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Optimisation of road location and design

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Optimisation of Road Location and Design

A thesis submitted in fulfilment of the requirement for the award of the degree Doctor of Philosophy

from

UNIVERSITY OF WOLLONGONG

by

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1997
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ABSTRACT

The determination and design of road location is a comprehensive and demanding task. It requires team work and a range of different expertise for the most cost effective and environmentally satisfactory solution to be found.

The use of computers and GIS (Geographical Information Systems) enables the designer(s) to consider different road aspects in their design at the same time rather than sequentially. The result can be interpreted as an automated road location and design procedure.

The method described herein is such a technique. Using this method, the designer(s) is able to seek different experts' opinion on a particular road design aspect by asking them to provide a set of resistance factors (or weights) to a particular aspect of the particular road. The results of different resistance factors (weights) can be summarized into a single or multiple resistance factor set and can be used by the Road Location Program developed herein.

The environmental aspects of the road, whose importance is increasing, can be implemented in the design procedure at the earliest stage of the design, just as any other physical constraints of the road design procedure.
The principal aim of introducing such a method is to illustrate its ability to automate the road location and design procedure, and not to produce a sample road that represents the absolute optimum location. Determination of such a location requires different expertise with extensive databases of information and up-to-date costs.

Despite these facts, a sample road was designed in the Kiama region of New South Wales, Australia, to determine the functionality of the method. The reason for choosing the area was that a new bypass was built in that area recently (1993-1994). It was a suitable benchmark to allow a comparison with the designed road resulting from the method described herein. The comparison showed that the road designed herein followed the constructed location reasonably, but allowed for more stringent environmental considerations.
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LIST OF AYMBOLS AND ABBREVIATIONS

\(\delta\) = path difference;

\(d'\) = shortest slant distance from the source position;

\(W_{A\alpha}\) = the resistance factor of the line with \(\alpha\) degrees of declination respect to the aiming line;

\(A\) = potential barrier correction;

AEC = Average Earthwork for Cutting;

AEF = Average Earthwork for Filling;

\(A_t\) = noise barrier coefficients;

\(AL_\alpha\) = the additional length of the road due to the declination of \(\alpha\) degrees;

AM = Automated Mapping;

BD = Buffered Distance;

\(C\) = the average amount of cutting in a road section;

\(C*P\) = cost of cutting;

CAD = Computer Aided Design;

d = distance between the receiver and the nearest carriage way;

DoE = Department of Environment;

\(D_{SO}\) = distance between effective source point and barrier;

\(D_{sr}\) = distance between effective source point and receiver;

DSS = Decision Supported Systems;

EA = Environmental Assessment;

EIS = Environmental Impact Statement;
E-RMS = Environmental Resource Mapping System;

F = the average volume of filling in a road section;

F*Q = cost of filling;

FM = Facilities Management;

G = gradient of the road;

GIS = Geographical Information Systems;

H = average height of propagation;

h = height difference between the receiver and source;

HC = hydrocarbons;

h_o = height of barrier;

h_R = height of receiver;

h_s = height of source;

K = the intersection point of Source-Object and perpendicular from Receiver;

L = combined noise level;

L_n = noise level of nth segment;

\[ N = \frac{([\text{Basic noise level} - 10] - \text{Acceptable noise level})}{10} \]

NOX = oxides of nitrogen;

NSW = New South Wales;

O = the object between Receiver and Source;

p = percentage of heavy vehicles;

Q = total 18-hour traffic flow;

q = total hourly traffic flow;

R = Receiver;

S = Source;

SPANS = an acronym, stands for SPatial ANalysis System;

TD = texture depth of road surface;
TIN = Triangulated Irregular Network;

$V = \text{mean speed}$;

$x = \log_{10} d$; and

$\Delta H = \text{the height difference between the designed height and average ground height}$;

$\Delta V = \text{mean speed correction}$. 
CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The prime purpose for constructing any public road is to provide safe, effective and convenient movement of people and goods. Whenever the word road is used it means the optimum road between two terminal points that fulfil the required conditions. These conditions, namely, safety, effectiveness and convenience had different definitions in different times. For example in the far past when travelling was done only by live stock, the meaning of safety was mainly from robberies, whereas these days its meaning is quite different. The purpose here is to discuss the possibility of designing roads using an alternative approach that can ease the planning procedure and minimise the cost and time needed for this purpose.

Traditionally the design of roads consists of three stages:

Firstly: To investigate through available maps of the area of interest that were usually in small scale, and to plan a number of suitable variants that could satisfy the predominant requirements. These requirements will be discussed in full detail later.

Secondly: To go through the site and choose one (or more) of those variants as the most suitable, and to prepare topographic maps of those areas in appropriate bands.
depending on the type of road required. At this stage the final version of the road is
designed.

Thirdly: Set up the final road by surveying techniques and start the construction work.

Because of the importance of these stages in our later conclusion, the above stages, as
depicted in Fig. 1-1, are described in more detail.

Fig. 1–1 Three stages of road-making procedure

1.2 Transportation Development Process

In order to evaluate the optimum road path, information is collected consisting of
the following items; transportation inventories, traffic analyses, modal forecasts,
future system requirements, levels of service, population data and forecasts, land
use inventories, public facilities plans, and basic social, economic, and environmental data. This information comes from various sources, both public and private, and is updated on a regular basis. The result of the above information determines the type of road and its level of service. This thesis deals with the problems after this stage. It means that the type of the road and its level of service are set prior to this step.

In any road location and design procedure, there are different stages to perform the task. Many authors divided the whole procedure in three stages, which can be carried out by a different group with different expertise. The first stage, normally regarded as the preliminary design stage, is to find the preliminary road location. This road path normally would change several times during the second and third stages, which are described herein. The main concern of this thesis is to fulfill the first stage. Any other information that could be useful at this stage, in addition to information that is traditionally used in such procedures, is employed in the process. Environmental information is such a matter that is used herein. However, some detailed design elements such as the geometric design of the road and the exact amount of earthworks and places of borrowing and deposition are not of concern in this thesis. The operation requires the final version of the road, including geometric design, and uses mass diagrams to acquire the more precise amount of earthworks. However, a brief reference to a mass diagram is noted in Chapter 2. Therefore, this is not the final version of the designed road, and the more precise amount of earthwork is left for the later stages.

There are some locations that are regarded as places of interest for two reasons.
1. These places (areas) are far more important to be used as some part of the roadbed.

2. These places (areas) not only have the same significance as the first group, they are important not to be further than a certain distance from the roadbed, as well as for their tourist attraction values for example.

Both considerations can be achieved by the computer program developed herein. For the first purpose, this is enough to exclude the area from the road path and place them at the same rank as seas for example. For the second purpose, even though the areas are regarded as not suitable for road path, a point near those areas could be used as an interim ending point. The program chooses a path towards that point first, and then to any other interim points, if any, and the final ending point. Aesthetic reasons could be considered using this method, including the interim point as well.

1.3 Preliminary Investigation for Roads Design

Normally roads are built to join two or more areas. These areas (or points) are usually named as terminal points. It should be mentioned here that whatever the design is, the minimum cost that fulfils the requirements is the vital consideration. This cost is usually the cost of travel and the cost of construction. The principal factors influencing the formulation of road design standards and the factors governing the selection of road design are:

• volume of traffic (the average number of vehicles which travel the road in one hour)
• composition of traffic (the average type of vehicles travelling the road in one hour)

• terrain (the condition of terrain such as the topographical situation)

• environment (the distribution of the population, etc.)

One of the most popular methods to determine the suitable variants, especially in developing countries, is the compass method. The procedure is very simple and the maximum longitudinal slope is governed by the type of the road. The idea is depicted in the Fig. 1–2.

![Fig. 1–2 Route selection using compass method](image)

The aim in this figure is to join point A to B, while the maximum slope of a% is maintained. To maintain this slope when the contour lines are b meters apart:
\[ d = \frac{100b}{a} \]  

where \( d \) is the distance between each two points.

For example in Fig. 1–2 the starting point A has a height of 990 m, and the contour lines are 20 meters apart. If a maximum of 5% slope is required, the first point from A should be:

\[ d_1 = \frac{100 \times 10}{5} = 200 \text{ m} \]

that crosses the contour lines of 980 m or 1000 m. The points \( A_1 \), \( A_2 \) or \( A_3 \) are acceptable in this regard. The next point from points \( A_1 \), \( A_2 \) or \( A_3 \) is:

\[ d = \frac{100 \times 20}{5} = 400 \text{ m} \]

that crosses the contour lines of 980 m or 1020 m for \( A_1 \) and \( A_2 \), or 960 or 1000 for \( A_3 \) (Fig. 1–2). The procedure continues until the other terminal point (B).

With advancement in photogrammetric techniques, the first stage of the road making procedure, namely Preliminary Investigation for Road Design can be carried out in a more effective way if the required photogrammetric data and aerial photographs are in hand. This stage can be divided in four stages as follows

**First stage**

- Reconnaissance survey of the entire area between terminal points:
1. Stereoscopic examination of small-scale aerial photographs of the area, supplemented by available maps

2. Determination of controls of topography and land use

3. Location of feasible routes on the photographs and maps

Second Stage

- Reconnaissance survey of feasible routes:

  1. Stereoscopic examination of large-scale aerial photographs of each route

  2. Determination of the detailed controls of topography and land use

  3. Preparation of route maps by photogrammetric methods when necessary

  4. Location and comparison of feasible routes on photographs and maps

  5. Selection of best route

Third Stage

- Preliminarily survey of the best route:

  1. Preparation of large-scale topographic maps using route photographs and photogrammetric methods, or preparation of large-scale topographic maps by ground surveys, guided by best route location made on photographs in second stage

  2. Design of the primary location:

     a. Using topographical dimensions of the large scale map or computer-assisted interactive graphics

     b. While stereoscopically examining the route photographs
3. Preparation of highway construction plans

**Fourth Stage**

- Location survey staking of the right of way and of the highway and structures for construction

**1.4 Required Operations to Choose the Most Suitable Route**

At this stage the ground operations to determine the best possible route are carried out. For this purpose, different variants that are determined from the previous stage are examined more closely by preparing topographic maps of those areas at suitable bands. The width of the band differs with the importance of the road. For example for a normal highway, a band of 400 meters around the centre line is required. Besides these surveying operations, ground investigations to determine the type of soil, geological conditions and other relevant information will normally be carried out.

Design of the horizontal and vertical alignments, width of pavements and shoulders, drainage, cross sections, superelevation at curves, sight distances, bridge width and pavement cross slopes that are parts of the geometric design of roads are carried out in this stage.

**1.5 Setting Up the Final Road**

Now it is the time to build up the designed road. This part of the job is fieldwork and it is not the concern of the project discussed herein.
As mentioned earlier, to plan, locate, design, construct, operate, and maintain roads or public transportation facilities require the collection, processing, and reporting of vast amounts of data. In fact, collection of data is the most time consuming part of the design of the location of roads. For example, to design the location of a road, various data from distribution of population to topographical and geological information are required. The methods for data collection have changed during time, and alongside the improvement of other sciences and technologies, these techniques have improved. These days, satellite images are widely used in route locations and designs, whereas a few years ago, land surveying and use of existing maps, which were usually out of date, were the only ways to collect the required data for route location.

This section endeavours to show that Geographical Information Systems (GIS) are the best and the cheapest source of data that can be used for route location. The prominent characteristic benefit of using GIS is that it can maintain data sharing. Different organisations, including road design consultants obtain advantages from the GIS systems, which usually contain the various kinds of data with different resolution and accuracy. The use of these data also mimics the tedious field work as well, since traditional rural road location practice has been field oriented, that is, the major time of the location party went to measurement and observation on the ground. The operation consisted of several steps (Oblesby, 1982), (Behbahani, 1983), (Lay, 1990):

- The first step was reconnaissance of the area.

- The second step was reconnaissance of feasible routes.
The third step was preliminary surveying of planned line(s).

The fourth step was to lay out the final location or alternative location(s) by study of maps and profiles after plotting of the plan line data in the office.

The fifth and the last step was staking the final line on the ground. Profiles, cross sections, and drainage were derived from this line.

The development of computers and modern data acquisition techniques, can change the route location operations from field oriented operations to office oriented operations. Modern location selection of roads is carried out in three stages.

A road location designer should examine potential routes on the basis of the following requirements (Wright and Paquette, 1987):

- Traffic service for population and industrial areas.

It is obvious that the aim of constructing any road is to provide services to people, connecting the industrial areas to other areas of interest, etc.

- Directness of routes.

The shortest route that can satisfy different requirements such as standards, safety, etc., and minimise the cost of construction is the final aim.

- Suitability of terrain encountered.
The suitability of terrain is another factor for design of road location. For example, mountainous areas are not suitable for highways because it is very costly to maintain the standard slopes in these areas.

- Adequacy and economy of crossings at watercourses and at other transportation routes.

The required bridges and tunnels (if needed) are considered at this stage and the approximate costs are determined as well.

- Extent of adverse social, environmental, and ecological effects.

The impact of new roads on environment and ecology of the area and other areas is an important matter that should be taken into account. The great ability of GIS to analyse these effects is unique, and is the most distinguishing difference between GIS and other Surveying/Engineering Packages.

In rural areas, the location of a highway is dictated chiefly by the desired terminal points of travel, topography, and geology (Wright and Paquette, 1987). The road should serve a desired travel pattern with an alignment that provides consistent conditions within acceptable limits of curvature and grade over terrain that is capable of supporting the proposed construction without excessive costs.

**1.6 Statement of Problem**

Despite the advances in computer technologies and GIS techniques, the procedure of selecting the optimum road is still carried out by traditional methods in many
countries. With these methods, in many cases, the designer is not able to cope properly with the vast amount of information stored in different formats and the result might be not the best available solution. In addition, different aspects of the road path selection with the traditional methods are carried out in different stages. For example the road is designed firstly according to the physical condition of the ground and other aspects such as environmental factors decided in separate stages that result in complex phenomena. To maintain the environmental requirements of some areas might demand a substantial change in the primary designed road which may lead to redesign of the whole road path to satisfy the environmental need that in turn may not be suitable for severance purposes. So if a method that be able to take into consideration all required factors for the selection of the optimum path in the early stage of the procedure can be employed, a better and cheaper road path could be designed. A new method, which can help the designer to overcome dealing with the diverse amount of data, is possible with current technologies.

1.7 Research Objectives

The major objective of this study is to introduce a method to furnish a model to help the road designer to determine the optimum road path. The model would consider both physical and environmental aspects of road design.

1.8 Scope of the Thesis and its Structure

The scope of this thesis is focussed on the development of a practical model to enable the designer to select the optimum road path, using numerous different data sets. The development of computer programs to model the different data related to the ground
conditions and its attributes that are, or can be, used to determine the optimum road path. The programs are designed just to cover this particular area, but can be modified to deal with a wider range of information and data sets if required.

The thesis consists of nine chapters (Fig. 1–3):
Fig. 1–3 Structure of the thesis
CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 ROAD LOCATION AND DESIGN

The procedure of route selection differs from one country to another. The difference is especially obvious when the comparison is carried out between two countries, one a developing country and the other, a developed one.

In most developing countries the basic aim is usually to provide a network that connects all villages whilst minimising the sum of the construction costs and travel costs (Makarachi and Tillotson, 1991). The environmental parameters play a trivial role in determining the construction costs. This viewpoint, for most developing countries, can be justified if the environmental conditions are already poor, as the increase in noise, air pollution, severance, risk etc. will not make them worse (Ferrary, 1990).

For the purpose of establishing a route selection model in these countries, the costs have usually been divided into two types. One type has been called construction costs, and these should be taken to include maintenance costs suitably discounted over the life of the road. In principle, these costs can be estimated with reasonable accuracy (Bell and Kaminsky, 1987). The other type of cost has been called travel costs, and these cannot be estimated with reasonable accuracy. This limitation has
led to a model that seeks to avoid dependence on the absolute value of travel costs (Makarachi and Tillotson, 1991).

