and choosing actual routes to be taken. A more practical way of measuring $L_a$ can be just reading milemeter records from ambulance journey reports.

If $e = L_e - L_a$ is the journey distance error, by the central limit theorem, it will tend to be normally distributed. This is so because $e$ is the sum of distance errors from address to address for a journey.

Then, setting limits for the estimated distance error of the type:

No more than $P$ per cent of the journeys will have a distance error greater than $E$ Km.
will enable the validation to be carried out.

![Diagram showing a normal distribution with labels for \(-E\), \(E[e]=0\), and \(+E\).]

**Fig 1.1 Journey distance error distribution**

From a sample of journeys \(\sigma_e\) can be estimated. If there is evidence, at some confidence level, to reject the hypothesis that \(E[e]\) is zero, it will mean that some bias exists in estimated values, and they can be corrected so we get a distribution with mean error zero.

These are some problems when choosing the \(E\) value. It is possible that for short journeys, this error is small while the relative error, \(e/\ell_a\), is large. For long distance journeys \(E\) may be large but the relative error small.

So, a previous study of absolute and relative error according to journey distance may be necessary. It will help in setting values for \(P\) and \(E\) and even can check if normality actually arises in \(e\) distribution.