To model the design of a network of links Makarachi and Tillotson (1991) adopt the following assumptions.

- The area is uniform from a topographical point of view.
- The area covered by the road has the same agriculture, demography, etc.

In a district of reasonably uniform topography it seems reasonable to suppose that the construction cost will be proportional to the lengths of the links to be constructed. This assumption can be modified to advantage later by introducing different construction standards for roads carrying different levels of traffic.

More formally, the travel costs are likely to be proportional to:

- the number of people connected by the link,
- the distance traveled through the link to reach the destination.

It is therefore argued that whatever the travel costs may be, they will be proportional to a factor called ‘person-kilometre’, which is defined as the product of population connected by the link and the distance between the village and the destination through the link. Clearly, this assumption can only be expected to apply over a region of similar agriculture, demographic structure, village type and average income. The model is therefore aimed at relatively small uniform areas (Makarachi and Tillotson, 1991).
In a more complicated model the role of the geometric design of the road, which is interrelated to the topography of the area, demographic structure and average income of people, should be considered in order to estimate travel costs. In this case the travel cost seems to be proportional to another factor namely 'person-kilometre-time'. As an example, the travel cost for one kilometre of a flat road with a certain car model is different from the travel cost of one kilometre of another windy road with another car model. Such procedures are carried out in order to design a road or a network of links in most developing countries.

In contrast, the role of environmental factors could be more important than construction costs in most developed countries. Sometimes even the construction costs are of lesser concern than more important factors (Kulkarni et al, 1993). In such countries, the selection of feasible routes is subject to many factors.

Public consultation is one of the stages, which normally is carried out before any construction work is commenced. The alignment chosen for public consultation should be considered to avoid passing through villages and environmentally sensitive areas as much as possible. Careful consideration also should be given to severance problems and the quality of the agricultural land affected, and possible visual intrusion (Heptinstall and Blood, 1993).

Whatever the situation is, and regardless the number of factors taken into account for design purposes, the Decision Analysis Method is a suitable approach to modelling the design elements. The method is particularly effective for the problems involving multiple and often conflicting objectives (Keeney and Raiffa, 1976), which are the
nature of any road location and design project. Techniques of decision analysis are used by Kulkarni et al. (1993) for separately assessing technical and value judgements, and then combining these judgements in a consistent manner to provide rational criteria for ranking alternatives. Technical judgments are needed to estimate the impact of an alternative alignment on the relevant objectives. Value judgments are needed to assess the decision-maker's preferences for different impacts.

The following steps are normally involved in order to implement the decision analysis method.

1. Structure the decision problem.
2. Assess preferences (values) of decision-makers.
3. Estimate possible impacts of each alternative.
4. Evaluate and compare alternatives.

All the above four steps are subjective matters that differ from one country to another and even from one project to another, although many common rules have been established.

2.2 ENVIRONMENTAL CONSIDERATIONS

The implementation of almost any transportation project brings with it a series of impacts or consequences that may well be negative in nature. On the other hand, the impacts may be positive. For example, a highway on a new location may reduce
truck traffic on an existing route to the extent that residential noise levels significantly drop. More typically though, environmental impacts from transportation projects are likely to be perceived as negative in nature, and in need of impact analysis and even serious abatement consideration (Cohn et al, 1987).

Planning applications for certain specified types of development and orders made under the relevant Highways Act in most developed countries are now required to be accompanied by an “environmental impact statement”. This statement should set out the likely effects that the development or highway will have on people and the environment. The consideration of the environmental impact statement (EIS) by the appropriate authorities, together with the comments from interested parties, forms the procedure known as “environmental assessment (EA). Formal EA is a technique which draws together quantitative analysis and qualitative assessment of the environmental effects of a project, as well as providing for the investigation of measures needed to avoid, reduce or remedy these effects. The result should be presented in a way in which the importance of the predicted effects, as well as modifications or mitigation measures, can be properly evaluated before a decision is made by the relevant decision-making body or competent authority. The starting point of the EIS Directive is that “the best environmental policy consists in preventing the creation of pollution or nuisance at source, rather than subsequently trying to counteract their effects” (Commission of the European Communities, 1985). The submission of an EIS is required with planning applications for developments such as oil refineries, power stations, chemical plants, major roads and railways, ports, waste disposal plants etc.
No specific form of an environmental impact statement is prescribed, but it must contain a description of the likely impacts of the development on the following (Ferrary, 1990):

- Human beings, flora and fauna;
- Soil, water, air, climate and landscape;
- The interaction between any of these;
- Material assets and cultural heritage;

Typically, a five-stage approach is adopted, comprising:

1. Identification of likely sources of impact
2. Prediction of the magnitude of impacts
3. Evaluation of the significance of impacts
4. Mitigation of impacts through the recommendation of appropriate measures
5. Communication of the results of the assessment through the medium of ES

In most developed countries EA is obligatory for proposals such as:

- Motorways, express routes and long-distance railways;
- Airports (with over 1.2 kilometer runways);
• Trading ports

In addition, projects such as:

• Other roads

• Harbors

• Other airfields

• Tramways and other railways

• Pipelines

• Marinas

may require EA as well.

The EA should consider the impacts of transport on:

a) Occupiers and users of facilities near transport corridors;

b) Travellers using various transport modes, and flora and fauna in the transport corridors.

The impacts to be considered might include:

1. **Noise**, which can cause disturbance to people at home or their workplace, day or night.

2. **Vibration**, which can occur from the passage of road traffic, trains and aircraft. The impacts of vibration on human beings and fauna are broadly
similar to noise. Vibration may have physical impacts on land and property that can range from hairline cracks to structural damage. However, incidents of the latter is extremely rare.

3. **Air quality problems**, which are the result of emission of lead, nitrogen oxides, carbon monoxides, unburned hydrocarbons, pure carbon diesel by cars and lorries are the most common problems likely to arise.

4. **Visual impact**, which can be caused by structures such as viaducts, bridges, embankments and cuttings in the form of intrusions and obstructions.

5. **Safety**, which decreases when the traffic flow increases.

6. **Severance**, which can be the result of enforced changes to routes or additional delays, can increase journey times for travellers having to cross new or more heavily-used routes, either on foot or in vehicles of various types; even journeys may be deterred. Severance may also have an effect on land uses by causing alterations to catchment areas of commercial uses or community facilities and thereby their viability.

7. **Physical damage**, which can occur, such as loss of housing, business, landscape and ecological resources due to construction of new roads.

8. **Ecological impacts**, which can be arise from loss, severance or disturbance of habitants. Pollution, such as vehicle emissions or
discharges, spillage and run-off, alteration to hydrology and drainage, and the physical danger from passing vehicles and wind are other issues.

9. **Water quality**, which can be affected by the various pollutants that were mentioned earlier, can affect the water quality at all levels.

10. **Impacts on historical and cultural resources**, which may occur in a number of ways. Damage or disturbance to archaeological deposits and listed buildings can occur through:

    - land occupation and direct physical loss;
    - vibration and subsidence;
    - damage from associated works;
    - changes to hydrology, which may damage deposits preserved in a wet state;
    - changes in land use and management (e.g. farming practices);
    - loss of amenity through noise and visual impacts.

These elements are depicted in Fig. 2-1.
The UK Department of Transport's technical memorandum (Calculation of Road Traffic Noise, 1988) recommends the $L_{10}$ (18-hour) index as the most appropriate measure for road traffic noise, and it is this which is typically used in EA. In the study herein the same memorandum, which is stated in Standards Australia catalogue 96 as a reference source, is the basis for traffic noise calculations. The environmental impact of transport is an issue which not only is already highly important, but one that will increase in importance in the next few years.
In practice an environmental study for road location is appropriate to be carried out in two stages (Heptinstall and Blood, 1993):

a) An evaluation and comparison of alternative routes. This involves the collection of data over a wide corridor. The information collected would provide a useful background for processing objectors’ proposals at a public inquiry.

b) A detailed study of the preferred route leading to an optimisation of the engineering design and the preparation of effective proposals in mitigation of the environmental impact.

A more detailed appraisal of the alternatives is carried out, with an examination in depth of the engineering constraints, capital and user costs, the environmental aspects and effects. Account must be taken of particular route location hazards, such as the incidence of fog in any situation especially during the Autumn and Winter months.

Within all the technical, financial and environmental constraints, the aim is to define a sensible, practical option, with adequate junctions, and giving all due attention to the proximity of development, and to the effect on any essentially rural landscape.

In terms of highway design itself, the best way to minimise the impact of noise and other environmental effects is to take them into account at an early stage in the design (Box and Forbs, 1992), (Jacob and Moore, 1993), particularly at the time of route selection. The fundamental influence on noise impact will be the alignment of the highway, its position in relation to affected properties, and whether or not attenuation can be achieved by landform, by the use of cuttings.
2.3 OTHER CONSIDERATIONS

2.3.1 Ecological Effects of Roads

Road scheme planning should ensure that sites of special importance are avoided and that some compensatory provision is made where areas of general wildlife value might be destroyed or damaged. In this context, cost-benefit analysis should incorporate the cost of these compensating projects when alternative schemes are compared. Where for technical or scientific reasons it is not possible to recreate the habitat elsewhere, then an alternative scheme should be chosen (Fig 2-2). There should be no net loss of environmental capital as a result of development (Box and Forbes, 1992).

a) Loss of Natural Features

A new road can cause direct loss of, or damage to, a wildlife habitat, a geological exposure, or a physiographical feature. Where a new road passes through wildlife habitats, such as a wood or forest, there will be an interface between the new road and the adjacent wildlife habitats. Resultant changes in ecological factors, such as light, wind, temperature, humidity and soil nutrients will cause changes in the abundance and composition of the species forming the plant and animal communities.
Fig. 2-2 Ecological input to highway works (Box and Forbes, 1992)
b) Hydrology

Hydrological disturbances causing changes in the quality and quantity of surface and ground water flows can affect plants and animal in sites some distance from a road as well as those nearby. Road construction can give rise to water run-off having various pollutants as well as fluctuations in pH and conductivity.

Methods for minimizing ecological impacts of new roads are suggested as follows:

Change course of roads

Change those sections of roads, which may cause disturbance to the ecology.

Bridges and tunnels rather than cuttings and embankments

Cuttings and embankments function as a barrier to most non-flying animals.

Wherever necessary, to avoid endangering some species, bridges and tunnels can be an alternative solution rather than to change the course of roads.

Tunnels under road

This action could be suitable for a few species such as echidnas, badgers and toads.

Drainage

Careful design can minimise the impact of a road on surface and ground water flows preventing drying out.

Landscaping

Should use native species which are typical of the local area and come from local sources.
Timing
Work programs should be phased so as to avoid critical bird and amphibian breeding times.

Spoil disposal
Surplus excavated material should be used on site to reshape slopes so that there is no net import or export of soil. If there has to be surplus soil, then this should be tipped in defined sites of no nature conservation value instead of in marl pits, wet hollows etc. where wildlife would be displaced.

Habitat creation
An equivalent or greater area of those wildlife habitats that are adversely affected should be created.

2.3.2 Landscaping of Roads
Since the invention of motor vehicles, cars and roads are among the most important factors influencing our society. While roads are essential for communication movement of people and goods, an added bonus is to create opportunities for travellers to see and appreciate the attractive scenery. Therefore, one of the designer's aims in order to design an acceptable road is to integrate the road into the landscape and the built environment. Clearly cost is an important factor. Nevertheless, on occasions a structure may be justified if the landscape is of particular beauty or is seen by large number of people (McCluskey, 1989).
There may, perhaps, be cases where consideration can be given to lowering the design speed so that the scale of the road will be a closer match to that of the landscape. This could occur, for example, in the design of a highland road through beautiful country, attractive to tourists. Here enjoyment of the journey might be more important than travelling the road in the shortest time.

Landscape is "viewed external environment" including such elements as land, water, flora, fauna, farms, cities and their connecting roads. Just as the artist creates a harmonious, appealing picture with his brush, so too an attractive and well-balanced landscape should be produced with the elements that make up the external environment. Consideration is thus given to the landscaping of roadways from the planning stage, through to construction and finally maintenance. Landscape philosophies will vary between different categories of roads serving the community needs. Two points of view should be considered at this stage.

1) View from the road (driver and passengers)

Boredom can constitute a safety hazard for drivers on major rural roads, while passengers often have nothing to do but look out of the windows. Furthermore, roads are part of our environment, where many spend a considerable period of time each year. This environment, then, should be of a high quality, and that includes designing for visual interest. Variety is an important element in creating interest. Thus a road corridor might be contained by vegetation along parts of its length, these parts alternating with lengths where the view opens out to panoramas or important landscape features.
Sometimes a notable feature (a church or village on a hill, an outcrop of rock) can be made a focal point on the line of a length of straight road.

2) View of the road (observer seeing the road as a feature in the landscape)

A pleasant landscape and suitable horizontal and vertical curves reduce a driver's fatigue dramatically. Each type of landscape has its own scale. A high-speed road requires large radius curves both horizontally and vertically. These can be difficult to match to a small-scale landscape. To match the road with the surrounding landscape, consideration can be given to lowering the design speed. Setting roads in cuttings is preferable to an embankment from an external visual point of view. In addition, noise nuisance is less likely with cuttings.

2.3.3 Severance

Across farming countryside, alignment should be chosen with a view to minimising the severance of land on holdings. Where this is unavoidable, the severance should be such that the size and shape of the land on both sides of the new route are useable by the farmer. If there must be parcels of land isolated and not of use for farming, then the future of these parcels of land should be determined.

Although the severance problem differs from one situation to another, the categories used by Kulkarni et al, (1993) can be regarded as a guideline. According to these authors, the following definition and groups were introduced (Kulkarni et al, 1993). Defining the following categories (in a descending order of impact) can assess the degree of impact of a split parcel:
• Alignment splits the parcel of land so that one or more of the remnants become economically unviable for existing land-use. Economic viability is defined as a minimum of 40470 m² (10 acres) of prime farmland or 161880 m² (40 acres) of non-prime farmland.

• Alignment splits the parcel so that one or more of the remnants become economically unviable for the current landowner; however, if the remnant(s) is combined with an adjacent parcel, it will remain economically viable for the existing land uses.

• Alignment splits the parcel so that all of the remnants remain economically viable to the current landowner.

2.3.4 Mass diagram

A mass diagram is a graphical representation of the amount of earth excavation and embankment involved on a project and the manner in which the earth is to be moved. It shows the location of balance points, the direction of haul, and the amount of earth taken from or hauled to any location. It is a valuable aid in the supervision of grading operations and is helpful in determining the amount of overhaul and the most economical distribution of the material. It shows the algebraic sum of the cuts and fills (or excess of cut material) after allowing for compaction, between any selected points on the road. In order to compute the exact amount of cut and fill a certain distance is considered as free-haul. This means that the moving of earth up to this distance is paid a fixed price. Normally most of the cutting will use the filling areas. If there is a need to use extra mass to
complete the filling or the amount of cutting is more than filling, borrow pits and depot pits are needed. At this stage with the use of the mass diagram, the optimum amount of overhaul distance, which is the total haul distance minus free-haul distance, can be determined. This distance is set by agencies at values such as 500, 1000, 1500 or 2000 meters and so on (Oblesby and Hicks, 1982).

Overhauled volume is measured in the space originally occupied in the cut. These diagrams are produced after the road is ready for construction and all design stages are carried out.

Using a mass diagram enables the designer to have a better idea of the more precise determination of earthworks cost. Each horizontal line intersecting the mass curve at two points indicates the balance between those two points. The amount of cut is enough to fill the areas needed filling between those two points. Points A and E are an example for this balance. A mass curve falls when the road is in fill and rises when the road is cut. For those parts of the mass diagram located under base line, the cut should move from right part to fill the areas on the left and for those areas located over baseline, the cuts should move to the right to fill the required areas (Fig. 2-3).
CHAPTER 2: GENERAL LITERATURE REVIEW

Vertical Alignment

Mass Diagram

Fig. 2-3 Vertical alignment and mass diagram
2.3.5 Overtaking lanes

An overtaking lane is an additional lane provided on a conventional two-lane two-way road to increase overtaking opportunities (Hoban and Morrell, 1985). It may be used in flat or rolling terrain, or on sustained grades. In this latter case, it is usually called a climbing lane. While climbing lanes are used to improve particular bottleneck or hazardous situations on sustained grades, the purpose of an overtaking lane is to improve the overall traffic operation over a relatively long length of road.

When locating overtaking lanes, the following factors should be taken into account: (Underwood, 1995)

1. Subject to other constraints, locations that minimize construction costs will provide the greatest cost effectiveness.

2. The location should appear logical to the driver.

3. Overtaking lanes are effective in flat terrain.

4. There should be adequate sight distance at the tapers at each end of the overtaking lane.

5. Major intersections should be avoided because turning traffic may reduce their effectiveness.

6. Physical constraints such as bridges and culverts should be avoided if they provide a width restriction.

2.3.5.1 In order to give delayed vehicles reasonable opportunity to overtake slower moving vehicles and to provide effective reduction in bunch (or platoon)
size, overtaking lanes should usually be between about 0.8 km and 1.6 km long (Harwood and Hoban, 1987).

2.3.6 Climbing Lanes

On long and / or steep up-grades on two-lane undivided rural roads carrying a significant proportion of trucks, the provision of an additional lane in the up-hill direction, i.e. a climbing lane, may be an effective means of increasing capacity and reducing delay and hazard. Various criteria for deciding the need for the provision of climbing lanes are available. For example:

1. The American Association of State highway and Transportation Officials (AASHTO 1984) says that it is desirable to provide a climbing lane in the up-hill direction of a two-lane two-way pavement when the length of grade causes a reduction of 16 km/h or more in the speed of loaded vehicles, provided the total volume of traffic and the percentage of heavy vehicles justify the added cost.

2. The 1985 Highway Capacity Manual 1985 suggests that one of criteria that might be applied to reflect the economic considerations is when:

(a) The traffic volume in the up-hill direction exceeds 200 vehicles/hour; and

(b) The truck volume in the up-hill direction exceeds 20 truck/hour; and

(c) One of the following conditions exists;

- Level of service E or F exists on the grade;
• A reduction of two or more levels of service is experienced when moving from the approach segment to the grade;

• A 16 km/h or greater speed reduction is expected for a typical heavy truck.

3. NAASRA 1980 suggests that a climbing lane should be considered when both of the following conditions are satisfied:

(a) The length of grade under consideration is long enough to cause a decrease in truck speed to approximately 40 km/h; and

(b) Traffic volumes are equal or greater than those in the following table are.

<table>
<thead>
<tr>
<th>Percentage of trucks (more than two axles)</th>
<th>Flat terrain</th>
<th>Undulating terrain</th>
<th>Hilly terrain</th>
<th>Hilly terrain with no overtaking for 3km (2 miles) in each direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>700</td>
<td>600</td>
<td>450</td>
<td>150</td>
</tr>
<tr>
<td>10</td>
<td>550</td>
<td>500</td>
<td>350</td>
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<td>20</td>
<td>350</td>
<td>300</td>
<td>200</td>
<td>70</td>
</tr>
<tr>
<td>30</td>
<td>250</td>
<td>200</td>
<td>150</td>
<td>50</td>
</tr>
</tbody>
</table>

Even if the above types of criteria are not met, consideration may be given to the provision of climbing lanes in special cases, such as:

1. Long grades over 8 percent.

2. Accidents attributable to traffic congestion resulting from slow moving trucks.
3. Heavy trucks originating from a traffic-generating industry or intersecting road and joining the through traffic on an up-grade.

2.3.7 Turn-outs

A turn-out is a widened and fully trafficable shoulder area on a two-lane road to enable slow moving vehicles to pull out of the through lane so that following vehicles can pass. They are an alternative to passing lanes on roads in mountainous areas, and in other areas where full overtaking lanes are not justified or cannot reasonably be provided. At a turn-out, the driver of a slow moving vehicle that is delaying one or more following vehicles is expected to pull out into the turn-out to permit the delayed vehicles to overtake.

Turn-outs may be used at spacing of typically 2 km to 5 km along a road to provide overtaking opportunities. Their length varies from about 100 m to 200 m. They usually should be paved to a width of 3.5 m with a 1.2 m outside shoulder (Underwood 1995).

2.3.8 Use of Paved Shoulders

Provided shoulders are paved to an adequate depth for structural stability, are continuous and are of sufficient width, they may be used by slow moving vehicles to allow faster moving vehicles to overtake them. Basically they operate as long turn-outs in that slow moving vehicles use them only when there are faster moving vehicles desiring to overtake them. The clear width available for moving traffic should be at least 2.4 m but preferably 3.0 m. Suitable signing should indicate the desired use of the shoulder (Underwood 1995).
2.3.9 Short Four-lane Sections

If a pair of overtaking lanes is provided the result is the same as a short section of four-lane undivided road, and this may be relatively cheap and economic means of providing increased capacity on a section of road. In some situations, provision of a short length or several short lengths of four-lane divided road may be an appropriate means of augmenting capacity. Sections of duplication as short as 1.6 km will provide substantial operational benefits. However, construction and safety considerations, such as the location of transitions from two to four lanes and vice versa, may make the adoption of somewhat longer sections desirable in some cases. The spacing between duplicated sections can be up to 8 km to 13 km (Underwood 1995).

2.3.10 Safety

Safe roads are one of the prime objectives of road design. It has been estimated that 60 percent of road injury accidents could be avoided using proven remedies and measures. Of this reduction, 15 percent would come from measures applied to the road, 20 percent from measures applied to the vehicle and 25 percent from measures applied to the driver (Sabey, 1976). Measures that can be applied to the road are the changes to the following categories (Boughton 1975a and b).

- Geometric design
- Intersections
- Access control
- Traffic management
- Traffic guidance, warning and control devices

2-25
• Cross section

• Surface skid resistance and drainage

• Structures

• Roadside furniture, obstacles and guardrail

• Lighting and delineation

The aspects of these measurements and improvements are out of the scope of this thesis.

2.4 AUTOMATION OF ROAD LOCATION AND DESIGN

There have been some attempts to develop computer packages to assist the planning stage of road design, but not to automate the design. The main reason not to produce such design packages is the subjective part of the design procedure. O'Brien and Bennett (1969) suggested a method using the dynamic programming procedure based on a rectangular grid to solve the problem of minimizing costs. The problem of the large number of alternatives to be considered in order to find the best road solution can be reduced in size if this technique is used. Nicholson et al., (1976) suggested a two-stage model, in which the first stage was based on the O'Brien and Bennett method, and the second stage used unspecified calculus of variations. They used the O'Brien and Bennett method as an approximation to their second stage of the approach. Parker (1977) suggested an alternative grid-based model for minimizing construction costs subject to slope constraints. All of the methods involved some form of grid
search together with a method for calculating the costs for arcs between the straight sections of the route.

Align_3d (Gipps, 1992) was introduced as a commercial computer package, with claims that it can achieve a balance between low cost and certain criteria that are accepted as constituting good design. It has been introduced as planning and not design software. Many aspects of road planning such as environmental issues that are regarded as highly subjective matters, are not dealt with. The planned alignment of the road should be examined by the designer and further changes to the alignment to satisfy the subjective matters should be added to the alignment in another stage by the designer.

The optimization technique employed by Align_3D is a variation of stochastic optimization. A randomly selected intersection point defining the alignment is moved at random in a plane perpendicular to the local alignment of the route and subject to the geometric constraints described earlier. The cost if the new alignment is calculated and compared with the cost of the old alignment, and a decision is made to accept or reject the change. Once a decision has been made, another intersection point is selected at random and the process repeated.

2.5 INTEGRATION OF GIS AND ROAD LOCATION AND DESIGN

Information is data directed towards particular goals or understanding. Ever since man began exploring his environment he has collected information. Innumerable
manual methods were developed to record, keep and replicate this information. Until the 1960s, the major challenge was retrieving the information. Often, problems arose which were either a question of not knowing where the information was kept, or not knowing if it had been collected yet. Beyond this problem there was also the problem of trying to find it.

The computer became a tool for collecting, storing and retrieving information. Custodians of document information libraries became custodians of computer information libraries. With computers, more and more data could be collected. Information organisations as businesses came into their own. They serviced information and data processing for companies that could not afford the computing power. These service bureaus helped to develop methods and standards for maintaining information.

The need for new tools that allow managers to display and analyse information has been the driving force behind what has now become known as Geographical Information Systems (GIS).

A GIS is by definition an abstraction of landscape complexity (Berry, 1993). Also, GIS is the broad technology that attempts to integrate data from a number of acquisition systems, and provide them to the user with appropriate analytic tools.

A GIS, as a computerised system, lets users literally see their data by blending digital maps with databases, and then generating colour-coded maps that display everything from traffic patterns to the likelihood that customers in certain areas will purchase
products. This system makes tracking data with push pins, and wall maps virtually obsolete.

In order to use GIS packages for a specific modelling purpose, the required spatial data should be available in digital form. Some modelling problems require limited sets of information which can be gathered in a short time for that special purpose, and the cost of capturing data in digital form is negligible compared with the total expenditure. In some other cases, when the size of the information required is very large and the data are not available in digital format, converting data into a format that can be used by GIS packages requires a significant amount of expenditure regarding the overall design budget. To utilise GIS capabilities in such cases, if the required data is not already available in digital form, requires the additional costs to be justified, although the use of GIS packages could result in a faster and more accurate result. Fortunately, many of the developed countries have either finished or are about to finish digitising maps to various scales. For example, in Great Britain landline digital maps of urban (1:1,250) and rural (1:2,500) areas are already available (Cooper, 1995). These scales enable designers to carry out almost all the stages required in the design procedures. Landform data that use the contours from 1:10,000 to 1:50,000 maps to provide digital terrain models are increasingly used by planners to assess the visual impact of road schemes.

The GIS market is growing very quickly. According to industry analyst, Daratech of Cambridge, Massachusetts, 1994 revenues among major GIS vendors worldwide were projected to increase to about £650m and of this amount software sales accounted for over half. But, according to industry analysts, as cheaper and more
powerful systems appear, sales of GIS hardware, software and services worldwide in 1995 may exceed £3.6bn (Highways and Transportation, February 1995).

It has been estimated that there are around 300 proprietary software GIS packages around in a market that looks set to bring in more than £700m in sales over the next few years. Many firms offer computer aided design packages that make use of GIS information for design work. Its applications are many, with customers ranging from local government, financial institutions, health services, utilities such as water, electricity and gas, environmental interests, agriculture, retailing, and transportation.

On the transportation side these benefits include life cycle planning, infrastructure planning, integrated transport programming, electronic chart information display systems, and vehicle navigation and detection.

A GIS is seen as a general-purpose technology for handling geographic data in digital form, and satisfying the following specific needs, among others:

- The ability to process data from large storage into a form suitable for analysis, including such operations as reformatting, change of projection, re-sampling, and generalization.

- Direct support for analysis and modeling, such that forms of analysis, calibration of models, forecasting, and prediction are all handled through instructions to the GIS.

- Post-processing of results, including such operations as reformatting, tabulation, report generation, and mapping.
In all of these operations, the typical GIS user now expects to be able to define requirements and interact with the system through a user-friendly interface that makes use of such contemporary concepts as graphic icons and desktop metaphors (Mark and Gould, 1991).

Looking to the future, there are several reasons why integration of GIS and spatial process models should occur. The principal benefit to modelling is to be able to deal with large volumes of spatially oriented data that geographically anchor processes occurring across space. The principal benefit to GIS is the in-depth injection involving temporal and attribute issues to make GIS models more realistic. Both will undoubtedly gain from the other (Berry, 1993).

The human eye and mind are incredibly powerful processors of two-dimensional data, and compared with them even supercomputers sometimes appear impossibly clumsy. At the same time, computers are much more efficient at primitive operations like the measurement of length and area and the combination of data from different sources. Using this fact, computers could play a number of roles in helping a designer to determine the optimal route path for road location using GIS. Unfortunately, the number of papers discussing the integration of GIS in road location and design is very limited. Oshima et al, (1986) have introduced the applications of GIS in road location and design. In the same paper, the weighting system to locate the road location according to a minimum earthwork requirement using a search method was introduced.
Designing individual components of roads has also been carried out. For example, Hammad (1993) used GIS and an expert system to locate and design the optimum location for road bridges.
CHAPTER THREE

ENVIRONMENT AND ROAD LOCATION AND DESIGN

3.1 INTRODUCTION

This chapter describes some of the aspects of environmental concerns in road location design procedure, which are of greater interest these days. The impacts of noise and air pollution resulting from road are discussed. Flora and fauna, places of interest, severance and hydrology are discussed in this chapter. Some methods, which can be used to add these factors to choose a better road location, are addressed as well. The computer programs, which carry out these tasks, will be discussed later in Chapter 7.

3.2 NOISE POLLUTION

Road traffic noise has become an important issue in most industrialised countries over the last 20 years. About 17% of the inhabitants of industries countries are exposed to noise level exceeding the recommended limit of 65 dB(A) on the facade of their houses (Lamure, 1985). The result is the development of some regulations to maintain the noise level below the maximum acceptable level for residential
areas. Some developing countries have not adopted these regulations so far. One of the most prominent reasons could be the complexity and expense of the available methods to assess and analysis traffic noise.

Despite successes on reduction of the average vehicle noise emission by 8 dB(A) for passenger cars and 3 dB(A) for heavy vehicles during the past 20 years, the actual road traffic noise levels have decreased by as little as 1-2 dB(A) for the same traffic flow (Berge and Truls, 1994). Therefore other solutions such as land-use planning, traffic restraints, sound insulation of houses, highway noise barriers and optimum road location are still in high priority on the list of traffic noise analysis. The importance of optimum road location becomes significant when the fact that noise barriers would have no significant effect for many of the people concerned, especially in communities about 1 km from the roads.

Throughout the Western World highway barriers to shield residential areas against traffic noise have become a common sight. In the United States, because of a federal design manual, most highway barriers are constructed of solid materials such as concrete, wood, or metal. However, in Europe and Japan, the majority of highway barriers installed appear to be sound absorptive. It is generally understood that sound absorptive barriers prevent the built-up reverberant noise and therefore provide more noise reduction for the same height of barrier or as much noise reduction as a sound reflective barrier but at a lower height.

In the 1960s, some people thought that to avoid the dangerously noisy environment, the best way was to scatter the traffic. Today there is no more question about the general efficiency of concentrating the traffic on the main roads
Lamure, 1985). In fact doubling the traffic means only 3 dB(A) more which is just noticeable; second, for the main transport infrastructure noise barriers, complete cover, or building insulation can be afforded.

The mitigation of noise by traffic planning is rather a complex matter. For an abatement of the noise level by 10 dB(A), it is needed to:

- reduce the vehicle flow by 90%
- reduce the percentage of heavy vehicles from 50% to 0%
- reduce the speed from 80 km/h to 40 km/h

Equation (3-1) is the general formula to compute the total noise level for a point caused by traffic flow.

\[
L = 10 \log_{10} \left[ \sum_{i} \text{Antilog}_{10} \left( \frac{L_{n}}{10} \right) \right] \text{dB(A)}
\] (3-1)

where \(L_{n}\) is the noise level of the \(n\)th segment.

This equation can be used to determine the areas of interest, which can be affected by a certain road scheme when crossing those roads. Therefore, to design the location of a road in the vicinity of such areas, it would be advisable to determine those areas around interested locations such as residential areas. This would be done only if the road happens to cross these areas, and it was the best alternative, and to calculate the noise impact for that particular area and to consider necessary
mitigation techniques if required. This procedure can be carried out using a buffering technique, which is introduced herein.

**Buffering Method**

The process of computing noise levels of a certain area of a road design scheme is a time intensive task. In addition, the available screening methods for noise levels apply when the procedure of road location is finished. In other words, the design of the location of the road and the calculation of road traffic noise are carried out in two different stages. To reduce the cost and to enable the designer to combine these two stages in one, the following procedure is introduced prior to any other noise assessment computation. The Buffered Distance (BD) can be calculated from the following equation.

\[
BD = 13.5(10^N) - 3.5, \text{ (m)}
\]

(3-2)

where:

\[
N = \frac{[(\text{Adjusted noise level} - 10) - \text{Threshold of acceptable noise abatement levels}]}{10}
\]

where Adjusted noise level is the result of applying Eqs. 5 or 6, and 12 or 13 (Appendix III), and 10 in the numerator of the equation is the minimum noise reduction provided by various type of building structures (Table 5) (Appendix III).

Eq. 3-2 implies that for a certain road scheme if the distance from the road is equal to or greater than BD, the noise level will be less than the maximum acceptable value. Because the location of the road is not known at this stage, a buffer around
the sensitive area, whose dimension is BD m wider than the original area, is regarded as a possible sensitive region. The width of the buffer zone is therefore taken as the horizontal distance of the receiver to the edge of the nearest carriageway (Fig. 1) (Appendix III). If the proposed road happens to intrude upon these area further computations should be carried out. Areas whose distances are greater than BD m are suitable for road location from a noise viewpoint. This concept will be used in Chapter 6. More information is provided in Appendix III.

3.3 AIR POLLUTION

Motor vehicles are a major cause of air pollution problems in most cities (Farrell, 1985). For example, approximately 90% of lead in urban air comes from the combustion of gasoline in motor vehicles (Walsh, 1985). The major pollutants caused by traffic include carbon monoxide, nitrogen oxides, Photochemical smog and lead. The harm these pollutants can cause to the environment result in various regulations in different countries to control these pollutants. As an example Table 3-1 lists the Victorian objectives for air quality.

Table 3-1 Air quality objectives and measured levels (Farrell, 1985)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Objective (1 hr average)</th>
<th>Peak level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>0.12 ppm</td>
<td>0.29</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>30 ppm</td>
<td>43</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0.15 ppm</td>
<td>0.03</td>
</tr>
<tr>
<td>Lead (3 months)</td>
<td>1.5 μg/m³</td>
<td>2.6</td>
</tr>
</tbody>
</table>
The reaction of hydrocarbons (HC) and oxides of nitrogen (NOx) cause photochemical smog in stable atmospheric conditions under high solar radiation. Although the research indicates that reducing HC emissions will be more effective in controlling smog than reducing NOx, control policy development in the 1970s was aimed at controlling both precursors.

Lead pollution is, at least on the surface, a less complex issue. A reduction in the lead content of petrol should produce a corresponding reduction in the contribution of vehicle emissions to lead intake. However, lead from petrol is not only inhaled from the air, but also absorbed indirectly through its lingering presence in soil and dust. Secondly, seasonal and meteorological factors have a marked effect on reduction in lead levels. Thus, it is difficult to feel confident that a particular reduction in lead content will have the expected effect. Table 3-2 describes the Australian design rules legislation for different type of motor vehicles.

Table 3-2 Australian Design Rules for Vehicle Emission Control (Farrell, 1985)

<table>
<thead>
<tr>
<th>ADR</th>
<th>Vehicle Class</th>
<th>Date</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Passenger Cars</td>
<td>1 January 1972</td>
<td>4.5% CO (at idle)</td>
</tr>
<tr>
<td>27</td>
<td>Passenger Cars</td>
<td>1 January 1974</td>
<td>8.0-12.8 g HC/test, 100-220 g CO/test (ECE 15 procedure)</td>
</tr>
<tr>
<td>27A</td>
<td>Cars, Derivatives</td>
<td>1 July 1976</td>
<td>2.1 g/km HC, 24.2 g/km CO, 1.9 g/km NOx (US 1973 test)</td>
</tr>
<tr>
<td>27C</td>
<td>Cars, Derivatives</td>
<td>1 January 1982</td>
<td>6 g HC vapours/test (SHED procedure)</td>
</tr>
<tr>
<td>30</td>
<td>Diesel Vehicles</td>
<td>1 July 1976</td>
<td>Smoke opacity limit (ECE 24)</td>
</tr>
<tr>
<td>36</td>
<td>Other Petrol Vehicles</td>
<td>1 July 1978</td>
<td>1.0% CO, 180 ppm HC</td>
</tr>
</tbody>
</table>
Fig. 3-1 depicts the vehicle emission trend in the next few years using leaded petrol.

![Graph showing vehicle emission trends](image)

Fig. 3-1 Vehicle Emission Trends (normalised to 1968) (Farrell, 1985)

Contrary to leaded petrol that is the main source of lead pollution in the environment, unleaded petrol will reduce the amount of lead pollution significantly during the next few years. Table 3-3 describes the Australian design rules for unleaded petrol.

Table 3-3 Australian Design Rules for Unleaded Petrol (Farrell, 1985)

<table>
<thead>
<tr>
<th>ADR</th>
<th>Vehicle Class</th>
<th>Date</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Cars, Derivatives</td>
<td>1 January 1988</td>
<td>ULP use, 0.93 g/km HC, 9.3 g/km CO, 1.93 g/km NOX, 2 g HC vapours (US 1975 test)</td>
</tr>
<tr>
<td>40</td>
<td>Light Duty Petrol</td>
<td>1 July 1988</td>
<td>ULP use, 1.24 g/km HC, 12.4 g/km CO, 1.93 g/km NOX, 2 g HC vapours (US 1975 test)</td>
</tr>
<tr>
<td>41</td>
<td>Other Petrol Vehicles</td>
<td>1 January-1 July 1988</td>
<td>ULP use</td>
</tr>
</tbody>
</table>
Fig. 3-2 depicts the vehicle emission trend using unleaded petrol. In reality the trend would be something between the two figures that would be very close to Fig. 3-2 near the year 2000.

Catalyst systems were identified as the only means possible of achieving the required 90% control of exhaust emissions of carbon monoxide, hydrocarbons and nitrogen oxides.

As described above, most activities regarding the control of motor vehicle emissions are concentrated on the change to petrol and the motor vehicles themselves. From a design point of view the following considerations can be applied to preliminary road location and design.

- Design the road at such a distance from the residential areas so that the affect of pollutants on those areas is minimized.
• If the designed roads have to pass some critical areas, minimise the length of that portion as much as possible.

• Use the available vegetation as barriers to control the level of some pollutants reaching the residential areas.

• Planning to plant suitable vegetation cover to control some pollutants levels.

3.4 FLORA AND FAUNA

Roads can have significant effects on wildlife, particularly by severing existing habitats and preventing the passage of animals along established tracks.

3.4.1 RETENTION OF EXISTING FEATURES

Because new tree and shrub planting takes time to grow, the retention of mature trees close to the roads can be very valuable, providing instant screening and attractive views for road users. Retention of existing features needs to be taken into account in the design of the alignment. It is also essential that they are properly protected during construction stage by fencing them out of the contractor’s working space.

Retained features such as mature trees and shrubs should keep much of their wildlife interest and provide a base from which new areas of vegetation can be colonised by both plants and animals.
3.4.2 TREE AND SHRUB PLANTING

The objective of planting is not only to provide screening but also to blend the road with the background scene. Long dense strips of planting which closely parallel the line of the road should be avoided where possible because they draw attention to the line of the route. It is better to relate new planting to existing features in the landscape, reinforcing existing shrubs or planting up the line of streams.

3.4.3 NATURAL CONSERVATION

It is now generally accepted that new motorways can provide a valuable resource for wildlife given large areas or native trees and shrub planting as well as grasslands relatively undisturbed by human visitors and agricultural sprays.

3.5 SEVERANCE

In order to consider the severance issues regarding the location of a road, the guidelines stated in Chapter 2 are used. Every road segment will be examined against the land ownership data sets, if available. The first intersection of the road and land ownership will be regarded as the first point on a new land ownership data set. The next intersection point between a land ownership data set and a road segment in the second point of the new ownership data set will be the first point for the adjacent piece of land as well (Fig. 3-3).
Fig. 3-3 Severance issue in road location and design

Fig. 3-3 illustrates two adjacent pieces of land of a part of a designed road. The road segments cross the first piece of land at point A and B, and create two
polygons of P1 and P2. Points B and C divide the adjacent piece of land into two polygons of P3 and P4. The area of each polygon will be calculated using Eq. 4-13 (Chapter 4). Any polygon, whose area complies with the requirements stated in Chapter 2, will result in a minimum resistance factor. Other resistance factors will be assigned to each area of individual lands that do not comply with the requirements mentioned in Chapter 2, according to their situation and price, which should be included to the data set for road location and design purposes.

3.6 PLACES OF INTEREST

Any road location project might be confronted with some places that are important. In general these places of importance can be categorised into following groups.

- Sites of international importance,
- Sites of national importance, and
- Sites of regional/local importance

Sometimes the importance of these sites is more important than the road itself, and these locations should be identified precisely in the vicinity of the project in order to take all precautions to avoid any damage the during construction period.

These places of interest are different from one country to another and should be treated separately for each project.
3.7 HYDROLOGY

Wetlands can be especially valuable for wildlife, and like wild flowers can establish conservation value relatively quickly. Roadside ditches lined with geotextile and sown with grass have already been colonised with waterside plants such as reeds. Such colonisation can also take place on the margins of several balancing ponds that are over-deepened to provide permanent water areas.

3.8 SUMMARY AND CONCLUSION

Some of the most important environmental elements, which are to be considered in almost any road location and design, are addressed here. Although some of the factors can be programmed to perform that part of the design task, such as noise pollution and severance, some other factors can be regarded only as a sub-set of other design elements. For instance, the inclusion of air pollution is considered only as a dependent of road length.
4.1 INTRODUCTION

To design a roadway, the designer's goal is to plan a road that meets the accepted road construction standards of minimum cost. This aim is not an easy task and to design such a road various data should be considered and processed. To this end, a system that is able to handle and process the various types of data is needed.

The data needed to be processed normally comes in a variety of forms. For example, a topographical data set represents the physical shape of the earth's surface as x, y, and z coordinates, geological data describe the formation of the earth both on the surface and underground, demographic data indicate the population of the areas, and so on. In order to use these data effectively and use them in a computerised model for the purpose herein, all data should be in digital form and amenable to graphical representations such as maps. These maps, in turn, would be used for future construction and planning procedures.

The following data sets will be considered in this study.

1) Topographical
2) Geological

3) Demographic

4) Landscape

5) Environmental

6) Land use

Data about topographical, geological and demographic information are used for designing purposes in the first stage, and other data sets will be considered in the second stage. These data sets will be described later in more detail.

The principle of the method to be used is to give a resistance factor to each point or set of points proportional to the significance of the point or set of points for road design purposes. The bigger the resistance factor, the less significant the point or set of points. Therefore the point with the smallest resistance factor is more suitable for the road path, as it leads to an optimal road location between the two end points. The topographic data are considered individually for individual points, whereas the other data sets are considered as a group of data, and are divided into different groups having the same property.

4.2 RESISTANCE FACTOR METHOD

In order to divide the area under study, with the intention to assign different resistance factors to different segments of it, two methods can be used. The first method is to divide the area into equal squares and give a suitable resistance factor
to a square with the same property. If any square is not homogenous, it is divided into further squares until the areas with similar properties are obtained. For example, in Fig. 4-1, the study area is divided into three sub-areas. The same number in each square indicates the same resistance factor.

![Fig. 4-1 Quadtree data structure](image)

This kind of data representation is effective for some data sets such as geological information, and it requires less run-time computer memory than the vector method (Fig. 4-2). The above shown graphic presentation of data is termed as a Quadtree data representation.

The other method for presentation of data is the vector form of data representation. For this purpose the areas of interest are considered as points, lines and polygons, and each polygon is assigned a suitable resistance factor. If a point
is inside a polygon it will be assigned the same resistance factor number as the polygon has, as depicted in Fig. 4-2. For more detail refer to Chapter 5.

![Fig. 4-2 Vector data structure](image)

The principal method of choosing the best route in this study is to search the condition of the ground among terminal points, and design a road that satisfies the standards and minimises the cost (optimum road).

### 4.3 Minimum Length

The first consideration is to minimise the length of the road with respect to the existing restrictions. Consider two different roads going from the same starting point to the same ending point. The first one is the straight-line $l_1$ and the second one consists of two segments $(l_1 + l_2)$ wherein $l_1$ has a declination of $\alpha$ degrees from the straight-line $(l_1)$ (Fig. 4-3).
Therefore, the additional length using the equation;

\[ l_2^2 = l_1^2 + l_1 \cdot l_2 \cdot \cos \alpha \]  

will be:

\[ AL_\alpha = l_1 + l_2 - 1 = \sqrt{l_1^2 + l_2^2 - 2 \cdot l_1 \cdot l_2 \cdot \cos \alpha} + l_1 - 1 \]  

where \( AL_\alpha \) is the additional length of the road due to the declination of \( \alpha \) degrees.

Equation (4-2) can be used as the basis for resistance factor assignment using a searching method as will be described herein, and the procedure of further resistance factor assignment is based on this stage.

In order to determine the optimum route between two terminal points, the searching method of Oshima et al. (1986) is adopted. The principle of the method is to search the area between two terminal points by dividing the area into smaller portions, which have the greater possibility to be able to provide an optimum road path. Each area has a starting point and an ending point. The ending point of each segment would be the starting point of the next segment as shown in Fig. 4-4.
order to perform the searching method, a predominate radius is needed. This radius could be constant during the design procedure or could vary depending on the ground conditions. For example in areas with steep slopes or expensive land the length of the searching radius could be reduced. The length of the searching radius depends the accuracy of data, scale of the maps and importance of the road. Fig. 4-4 depicts the idea of a searching radius.

![Fig. 4-4 Illustration of searching areas](image)

The searching area between terminal points is $90^\circ$ on the each side of the aiming line (which is the straight-line from starting point to ending point in each stage). Whenever a new segment is accepted as the optimal solution for that segment of the road, the end of that point is considered as a new starting point and a new
aiming line will occur. It is obvious that the aiming line in each stage is the shortest road and the resistance factor number for this line is considered as 0. The farthest road is that one, which has a 90° declination from the aiming point, and it is assigned 3 as its resistance factor number. These resistance factor numbers are quite arbitrary and any other numbers can be chosen in this stage, but other resistance factors are dependent on these numbers. Other lines have resistance factors between 0 and 3 depending upon the degree of declination between them and the aiming line. Those resistance factors can be calculated as:

$$W_{AL_0} = 0$$ (4-3)

$$W_{AL_90} = 3$$ (4-4)

$$\Rightarrow W_{AL_\alpha} = 3 \cdot \frac{AL_\alpha}{AL_{90}} = 3 \cdot \frac{\sqrt{(l^2 + l_1^2 - 2 \cdot l \cdot l_1 \cdot \cos \alpha) + l_1^2}}{\sqrt{(l^2 + l_1^2 - 2 \cdot l \cdot l_1 \cdot \cos 90) + l_1^2}}$$

$$= 3 \cdot \sqrt{\frac{(l^2 + l_1^2 - 2 \cdot l \cdot l_1 \cdot \cos \alpha) + l_1^2}{l^2 + l_1^2 + l_1^2}}$$ (4-5)

where $$W_{AL_\alpha}$$ is the resistance factor of the line with $$\alpha$$ degrees of declination respect to the aiming line.

For example, if the distance between two terminal points is 100 km, and the searching radius is 100 m, then the resistance factors due to the first 17 directions are given in Table 4-1.
Table 4-1 The relative values of $W_{AL\sigma}$ for first 17 directions for two terminal points with 100 km apart

<table>
<thead>
<tr>
<th>$W_{AL\sigma}$</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{AL\sigma}$</td>
<td>0</td>
</tr>
<tr>
<td>$W_{AL10}$</td>
<td>0.0456</td>
</tr>
<tr>
<td>$W_{AL30}$</td>
<td>0.1809</td>
</tr>
<tr>
<td>$W_{AL50}$</td>
<td>0.4020</td>
</tr>
<tr>
<td>$W_{AL70}$</td>
<td>0.7020</td>
</tr>
<tr>
<td>$W_{AL90}$</td>
<td>1.0719</td>
</tr>
<tr>
<td>$W_{AL110}$</td>
<td>1.5004</td>
</tr>
<tr>
<td>$W_{AL130}$</td>
<td>1.9743</td>
</tr>
<tr>
<td>$W_{AL150}$</td>
<td>2.4793</td>
</tr>
<tr>
<td>$W_{AL160}$</td>
<td>3</td>
</tr>
</tbody>
</table>

The cost of constructing a road regardless of the earthwork costs depends upon many factors that vary from one country to another. But in any project the average cost of a meter of a certain road can be estimated to a value, say $X$. Therefore the difference in expense for two different roads, namely the straight line and declined line is:

$$X \cdot AL\sigma$$

(4-6)
4.4 EARTHWORKS

In addition to the length of roads, which is a very important factor to determine the optimum road path, the amount of earthwork is another important factor. Any type of road demands certain technical conditions. One of these conditions is not to have a slope more than the maximum allowable one. It means that if the design road crosses an area that results in slopes in excess of the maximum allowable slope, earthworks should be carried out to retain the required slopes. In order to find the amount of earthwork, assume the slope remains constant in a predominant radius, and the width of the road is considered to be Y, as shown in Fig. 4-5.

Fig. 4-5 Plan of road surface

Slope i in Fig. 4-6 and Fig. 4-7 refers to the average slope of the natural ground and Slope j represent the amount of slope needed to be added to or subtracted from the slope i to maintain the maximum allowable slope for a particular job.
Therefore:

maximum acceptable slope is \( i \)

the slope of the ground is \( i + j \)

\[
C = \frac{Y \cdot l_1 \cdot (I + J)}{2} - \frac{Y \cdot l_1 \cdot I}{2} = \frac{Y \cdot l_1 \cdot J}{2} \tag{4-7}
\]

where \( C \) is the average amount of cutting in a road section.
\[ F = \frac{Y \cdot L_1 \cdot (I + J)}{2} - \frac{Y \cdot L_1 \cdot I}{2} = \frac{Y \cdot L_1 \cdot J}{2} \]  \hspace{1cm} (4-8)

where \( F \) is the average volume of filling in a road section.

Therefore in order to differentiate the Eqs. 4-7 and 4-8, they are used as follows.

\[ C = -\frac{Y \cdot L_1 \cdot J}{2} \]  \hspace{1cm} (4-9)

\[ F = \frac{Y \cdot L_1 \cdot J}{2} \]  \hspace{1cm} (4-10)
The positive or negative sign for C and F can be set by the amount of \( \Delta H \). \( \Delta H \) is the height difference between the designed height and average ground height as depicted in Figs 4-6 and 4-7.

if \( \Delta H > 0 \) \( \Rightarrow \) the sign is (+)

if \( \Delta H < 0 \) \( \Rightarrow \) the sign is (-)

If the costs for filling and cutting are P and Q for unit volume respectively, the cost is \( C \times P \) and \( F \times Q \), respectively.

These amounts of cutting and filling only relate to the roadbed regardless of the side slopes. Therefore these latter amounts should be added to the previous values. Figs. 4-8 and Fig. 4-9 illustrate the idea.

Fig. 4-8 Cross section in cutting
In both cases the two shaded parts are the additional earthwork cross sections (AEF and AEC). If the natural ground is considered to be level the additional earthwork can be calculated by the following equations.

\[ AEF = \frac{1}{2} \cdot j \cdot (h_1^2 + h_2^2) \]  \hspace{1cm} (4-11)

AEF (Average Earthwork for Filling) is a positive value.

where \( j \) (Fig. 4-7) is the difference between the natural slope of the ground and maximum acceptable slope (or design slope), when the natural ground is lower than design slope (Fig. 4-7), and \( h_1 \) and \( h_2 \) are the differences between ground level and design level on each side of the road segment (\( h_i \) in Fig. 4-9).

\[ AEC = -\frac{1}{2} \cdot j \cdot (h_1^2 + h_2^2) \]  \hspace{1cm} (4-12)

AEC (Average Earthwork for Cutting) is a negative value.

where \( j \) (Fig. 4-6) is the difference between the natural slope of the ground and the maximum acceptable slope (or design slope), when the natural ground is higher.
than design slope (Fig. 4-6), and $h_1$ and $h_2$ are the differences between ground level and design level on each side of the road segment ($h_i$ in Fig. 4-8).

Now the sum of the values in Equations (4-9), (4-10), (4-11) and (4-12) can be used for earthwork calculations.

If the ground has an undulating shape (as depicted in Figs. 4-8 and 4-9), for better results the Gaussian equation can be used to calculate the additional areas.

\[
(x_{y_1} x_{y_2} x_{y_3} + \ldots + x_{y_n}) - (y_{x_1} + y_{x_2} + y_{x_3} + \ldots + y_{x_n})
\]

The next step is to find the required resistance factors ($W_{A_{L_1}}$) with respect to the price of the additional length ($X^{*}A_{L_1}$).

Concerning a suitable resistance factor for these earthwork values, if there is no earthwork in a direction the required weight is 1. The expense for 1 cubic meter of cutting is taken as $P$, and for 1 cubic meter of filling is taken as $Q$. If the expense in any direction is more than $X^{*}A_{L_1}$ then that direction is unsuitable and it is not considered any further. The value of 100 will be assigned to such situations, indicating that this section of road is not suitable. For values of cost between these two extremes, the procedure is to give the resistance factor of the direction with the larger degree of declination to the earthworks because the resistance factor of the direction with the smaller degree of declination is not suitable and the next direction should be accepted as the road segment. For example, if,

\[
X^{*}A_{L_{10}} = 1000 \\
W_{A_{L_{10}}} = 0
\]
\[ X \times AL_{20} = 2000 \quad W_{AL_{20}} = 0.0456 \]

\[ C \times P \text{ and/or } F \times Q = 1400 \]

\[ \Rightarrow W_{(C \times P \text{ and/or } F \times Q)} = 0.0456 \]

where the resistance factor of \( W_{AL_{20}} \) is assigned to this direction, which is the resistance factor belong to the direction with 20° of declination rather than the direction with 10° of declination.

If all directions are assigned 100 as an earthwork resistance factor then the minimum sum of horizontal and vertical expenses determines the resistance factor, which is assigned 4; it will be discussed later.

### 4.5 GEOLOGICAL AND SOIL PROPERTIES OF LANDS

#### 4.5.1 GEOLOGY

Geological features of the ground are one of the most important factors which determine the optimum route path. Ignoring the geological characteristics of the land may cause immense loss of capital and life.

In order to determine the suitability of areas for road location from a geological point of view, areas which are not suitable for this purpose are described. About three-quarters of the surface of the earth, other than under the sea or fresh water
and the part covered by icebergs, consists of soil and one-quarter of the earth's surface is covered by bedrock (Legget, 1973).

In general when soils and rocks of different properties alternate, the road should be located on the soils or rocks of a better quality. Sandstones and their weathering products provide better conditions for the location of the road than claystones and marls which exhibit unsuitable properties, such as volume changes and water accumulation on their surface which may result in sliding movement of the overlaying beds.

If the local geological surface is in a such condition that location of the road is required on crystalline rocks, because these kind of rocks are less weathered on the lower parts of the valley than higher up, it is therefore advisable to place the road with a tunnel near the valley floor.

Karst plains, no matter how hard, are dissolved by rain or rivers, therefore a route over a karst plain necessitates repeated cut and fill, otherwise the road will be flooded after heavy rains as sinkholes fill with surface run-off.

Glacial terrains present many types of engineering problems. A flat till plain (nonstored, nonstratified sediment carried or deposited by a glacier) is topographically ideal for road construction, but in areas where end moraines (drift deposited chiefly by direct glacial action), kames (assemblages of short, conical, often steep hills, built of stratified materials), or drumlins (a streamlined hill or ridge of glacial drift with long axis paralleling the direction of flow of the former glacier) exist there is need for cut and fill to avoid circuitous routes. In an area of
Wisconsinian glaciation (fourth Pleistocene glaciation), there may be numerous lakes or former lake sites now filled with lacustrine materials (produced by or belong to lakes) which must be avoided. Muck areas, which mark sites of former lakes, are unsuited for roads which are to carry heavy traffic. If a road is built across them as they are, heavy traffic will cause the plastic materials beneath the lake floor to flow, and sinks in the roadbed will result. To avoid this, the lacustrine fill may have to be excavated and replaced with materials that will not flow under load.

Areas with considerable relief, which geologically characterise late youth and early maturity, will necessitate much bridge construction and much cut and fill. In such areas landslides, earthflows and slumping may become serious problems.

Other than the information about soils and rocks and their properties, geological maps contain information showing zones where geological hazards are to be expected. Slopes threatened by rock-falls, landslides, erosion, debris and earthflows are plotted on these maps. Other areas present places of possible accumulation of moving masses. These maps are a suitable aid for avoiding geologically hazardous areas, chiefly in the mountain regions. These maps can be also used to demonstrate areas to be flooded by reservoirs and rivers, and any faults due to water erosion. All of these areas should be considered in a resistance numbering procedure for optimal route location.

As mentioned earlier, soils cover three-quarters of the earth's surface, and for road location purposes the type of soils and their properties which are going to be used
as sub-grade materials should be taken into account. The soil-type maps are the principal information source used for this purpose. For this purpose a unified soil classification is used which shows the suitability of the different soils for the purpose of sub-grade and drainage. If the soil maps are classified differently from those in a unified classification of soil groups, conversion to these groups is required. However, for more detailed information, ground investigation is needed which is not of concern for this study.

4.5.2 UNIFIED SOIL CLASSIFICATION

I. COARSE GRADED SOILS

A. Gravel and Gravelly Soils:

1. GW -well graded gravels or gravel-sand mixtures, with little or no fines. These group of soils are excellent as subgrade material when they are not subject to frost action, potential frost action is nil to very slight, compressibility and expansion is almost nil to very slight, and drainage characteristics are excellent.

2. GP -poorly graded gravel or gravel-sand mixtures, with little or no fines. These groups of soils are good to excellent as sub-grade when they are not subject to frost action, potential frost action is nil to very slight, compressibility and
expansion is almost nil to very slight, and drainage characteristics is excellent.

3. GM -silty gravels, gravel-sand-clay mixtures. These groups of soils are good as sub-grade when they are not subject to frost action, potential frost action is slight to medium, compressibility and expansion is slight and drainage characteristics are fair to poor.

4. GC -clayey gravels, gravel-sand-clay mixtures. These groups of soils are good as sub-grade when they are not subject to frost action, potential frost action is slight to medium, compressibility and expansion is slight, and drainage characteristics are poor to practically impervious.

B. Sand and Sandy Soils

1. SW -well graded sands or gravelly sands, with little or no fines. These groups of soils are good as sub-grade, when they are not subject to frost action, potential frost action is none to very slight, compressibility and expansion is almost nil, and drainage characteristics are excellent.

2. SP -poorly graded sands or gravelly sands, with little or no fines. These groups of soils are fair to good as subgrade, when they are not subject to frost action, potential frost
action is nil to very slight, compressibility and expansion is almost nil and drainage characteristics are excellent.

3. SM - silty sands, sand-silt mixtures. These groups of soils are fair to good as subgrade when they are not subject to frost action, potential frost action is slight to high, compressibility and expansion are slight, and drainage characteristics are poor.

4. SC clayey sands, sand-clay mixtures. These group of soils are poor to fair as subgrade when they are not subject to frost action, potential frost action is slight to high, compressibility and expansion are slight to medium, and drainage characteristics are poor to practically impervious.

II. FINE GRADED SOILS

A. Silts and Clays are less than 50%

1. ML - inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity. These groups of soils are poor to fair as subgrade when they are not subject to frost action, potential frost action is medium to very high, compressibility and expansion is slight to medium and drainage characteristics are fair to poor.
2. CL -inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. These groups of soils are poor to fair as subgrade when they are not subject to frost action, potential frost action is medium to high, compressibility and expansion is medium, and drainage characteristics are practically impervious.

3. OL -organic silts and organic silt-clays of low plasticity. These groups of soils are poor as subgrade when they are not subject to frost action, potential frost action is medium to high, compressibility and expansion is medium to high, and drainage characteristics are poor.

B. Silts and Clays is 50% or greater

1. MH -inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. These groups of soils are poor as subgrade when they are not subject to frost action, potential frost action is medium to very high, compressibility and expansion is high, and drainage characteristics are fair to poor.

2. CH -inorganic clays to high plasticity, fat clays. These groups of soils are poor to fair as subgrade when they are not subject to frost action, potential frost action is medium,
compressibility and expansion is high, and drainage characteristics are practically impervious.

3. OH-organic clays of medium to high plasticity, organic silts. These groups of soils are poor to very poor as subgrade when they are not subject to frost action, potential frost action is medium, compressibility and expansion is high, and drainage characteristics are practically impervious.

III. HIGHLY ORGANIC SOILS

A. 3-1- Pt-peat and other highly organic soils. These groups of soils are not suitable as subgrade when they are not subject to frost action, potential frost action is slight, compressibility and expansion is very high and drainage characteristics are fair to poor.

It is obvious that some of these soils are not suitable as subgrade materials. Some of them can be practically improved by various techniques, and some of them should be removed and changed with better soils. Depending the cost of these operations each group of soils can be given resistance factors. These parts will be used in Chapter 6, and a more detailed explanation will come in that chapter.

4.6 SUMMARY AND CONCLUSION

This chapter describes the physical considerations for designing the location of a road path. The method used was the search method, which divided the search area
into 17 smaller areas, with 10 increments, in which the condition of the ground is considered to be the same unless otherwise stated. If the predominant radius is taken as 100 m, the area of each segment is (Fig. 4-4):

$$\frac{\pi R^2}{36} = \frac{\pi \times 100^2}{36} = \approx 872 \text{ m}^2$$

In addition, a simple and complete method was introduced to determine the amount of earthwork, and the whole method is convertible to a computer program to calculate these amounts and to assign the respective resistance factors. The computer programs will be explained in Chapter 7 in full detail.
CHAPTER FIVE

REVIEW OF GIS SYSTEMS

5.1 INTRODUCTION

Because the use of Geographical Information Systems (GIS) in road design is a relatively new concept, the current chapter reviews some aspects of GIS techniques applicable to this study. The literature on GIS is vast and spread over a large number of areas, representative of many disciplines and covers an enormous number of application issues. The most relevant sources for the material presented in this thesis are, therefore, selected and explained. Sections 5.2 to 5.6 bring together the relevant conceptual issues of GIS systems. First of all, some of the currently used definitions, the common purposes, the principal mechanisms and operating systems of GIS are defined. Then, the use of GIS for road design applications is reviewed. Finally, data sources and those technical aspects of GIS, which were used for modeling purposes, are outlined in sections 5.6 and 5.7 respectively.

5.2 WHAT IS A GIS?

Much of the information that people deal with everyday has its basis in geography. Familiar questions include: what effect will this development have on the
landscape?; where do we find our target audience?; and what is the quickest route between x and y?

Depending on the nature and extent of the job in the hand, the diversity and quantity of data differs. For example, if the object is to determine the location of a toy shop, the required data might be the average number of children in each suburb, the average income of the families and available shops for sale. This information could be enough to determine the best location for such a shop, whereas to determine the optimal route path between two terminal points, a much wider range of data and information are required, and operations are much more complex. GIS were initially developed to fill this niche.

Digital map data and information related to geographic locations can be viewed as an source of information which, when combined with other material in a systematic form, can be used to fulfil a variety of different business, planning and evaluation needs.

GIS dramatically evolved since the early days of mainframe computing, particularly in the past 12 to 15 years (Goodchild 1993). Its first commercial successes came in the early 1980s, primarily in resource management, but more recently large markets for GIS software have developed in local government, utility companies, and a host of activities that use geographic data or manage geographically distributed facilities.

GIS is a computer technology consisting of hardware and software that is used to produce, organise, and analyse information (Aronoff, 1989). In fact, GIS are
computer software for managing data that are spatially distributed over the Earth (Bonham-Carter, 1994). Maguire (1991) states that GIS are computer systems capable of storing, analysing, manipulating and displaying spatial data from the real world which can be represented spatially in a computer environment (Dangermond, 1986).

GIS are able to provide natural resource managers with a tool to merge spatial data and their attributes into computerised data base systems, allowing input, storage, retrieval and analysis of geographically referenced data (Calkins and Tomlinson, 1977). With this capacity for spatial and temporal modeling of the real world, GIS as a technology has been developed to accomplish the complicated tasks, which are grouped together as 'GIS' functions. Two selected definitions of GIS are as follows; Aronoff (1989:39), “any manual or computer based set of procedures used to store and manipulate geographically referenced data”; Koshkariov et al., (1989:259), “a system with advanced geo-modeling capabilities”. Many of the definitions are relatively general and cover a wide range of subjects and activities (Tomlinson et al., 1976; Moore et al., 1981).

GIS have three important components; computer hardware, sets of application software modules and a proper organisational context (Burrough, 1989). These three components need to be in balance if the system is to function satisfactorily. Maguire and Dangermond (1991) believe that four basic elements of GIS, which operate in an institutional context are: computer hardware, computer software, data and liveware (the personnel). However, some researchers think that GIS are the result of
CHAPTER 5: REVIEW OF GIS SYSTEMS

linking parallel developments in many separate spatial data processing disciplines (Cliff and Ord, 1981).

All these disciplines are attempting the same sort of operation, mainly to develop a powerful set of tools for collecting, storing, retrieving, transforming, and finally displaying spatial data from the real world for a set of particular purposes. These sets of tools were combined to constitute a GIS environment (Burrough, 1989). In other words, GIS should be thought of as being very much more than a means of coding, storing, and retrieving data about aspects of the earth's surface (Goodchild and Kemp, 1990). In fact, GIS are designed to bring together diverse spatial data sources into a unified framework, often employing a variety of digital data structures, and representing spatially varying phenomena as a series of data layers as models from the real world (Prisley, 1986; Rhind, 1988).

The set of objects representing the variation of a single variable is termed a layer and the associated models are layer models or field models.

GIS applications now span a wide range, from sophisticated analysis and modeling of spatial data to simple inventory and management. Some of the sophisticated analyses are carried out in areas such as atmospheric modeling, hydrological modeling, land surface-sub-surface modeling, biological/ecological modeling and so on.

More than 300 software products are listed in the GIS World Inc. (1991), which indicates the great demand of such a system in the market.
5.3 PURPOSE OF GIS

The purpose of using a GIS system can be reduced to about six activities dealing with spatial data: 1) organisation, 2) visualisation, 3) combination, 4) analysis, 5) modeling, and 6) query (Bonham-Carter et al., 1988; Burrough, 1989; Goodchild and Kemp, 1990).

1) Organisation is the ordering of information according to logical links (Bonham-Carter, 1994). Anyone who has collected a large mass of data for a particular purpose knows that data organisation is essential. Data can be arranged in many different ways, but all the data has to be spatially referenced in GIS. For example, a table of geographic data may be interesting for viewing relationships between elements, but without knowing the locations of samples the interpretation of spatial patterns and relationships with other spatial data, such as geographic features, cannot be made and understood (Johnston, 1987). A GIS must be concerned not only with location, but must also organise data to allow the extraction of other types of information (Aronoff, 1989). Because, the GIS can organise data both by spatial and non-spatial attributes, the efficiency and type of data organisation affects all the other five activities, and is therefore of fundamental importance (Maguire, 1989).

2) Visualisation is an important technique for analysing, explaining and understanding the distribution of a phenomenon on the surface of the earth (Buttenfield, 1987). Using new technology capacities, the graphical capabilities of computers are exploited by GIS for visualisation (Dangermond
and Smith, 1988). Generally, visualisation is the assessing of information through the use of sight which is normally carried out using the video monitor, but other output devices such as colour printers are used for hard-copy displays (Intera Tydac, 1992a). Often, visualisation is enhanced in a GIS system by specialised methods using colour, perspective, shadowing and other means. One of the immediate benefits of this function of GIS is that visualising data stimulates the mind in ways, which are different from traditional data analysis procedures (Cuff and Mattson, 1982).

3) In a GIS, combination is the bringing together of data sets. Data used in GIS often come from many different sources, are of many different types (even with a different spatial nature) and are stored in different ways (Flowerdew and Bantin, 1989). GIS provides the tool and method for combining, or integrating, these data into a format, which allows the data to be compared. This process of creating a common form of the data or the bringing together spatial data from a number of sources is described as data integration. The role of the GIS as an 'information integrator' was examined by several researchers on various approaches. DoE (1987:2) states that, 'The benefits of a GIS depends on linking different data sets together.' Dangermond (1989:25) said that, 'A GIS brings information together, it unifies and integrates that information. It makes available information to which no one had access before, and places old information in a new context. It often brings together information, which either was not or could not be brought together previously'. This integration is one of the really powerful features of GIS in which the
ability to link several maps together provides various kinds of models. The benefits that follow the integration of diverse information are widely recognised.

4) One of the important stages in the GIS environment is the analysis of the results of previous stages or the process of inferring meaning from data (Berry, 1986). In fact, analysis is the interpretation and the study of data and information that have been collected. With GIS, the relationships between different spatial data and their associated features can be measured and understood. Spatial analysis in a GIS simply means, the analysis of spatial data. For instance, the area cross-tabulation of two maps may lead to useful conclusions about the relationship between the two map layers. Therefore, with GIS the relationships between different spatial data and their associated features can be measured and understood (Samet, 1989).

5) Just as it is possible to analyse spatial information to extract knowledge, it is also possible to use known relationships to model geographically the outcome of a set of conditions (Intera Tydac, 1992b). This function of GIS is helpful for assessing models from patterns in the data. Normally, the final purpose of many GIS studies is often for the prediction and modeling of data. For example, a number of data layers can indicate new sets of maps which could be combined to predict the suitability of the final desired model (map). Such a map may then be used as a basis for making exploration or land use decisions (Dickinson and Calkins, 1988). In other words, prediction is sometimes a research exercise to explore the outcome of making a particular set of
assumptions, often with the purpose of examining the performance of a model (Alberti, 1991).

6) Finally, a strong feature of GIS is the ability to \textit{query} intellectually the underlying data simply by moving a pointer around on a map. Since all data in a spatial database are geographically referenced, a pointer to location means access to all data associated with that location (Intera Tydac, 1993). Spatial query is a complementary activity to data visualisation, because it permits the user to find the special circumstances of each case, by searching the name and other particulars of characteristics of individual geographic features in the selected locations of interest. Generally, GIS provides tools for two types of interactive query: geographical information of a location and its attributes (Unwin, 1981). This powerful function of GIS allows the user to enjoy the dynamic query of attributes of up to 19 map layers, simultaneously.

\section*{5.4 HOW GIS OPERATES}

At its most basic level, a GIS can be viewed as a simple input / output process. Data goes into the GIS (such as collected data), some form of processing occurs (averaging of data for different areas), and information comes out (perhaps in the form of a map). Regardless of its complexity the input / output view of GIS is a useful starting point from which to examine how the technology actually works. However, in order to understand the basic operations in a GIS environment, it is first necessary to understand the main structure and functionality of the GIS in which the data must be processed.
There are currently three common data structures used by geographical information systems; 1) vector, 2) raster, and 3) quadtree (Ibbs and Stevens, 1989). Each structure has an associated set of characteristics, some good, some bad (Bonham-Carter, 1993).

1) **Vector** approach uses collection line segments to identify the boundaries of point, linear, and areal features. The Vector format is defined as positional data in the form of coordinates of the ends of line segments in a point, line or polygon format (Intera Tydac, 1993). This is the most common method for representing spatial data in which 2-D space is assumed to be continuous and allows very precise representation of locations, lengths, distances and areas. Locations are described by coordinate pairs, and these pairs are the fundamental building blocks from which spatial entities such as points, lines, and areas are composed. In a vector structure, points are represented by a single x, y coordinate pair, while liner entities and area entities (polygons) are composed of straight line segments joining two coordinate pairs (vertices). The attribute of the values for point, line, and polygon entities are typically stored independently of the entity's spatial representation. Generally, the vector structure is ideal for representing point (rainfall stations) and linear features such as rivers, and for cartographic map production. This structure is also very useful for topological relations, but is very limiting for overlay modeling procedures (Cook, 1978).
2) *Raster* approach establishes an imaginary grid pattern over a study area, then stores values identifying the map characteristic occurring within each grid space. The Raster format is spatial data expressed as a matrix of cells or pixels, with the spatial position implicit in the ordering of the pixels. The simple raster data structure represents 2-D space as an array of matrix of square or rectangular grid cells. Each grid cell represents a square or rectangular portion of the Earth's surface. The resolution of raster data is determined by the size of the cell on the ground, thus, raster data represent a discrete space where the location precision is dependent upon the size of a grid cell (Brown and Norris, 1988). Each grid cell is assumed to have only one value for any given attribute. A grid cell attribute value may represent a point measurement (for example, elevation) or an integrated areal measurement (for example, land use map). In a raster data structure, points are represented as individual cells, while lines and areas are represented as clusters of adjacent pixels. The coordinated precision of raster data is constrained by cell size. Generally, the raster structure is ideal for representing continuous data, such as elevation and is excellent for multiple map overlays, but it is poor for certain data approximation (Knaap, 1992).

3) Finally, the *Quadtree* format is a data structure for thematic information in a raster database that seeks to minimise data storage. In fact, this kind of data structure is a hierarchical grid based data structure which is used to improve the storage efficiency of either its raster or vector counterparts (Ibbs and Stevens, 1989). A hierarchical spatial data structure is one which is developed
through a process of regularly subdividing the space occupied by geographical entities on a map layer into regular spatial units (Intera Tydac, 1993). This process continues until each unit produced by the subdivision is occupied by spatial entities with similar attributes (see Figs. 5-1, 5-2 and 5-3).

Although there are significant practical differences in these data structures, the primary theoretical difference is that the raster and quadtree structures stores information on the interior of areal features, and implies boundaries, whereas, the vector structure stores information about boundaries, and implies interiors. This fundamental difference determines, for the most parts, the types of applications that may be addressed by a particular GIS.

It is important to note that all systems are actually grid-based; it is just in practice that line-oriented systems use a very fine grid of "digitiser" coordinates. Point features, such as springs or wells on a water map, are stored in the same manner for both systems (a single digitiser x, y, or column, row, identifiers). If the same resolution is used, there is no theoretical difference between the two referencing schemes, and, considering modern storage devices, only practical differences in storage requirements.

Each data structure has its merits and its pitfalls (Ibbs and Stevens, 1989). Generally, vector data structure are used for digitising data and cartographic purposes which use (x, y) coordinates to describe point, line and area features. In this format, data structure retains information about the consecutiveness and adjacency of features, but are computationally more demanding. The raster data
structure is, however, useful when combining satellite imagery, which is already in raster format, into the database, and this is used for analysis (Johnston, 1987). A raster data structure is formed by a matrix of regular cells, each a specified size and area (Knaap, 1992). Many GIS have the capacity to use both data structures. The quadtree structure is ideal for representing both continuous data and discrete polygonal data. In other words, it can be thought of as a raster structure with the ability to have a variable sized grid cell (Webster, 1992).

Fig. 5-1 Data structures in GIS (vector structure)
Fig. 5-2 Data structures in GIS (raster structure)

Fig. 5-3 Data structures in GIS (quadtree structure)
In Table 5-1 two groups of GIS users are described. The data for a fire chief consist of surveyed roads, installed fire hydrants and tagged street addresses (lines real and data certain). Such applications are descriptive, involving computer mapping and spatial database management, and are identified by a field of GIS termed AM/FM for Automated Mapping and Facilities Management.

Contrast this a road designer's use of maps of soils, vegetation, geology, topography and so on (lines are artificial and data probabilistic) to identify the optimal route between two terminal points. Such applications are prescriptive, involving spatial statistics and modeling, and are identified by a field of GIS termed DSS for Decision Supported Systems.

Table 5-1 Two different groups of GIS users

<table>
<thead>
<tr>
<th>AM-FM (Inventory)</th>
<th>DSS (Analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines Real</td>
<td>Lines Artificial</td>
</tr>
<tr>
<td>Data Certain</td>
<td>Data Probabilistic</td>
</tr>
<tr>
<td>Descriptive processing</td>
<td>Prescriptive Processing</td>
</tr>
<tr>
<td>Mapping</td>
<td>Statistics</td>
</tr>
<tr>
<td>Database Management</td>
<td>Modeling</td>
</tr>
</tbody>
</table>

5.4.2 FUNCTIONALITY OF DATA IN GIS

In GIS, realistic spatial models of the world, called entities, can be developed using these structures. Entities are points, lines, areas, surfaces and networks (Martin, 1982). An entity has a spatial dimension which identifies its geographical location.
GIS data structures are able to accept both spatial and non-spatial data in any GIS project. Therefore, identification and collection of relevant structure and data are essential (Webster, 1990). Data used in GIS often come from many different sources, are of many types, and are stored in different ways. These mechanisms should be summarised into six stages as follows:

1) Geographic data sources which can be imported into the GIS environment include: paper maps; aerial photographs; satellite images, and digital data from other areas which can be combined to create new complex maps or tables (O'Neil et al., 1992).

2) After the data are collected and integrated, the GIS must provide facilities which can contain and maintain the data (Brown and Norris, 1988). Effective data management has many definitions but should, at least, include all of the following aspects: data security, integrity and maintenance abilities. In fact, data management refers to the ability of a GIS to manage functions efficiently, the ability to link to other data types and transfer data in compatible formats (Davis, 1991).

3) Data processing operations are those performed on the data to produce information. In GIS, data on its own may be impossible to interpret and data processing is not an end in itself. It should turn data into a form that is informative, that helps the user decide what to do next, and whether more data processing or qualitative analysis should be done. Data processing produces images, reports and maps.
4) Data integration and conversion is only part of the input phase of GIS. What is required next is the ability to interpret and analyse, quantitatively and qualitatively, the information that has been collected. This ability to analyse and manipulate spatial data has led to the use of GIS for both statistical and deterministic modeling (Cressie, 1991). Analysis is carried out on data organised as maps, and also on data organised as tables. Using the analysis function of GIS, it is possible to explore existing relationships between the data sets.

5) The ability to model geo-referenced information is critical in a GIS (Webster, 1992). In the geoscience fields, especially geographical exploration, this type of overlay modeling has been done for years, typically with several maps and a light table. The main objective is to create a new map, which highlights areas which meet a certain set of criteria favourable for modeling. The GIS allows combination of maps to produce new maps, without struggling with the variable scale and projection problems (Rasuly, 1991).

6) Finally, one of the most exciting aspects of GIS technology is the variety of different ways in which information can be presented, once it has been processed by the GIS. Traditional methods of tabulating and graphing data can be supplemented by maps and three-dimensional images. Also, tables and figures, having results, can be transformed into maps, which reveal spatial or non-spatial entities. The use of GIS technology allows information to be viewed on the computer screen, plotted as paper maps, captured as a image or slide, and used to generate a computer file. Generally, visual communication,
which is the most important aspect of GIS technology, can be enhanced by the diverse range of output options (Webster, 1990).

5.5 IMPLICATIONS OF GIS TECHNIQUES IN ROAD DESIGN

While CAD and GIS do not perform the same function, combining the capabilities of the two systems can benefit users. For instance, in the hypothetical case of designing a new bridge, CAD would be used to design the bridge which would then be located within a GIS framework to evaluate its location and positioning, potential environmental impacts and accessibility in both two and three dimensions and at a number of scales.

The GIS has been widely used in recent years for natural resource planning and management (Alberti, 1991 and Davis, 1991) and solving complex problems associated with multiple-use of land resources (Martin, 1985). Initially, the origins of GIS lie in environmental management (DoE, 1987), but uses of GIS have expanded to incorporate private and government planning in areas such as: property and land parcel data; transport and distribution networks; civil engineering; defence; industrial site selection; and water supply application (Tomlinson, 1987; Johnston et al., 1988).

In addition, GIS are used in many environmental spatial analysis and modeling situations. Technical and applications-oriented workers from many fields (for example, ecology, hydrology and geography) are interested in the use of GIS (Ferrier and Smith, 1990). Recent environment applications can be expanded to
include: survey design, dynamics and distribution of soil (Moore et al. 1981), individual species and soil-climate modeling (Duff and Eamus, 1992), vegetation communities (Head et al., 1992), bushfire patterns (O'Neill et al., 1993) and habitat modeling (Marthick, 1995). All these studies found that GIS can be used in the handling of environmental problems. But these are only a few applications within the general GIS literature which is both highly disparate and complex.

From 1991 there were rapid increases in further developments in the use of GIS for research in physical geography and the environmental sciences (Raper, 1993). This interest is growing fast, because a GIS can store cartographic data, showing topography or individual themes, such as soils or rainfall distribution, and attribute data associated with the spatial entities. Therefore, in many respects a set of disparate data can be only linked conveniently by GIS techniques.

The methodological problems and applications of this new sub-field have resulted in a number of publications. For example, an application was introduced to estimate crop yield in southwestern Ethiopia (Simmons, 1986). Using SPANS GIS it was possible to perform a series of map overlays of climatic and soils factors from which predictions of crop yields were calculated. In this study three input maps (climate zones, elevation and soil types maps) were used to produce different classes of climatic suitability.

Although, GIS has been used for a variety of projects, many with environmental themes, there are examples of GIS techniques being used in road location and
design studies. For example Oshima, et al, (1986) introduced for the first time the use of micro computers and GIS to select the optimum route between two points.

The topic of GIS and road design is relatively very new, but, because of the ideal application of the GIS technology to environmental subjects, there is already a strong tendency to use the GIS for road design purposes. In many circumstances, new technology allows the rapid mapping of points or polygons, the correlation of maps, and the use of maps as variables in computer models.

In the literature, there are some examples of the use of GIS, which can demonstrate its suitability to road design. For example, Hammad, A. (1993) used GIS techniques in the study of planning the best location of bridges.

5.6 DATA SOURCES ON GIS SYSTEM

Although the learning of a GIS technique seems a time consuming task, in the current study only a short time was spent establishing a database and in converting and translating existing maps and spatially referenced data into a SPANS GIS system. The various types of data created for the road location study herein included elevation data, a base map, a proximity map, forest map, geological map, places of interest, existing road network map, existing river network map, and a land use map. These are outlined in Chapter 6 with a brief description of their sources.
5.7 METHODS USED IN A SPANS GIS

This section will explain the SPANS GIS module and all methods used in which the data have been analysed to construct GIS models. SPANS, which is an acronym, stands for SPatial ANalysis System. It is a microcomputer-based geographic information system, which was developed by Intera Tydac (established in 1982). SPANS GIS is currently being used and supported worldwide by professionals and decision-makers attempting to solve complex spatial problems. Therefore, the SPANS line of software products, as a tool, was selected for the organisation, integration and analysis of the geographic information obtained for the spatial study of an optimum road path in the Kiama region of NSW, Australia.

In this study, the power of the analytic and modeling capabilities of the SPANS GIS allowed the researcher to work with the diverse data sets needed for the study of the optimum road location. The SPANS version 5.3.1 was used for many spatial analyses in this study. Therefore, the following stages have been proposed as three more general categories: data entry, model building, and model analysing procedures.

5.7.1 DATA INPUT

Two GIS systems have been employed to enter the data and subsequent analysis. First, an Environmental Resource Mapping System, E-RMS (1992) was used for digitising a topographical map of the study area. The contour lines were entered by manually digitising from a 1:25,000 scale map of the Kiama region. The accuracy of digitising is estimated to be within 2.5 to 5 meter horizontally and 5 cm
to 1.5 meter vertically of the indicated location on the map. The E-RMS system was developed by the National Parks and Wildlife Service of New South Wales. Using this system, a topographical map of the region was entered in digital form, then edited and converted into a grid cell format to be exported. After that, the data export module of E-RMS allowed data to be exported to the SPANS GIS. Because many SPANS operations require a basemap, this study first established a basemap to define the boundaries of the study area in the SPANS GIS system. The basemap must be a binary map, which means, it could not contain classes other than 0 and 1.

In the second stage, a SPANS raster module was used to transform the basemap to a raster-base format to be imported into the GIS environment. These data were imported into a GIS coverage system showing point data, and were displayed on a computer screen to provide a visual impression of the distribution of sample elevation points. Imported data were then checked for possible errors or corrections.

**5.7.2 MODEL BUILDING**

Once the data were integrated into SPANS, various techniques were used to analyse the data sets. A major part of the analysis involved the generation of elevation from the point data sets. Several functions of GIS, for example, a contouring method, were used in SPANS to convert the data to thematic maps.

Firstly, a set of elevation data (with point structure) was used to create a digital elevation model by establishing topological relations between the elements using a
rectangular grid (or elevation matrix) with a Triangulated Irregular Network method (TIN). TIN structures are based on triangular elements, with vertices at the sample points. Generally, the TIN surface can be constrained to pass through the point data. In this case, the contouring program was used to convert point data representing spatially continuous phenomena into classified, trend surface maps such as elevation maps, which were used then for further analysis. After the TIN was created, some classification schemes, for each specific data, were applied to produce the desired classifications. The accuracy and reliability of this technique has been computed by Weibel and Heller (1991). They found that the surface models can be used to create, analyse and display surface information.

Generally SPANS GIS supports both linear and non-linear implementations and it allows extrapolation outside the convex hull defined by the data points. In this study, a linear interpolation model, which computes a linear interpolation surface, was applied for the data. During data analysis stages, a query module containing a query capability was used to verify the final results. The query function of SPANS GIS was also used to perform and confirm all geographic information in relation to locations specified on the map layers.

Secondly, some of the information related to topography elevation maps were automatically produced in the SPANS environment.

A set of satellite images and also hard-copy maps of the region were used to create the land use map of the Kiama region, which covers the whole of the study area.
5.7.3 MODEL ANALYSING

Within a SPANS GIS there are several predefined modeling functions, which allow a user to explore the possible relationships between the data sets and associated map layers. In addition to those predefined functions, the modeling ability of the SPANS GIS enables the user to write almost any modeling programs to deal with different maps. Such pre-defined modeling functions that are used in the research herein are described below:

Reclassification This function allows the map generalisation. If the map has many classes, which represent the same value for a certain purpose, with this function those classes can be reduced to fewer classes.

Impose overlaying This function cuts away portions of one map based on the boundaries of another. This function is useful when the user wants to cut away portions of a map to fit the region for analysing. When the map used as a cutter is the basemap, the impose operation is referred to as a basemap cut (Fig. 5-4).

![Fig. 5-4 Impose overlay](image)

Stamp overlay Stamps a map on a second map. The first map (Map 1) is placed on the second map (Map 2) and reclassified. In the new map, the classes from the
first map \((Map\ 1)\) are always reclassified by adding the maximum class of the second map \((Map\ 2)\). It is useful when the construction of a complex map from several simpler maps is needed (Fig. 5-5).

![Stamp overlay](image1)

**Fig. 5-5 Stamp overlay**

*Join overlay* Joins two maps. The first map \((Map\ 1)\) is slipped beneath the second map \((Map\ 2)\) and the classes are merged to create a new map (Fig. 5-6). This function is useful when the user wants to join two contiguous maps having a common legend. Except in regions where the two maps overlap, the classes of both input maps will remain unchanged in the output map.

![Join overlay](image2)

**Fig. 5-6 Join overlay**

*Index overlay* In order to perform an Index overlay, firstly creating a template is required. Normally creating a template is the first step in performing an Index overlay. An example of an index overlay template appears below:
An Index template contains the name and title of the output map (access and ACCESSIBILITY) and the names and titles of the maps to be overlaid (roads and drainage). A default weight is assigned to each map, which is 100 divided by the number of maps (50.00 in this example). A list of class values is created to which the suitable scores should be assigned. Each class value is labelled with the short legend title taken from the input maps. Lines starting with a colon (:), and items delimited by colons are comments. The map Weight (50.00 here) specifies the relative importance of each input map in the suitability analysis. The larger the value of this weight the greater the importance of the map for the design purpose.

The next step is to edit the Index template file in order to change the default map weights and class scores. The map weight can be any non-negative number and all weights need not add up to 100. Class scores represent an assessment of relative suitability and are assigned based on a user-defined scale. Each map has its own
scores. They can be positive or negative and do not necessarily have to be integers. The example of a completed template used to generate an accessibility map appears below:

```
: Indexing Overlay Input File
: new mapid & title : access ACCESSIBILITY
: no of Input Maps : 2
: Input Maps (Id Max Colour)
  roads  4     drainage  4
: Format = Weight Map Id Title
: 10     roads : DISTANCE TO ROAD
  :         -0 :         -1
  : 0.5 km - 1 : 10
  : 1.0 km - 2 : 7.5
  : 1.5 km - 3 : 2
  : 2.0 km - 4 : 1
: 50     drainage: SOIL DRAINAGE
  :         -0 :         -2
  : Well    - 1 : 10
  : Moderate- 2 : 3
  : Poor    - 3 : 0
  : Unclass - 4 : -1
```

In this example drainage is assessed to be of greater importance than road access. This is reflected in the assigned weights of 50 and 10, respectively.

### 5.8 SUMMARY AND CONCLUSION

In this study, the SPANS GIS helped to visualise, organise, combine, analyse, model and question the real data from different sources, which had been spatially organised in a computer environment. In other words, the power of a GIS is in its ability to integrate, manipulate, and process data from different sources. Data with spatial and non-spatial nature were handled to provide information and models, which aided in the understanding of the geographic locations and their attributes.
With SPANS, simple to complex models have been generated, modified, and regenerated to be compared to the originals in a matter of hours. With this flexibility and speed it was decided to use a SPANS GIS for entering, manipulating and modeling maps.

There is, however, a main problem with using a SPANS GIS. Firstly, the DEM (Digital Elevation Model) data are only samples, regardless of resolution. An interpolation model was required to approximate the surface behaviour between sample points. This technique was successfully used by Skidmore (1989 and 1990) who, for example, interpolated digital terrain data to identify terrain position and to calculate aspect values from a digital elevation model.

Although the topic of GIS and road design is relatively new, some functions of GIS can be applied to the raw data sets to create new products such as a slope map. Other outputs, such as land use and elevation maps, could also be suitable for road design applications. Furthermore, multiple maps, which are obtained using overlay techniques in a GIS environment, can be supported using statistical procedures.
CHAPTER SIX

CASE STUDY

6.1 INTRODUCTION

The aim of this chapter is to describe the study area, its limits, and the data sets used to define the different properties of the study, which are accompanied by different maps as the visual representation of the area. Data acquisition and manipulation techniques, which later will be used in computer programs, are discussed in this chapter. The structure of the data files and fields are explained herein.

6.2 STUDY AREA

In order to test the ability of designing an optimum path for a road using GIS and a resistance factor procedure, the West Side of the Kiama region in NSW, Australia, was chosen as the study area. The reason for choosing this area was that a new bypass has recently been constructed, and it was a good example to compare the result from the techniques herein with a constructed road.

The term “Study Area” is used in SPANS to define the location and description of the current project. Both SPANS and E-RMS (Chapter 5), which was used for digitizing the base map and land use maps of the study area, require that the
geographic coordinates of a square or rectangular boundary be defined for the study area database (Table 6-1). These coordinates define the rectangle in the projection plane containing the study area database. Both systems - SPANS and E-RMS - however, allow for irregular areas to be defined in the study area database as a study site for analysis and modeling purposes. These are called the "Base maps" and domain in SPANS and E-RMS respectively.

Limits of the study area, which define an area of 130 km$^2$ (10 km by 13 km), are shown in Table 6-1.

<table>
<thead>
<tr>
<th>Geographical Coordinates of the Study Area</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easting</td>
<td>295000</td>
<td>305000</td>
</tr>
<tr>
<td>Longitude</td>
<td>-34.7444</td>
<td>-34.6292</td>
</tr>
<tr>
<td>Northing</td>
<td>6153000</td>
<td>6166000</td>
</tr>
<tr>
<td>Latitude</td>
<td>150.7606</td>
<td>150.8728</td>
</tr>
</tbody>
</table>

As most of the required data for further processing were not available in digital format, which was essential in order to use in the GIS packages, the necessary information was digitized using E-RMS GIS software (Chapter 5).

The 1:25,000 topography, 1:50,000 geology, 1:100,000 soil, and some other maps produced by the consulting engineers, Connell Wagner company (NSW), that contained information about the places of interest, hydrology, existing and future land use, were used. The result of the attempt to define an optimum path is given in the following overlays (Fig. 1 to Fig. 6-21).
• Topography map which represent the physical shape of the study area.

Figs. 6-1a and 6-1b depict the topography of the study area in two and three-dimensional form. The elevation of the area increases from east to west from zero meter at the east side of the map to over 500 m on the west side of the map with a flat moor area on the top of the map.

The elevation varies from 0 meters at the beach to more than 500 meters at the Middle West side of the map. The steep slopes of more than 40% (23°) could be found in the area.
Fig. 6-1a Topography of the Kiama region, NSW, Australia (2D)
Fig. 6-1b Topography of the Kiama region, NSW, Australia (3D)

- Slope map of the area that can be very useful in road location and design.

Fig. 6-2 illustrates the slope variation of the area. One of the most important factors governing the location of road is the slope of the natural ground. The slope map is the result of topographic map using SPANS GIS package with the same data that produce the topographic map. The slope varies from 0 percent to more than 20 percent at Middle West part of the study area. Areas with slope between 0 to 3 percent regarded as suitable from an earthwork point of view. There is no need for any calculations according to Chapter four for such areas.
Fig. 6-2 Slope map of Kiama region, NSW, Australia

- Sea map that contains information regarding the coastline at the study area

The information about the location of the coastline is needed to design a proper road path (Fig. 6-3). Later in this chapter the area covered by sea are regarded as unsuitable areas and treated as unsuitable for road location.
Like the importance of knowing the location of the coastline, the location of beaches is of vital importance in road location and design. Although the designers are always reluctant to include these areas as part of the road location, these areas are possible to be included in road location design if no better areas are found. However, later in this chapter these areas are also regarded as unsuitable and are regarded as seas.
Fig. 6-4 Beaches of the Kiama region, NSW, Australia

- Forest map contains three different areas as:

  Dense timber

  Scattered timber

  Bare areas with no forest property
Forests are very valuable for the environment and should be protected. From this point of view the more condensed the forests the less suitable they are for road location purposes, which indicates that the third category namely bare areas (Fig. 6-5) are the most suitable areas for design purposes. On the other hand, a road passing through a forest is the more enjoyable road from a drivers’ and passengers’ point of view. Therefore this map should be considered from both view points in the location and design stages.
Geological map that contains the geological properties of the area.

The following features are present in the study area as depicted in Fig. 6-6.

Qt Talus

sa Yellowish-green to grey volcanic agglomerate

bb Basalt

Rh Quartzose sandstone and occasional lenticular mudrock interbeds

Rnz Interbedded quartzose and quartz-lithic sandstone, and mudrock and chocolate shale

Rnk Quartz-lithic sandstone and minor mudrock interbeds

Pi Interbedded quartz-lithic sandstone, mudrock, carbonaceous claystone and coal

Pipm Glomero prophy latite

Psgc Feldspatic latite

Psgs Mafic latite

Psgb Aphanitic to porphyritic latite

Psgh Mid-grey latite, generally aphanitic

Psg Red-brown and grey volcanic sandstone
The whole area can be summarized with the following relative hardness variation according to Table 6-2.

The area consists of eight groups according to their hardness. The group with the smallest hardness is good for cutting and needs reinforcing for filling. On the contrary, the groups with larger hardness are suitable for filling but are not suitable for cutting due to the cost of the cutting operations. Fig. 6-7 describes the idea.
Table 6-2 Summary of the geological features of the study area

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>General name</th>
<th>Hardness</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qt, Cbs</td>
<td>Talus</td>
<td>1</td>
<td>Can be removed by machinery</td>
</tr>
<tr>
<td>Qa</td>
<td>Alluvium</td>
<td>2</td>
<td>Can be removed by machinery</td>
</tr>
<tr>
<td>Pi</td>
<td>quartz-lithic sandstone</td>
<td>3</td>
<td>Can be removed by heavier machinery</td>
</tr>
<tr>
<td></td>
<td>carbonaceous claystone and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psb</td>
<td>siltstone to fine sandstone</td>
<td>4</td>
<td>Very hard to removed by machinery</td>
</tr>
<tr>
<td>Psg</td>
<td>volcanic sandstones</td>
<td>5</td>
<td>Normally needed explosion if not</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>subject to weathering</td>
</tr>
<tr>
<td>Rh, Rnz, Rnk</td>
<td>Quartzose Sandstone</td>
<td>6</td>
<td>Normally needed explosion</td>
</tr>
<tr>
<td>Sa, Pipm</td>
<td>Volcanic agglomerate</td>
<td>7</td>
<td>Explosion needed</td>
</tr>
<tr>
<td>bb, Psgd, Psg, Psgs, Psgb, Psgh</td>
<td>Igneous and Volcanic Rocks (Basalt)</td>
<td>8</td>
<td>Heavy explosion needed</td>
</tr>
</tbody>
</table>

Legend
- Talus 3
- Alluvium, gravel, beach 6
- Interbedded quartzose 9
- Red-brown, grey volcanic 12
- Quartzose sandstone 15
- Volcanic agglomerate 17
- Igneous, volcanic rocks 20
- Sea 25

Fig. 6-7 Generalized geological map
• Existing roads (main roads) of the study area.

The locations of existing important and major roads are needed to determine the possible crossing, bridges and underpasses. Fig. 6-8 illustrates such roads in the study area.

Fig. 6-8 Main roads of the Kiama region, NSW, Australia
• Major rivers of the study area.

The locations of rivers are needed to determine the location of possible bridges and underpasses.

Fig. 6-9 Rivers of the Kiama region, NSW, Australia
- Built-up map that shows the residential areas.

This map is depicted in (Fig. 6-10). This map is used to determine the optimum road location of the road concerning noise and air pollution. Moreover, it will be used to determine the justification of the construction of the road if destruction of some part of the residential area is needed.

Fig. 6-10 Residential areas of the Kiama region, NSW, Australia
• National and cultural heritage map.

Fig. 6-11 contains the information about the location of important buildings, sites, monuments and so on. Because of the importance of these buildings and structures, a suitable right of way should be determined for such buildings and excluded from the road path.
- Soil map that contains the required information about the soil properties of the area.

Fig. 6-12 Soil map of the Kiama region, NSW, Australia
Fig. 6-13 Big scale of the interested part of the soil map
Fig. 6-13 depicts those area of soil map which is used in Chapter 8 for design purposes. The area is mainly covered by ka, bo and wt, soil structures. The other soil structures are not of concern at this stage.

The ka soil structure (Fig. 6-14) consists of the following subgroups.

ka1 (topsoil): Friable brownish black sandy clay loam, rough-faced, porous, with 10-20% 2-20 mm sub-rounded, dispersed stones. Soil limitations are Stoniness, Sodicity, Low available water-holding capacity, and High organic mater.

ka2 (subsoil): Brown weakly pedal light clay, rough-faced, porous, without stones. Soil limitations are Low fertility, Sodicity, Strongly acid.

ka3 (subsoil): Dark red weakly pedal heavy clay, rough-faced, porous, with 2-10, 6-20 mm angular stones, dispersed. Soil limitations are Stoniness, Low permeability, Sodicity, strongly acid, Low available water-holding capacity, High organic mater.

ka4 (subsoil): Bright yellowish brown moderately pedal light medium clay, moderately pedal, 10-20 mm sub-angular blocky peds, rough-faced, porous, without stone. Soil limitations are Shrink-swell potential, Low permeability, Low wet bearing strength, Strongly acid.

(ped An individual natural soil aggregate)
(pedal Describes a soil in which some or all of the soil materials occurs in the form of peds in the moist state)

Other characteristics for all ka soils are moderate erosion and generally low limitations for urban development.

![Fig. 6-14 Schematic cross-section of Kiama soil landscape illustrating the occurrence and relationship of the dominant soil materials](image)

The bo soil structure (Fig. 6-15) consists of the following subgroups.

- **bo1** (topsoil): Friable reddish brown sandy clay loam, earthy and rough-faced, porous. Soil limitations are high organic matter, low wet bearing strength, high shrink-swell, sodicity, and high aluminum toxicity.

- **bo2** (topsoil): Hard setting brownish black sandy loam, rough-faced, porous, 2-10% 2-6 mm angular, dispersed abundant, ex-ped stones. Soil limitations are stoniness, hard setting low permeability and sodicity.

- **bo3** (subsoil): Reddish brown light medium clay, rough-faced, porous. Soil limitations are strongly acid and sodicity.
bo4 (subsoil): Reddish brown sandy clay, rough-faced, porous. Soil limitation is sodicity.

bo5 (subsoil): Brown strongly pedal medium clay, rough-faced, porous. Soil limitations are strongly acid and sodicity.

Fig. 6-15 Schematic cross-section of Bombo soil landscape illustrating the occurrence and relationship of the dominant soil materials

The wt soil structure (Fig. 6-16) consists of the following subgroups.

wt1 (topsoil): Hard setting brownish black fine sandy loam, rough-faced, porous, <2% 2-6 mm Stones. Soil limitations are strongly acid and high organic matter.

wt2 (topsoil): Friable brown silt loam, rough-faced, porous. Soil limitations are high organic matter, low wet bearing strength, sodicity and strongly acid.

wt3 (subsoil): Mottled brown light clay, smooth-faced, dense. Soil limitations are low wet bearing strength, sodicity and strongly acid.
wt4 (subsoil): Dark reddish brown strongly pedal light clay, rough-faced, porous. Soil limitations are high permeability, sodicity and strongly acid.

wt5 (subsoil): Mottled brown strongly pedal medium clay, rough-faced, porous. Soil limitations are low permeability, low wet bearing strength and sodicity.

Fig. 6-16 Schematic cross-section of Wattamolla Road soil landscape illustrating the occurrence and relationship of the dominant soil materials

In the next step, the digitized data was transferred into SPANS GIS package that was the GIS software used for this project. Apart from the topographical map, the other maps were dealt with as raster based maps even though the Roads and Rivers maps were originally considered as vector based maps. In other words, for the convenience and simplicity of the job, the vector-based data were converted into raster based data. For this purpose the lines are given a certain width, and with this assumption they can be considered as polygons and converted into raster data.
model (Fig. 6-17). For this purpose, the average widths of the rivers are 50m and main roads are 40m for this area.

Fig. 6-17 Raster map of rivers of the Kiama region, NSW, Australia

The chosen study area is shown on Fig. 6-18.
A further goal is to make a composite map so that any point represents a certain resistance factor. The resistance factor should be set according to the significance of that point for road location and design purposes. The points with the smaller resistance factor indicate a more suitable place for the location and design purposes. Overlaying the above-mentioned layers except the topography map can make the composite map.

Fig. 6-18 The rivers inside the study area
The procedure for giving a resistance factor can be carried out into two stages. Firstly the whole map is given a resistance factor, and secondly the entities inside any map are assigned the best estimate of the resistance factor.

For example, consider the forest map with its three forest classes. The first resistance factor is assigned to the forest map according to its importance to the other maps. If the forest's preservation is of greater importance than residential areas, a greater resistance factor should be assigned to the forest map rather than the residential map. In addition to this, another assignment should be considered, which is the resistance factor inside each map. Consider the same forest map with its three classes. The greater the resistance factor for each class of the forest region indicates the greater importance of that area for preservation and less suitable for location and design purposes.

The final resistance factor for any location will be the summation of the resistance factor of each point resulting from each map.

The SPANS GIS package supports a weighting system rather than the use of resistance factor. In other words the greater the weight, the better the place for road location and design purposes. Therefore, all the assignments are considered as weights and should be interpreted as resistance factors later because the program written for the final determination of the optimum location of road uses resistance factor concepts.

In addition, consider the forest map that consists of three categories: dense timber, scattered timber and others. If the design is determined to take place in such a way
that the damage to the forest be a minimum, the weighting numbers \( w \) may be something like this:

Dense timber = 1; Scattered timber = 3; Others = 5.

This means that the other area is the most suitable place for road location. On the other hand, consider that the Built-up map is weighted as follows:

Built-up areas = 0; Other = 5.

Assume an area that is covered by scattered timber and has 3 as the weight, and another area that is a built-up area inside a scattered timber area that has also 3 as the weight \((3+0, \text{ which means 3 because it is located in a scattered timber area and 0 for being a built-up area})\). In other words, a point located in a scattered timber area and another point located in scattered timber area and it is a built-up area as well have the same weight and importance for the purpose of road location. It is obvious that the result of the road location would be incorrect with this assumption, and the procedure should be carried out in a way that there is no scattered timber weight under a built-up area. In SPANS words it means a STAMP overlay. In this case the result of overlaying would be 0 rather than \((3+0)\), which is the correct result.

As another illustration, assume that an area is covered by scattered timber \((w = 3)\) and has the soil type one which is assigned 4 as the weight, and the same forest type with soil type two, that is assigned 7 as the weight. In this situation the weights should be accumulated to each other, and result in 7 and 10 respectively. In SPANS words it means a JOIN overlay.
6.3 DATA ACQUISITION

Data acquisition techniques range from remote sensing to interviewing people. It is the most costly part of the configuration of such a system and can constitute around 80% of the total cost of system implementation (Barker, 1988).

There are many techniques for data acquisition. Most of the data are usually input to the system by digitizing existing maps. Other techniques are:

Field surveying, Photogrammetry, Remote sensing and Global Positioning Systems.

Data collection and input are major problems in using GIS, and these are practically solved by the advances in remote sensing technology and Global Positioning Systems for new data. Remote sensing is often used for data input, especially in regional planning. The development of low-cost scanners with raster-to-vector conversion programs also facilitate the entry of maps into GIS by decreasing the cost and increasing the accuracy of data entry, while considering that the main source of data for GIS can be provided by existing maps and charts.

6.3.1 Digitizing existing maps

As previously mentioned, the main sources of data for GIS are provided from digitizing existing maps. There are various methods for this purpose. Some of them are listed below (Burrough, 1986):

1. Manual input to a vector system
2. Manual input to a grid system

3. Digitizing

4. Automated scanning (Raster scanners, Vector scanners, Video digitizers and Analytical stereo plotters)

5. Spatial data already in digital raster form

Largely the application, the available budget, and the type of data being input govern the choice of method. The types of data encountered are existing maps including field sheets and hand-drawn documents, aerial photographs, remotely sensed data from satellite or airborne scanners, point-sample data (e.g. soil profile), and data from censuses or other surveys in which the spatial nature of the data is more implicit than explicit.

The major drawback of existing maps is that they are usually out of date and the data should be corrected before inputting to the system.

Most of the data used in this thesis are the result of direct digitizing using the digitizing table and the E-RMS GIS package. Some digitized data such as soil information was created using colour scanners.
6.4 DATA MANIPULATION

6.4.1 TOPOGRAPHIC DATA

In order to use the results of above mentioned overlaying in road location and design procedure, a computer program was written. The whole perspective of this program was to use different polygons with different weights, and use them alongside with topographic data to determine the optimum road location. This program uses three files. These three files are:

1) The elevation file that contains, easting, northing and elevation data in ASCII format.

2) The file with VEC extension (*.VEC) that contains the easting and northing of vertices of polygons such as residential areas.

3) The file with VEH extension (*.VEH) that is the header file of the VEC file, and describes the data in the file with the VEC extension.

The original elevation data was obtained from digitized topographic maps of the study area, using E-RMS GIS package. The final result after exporting the data into an ASCII file was a file with the following format.

<table>
<thead>
<tr>
<th>Number of points</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>X coordinate</td>
<td>Y coordinate</td>
</tr>
</tbody>
</table>
To illustrate this format consider that the following data are part of the main
elevation data file: all the six points have the same elevation of 520m.

6 520  (6 points which are 520 m above the sea level)
297610 6157995
297588 6158025
297560 6158047
297541 6158068
297522 6158086
297504 6158120

To use this data format in other packages and programs such as SPANS GIS,
SURFER and other programs, data should be changed into a more suitable format.
The CHANGE FORMAT program, of which a copy of the source code is
enclosed, could satisfy the task. The result is a file with the following format.

<table>
<thead>
<tr>
<th>X coordinate</th>
<th>Y coordinate</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>297610</td>
<td>6157995</td>
<td>520</td>
</tr>
<tr>
<td>297588</td>
<td>6158025</td>
<td>520</td>
</tr>
<tr>
<td>297560</td>
<td>6158047</td>
<td>520</td>
</tr>
<tr>
<td>297541</td>
<td>6158068</td>
<td>520</td>
</tr>
<tr>
<td>297522</td>
<td>6158086</td>
<td>520</td>
</tr>
<tr>
<td>297504</td>
<td>6158120</td>
<td>520</td>
</tr>
</tbody>
</table>

For example the same data will be changed into the following format that is more
suitable for various applications.

297610 6157995 520
297588 6158025 520
297560 6158047 520
297541 6158068 520
297522 6158086 520
297504 6158120 520
As the primary aim of digitizing the topographic map is to have access to the elevation of any desired point whose X and Y coordinates are known, the original result of the CHANGE FORMAT program is not suitable. This file contains the data in an unsystematic order, and any method of programming that uses this file to find the elevation of a point other than those in the file will be time consuming and therefore will be unsuitable. For this reason the conventional idea of making a network of points is used. For this purpose, depending on the work in hand, the distance between each two points is determined. The distance of 100m is chosen here. The idea is depicted in Fig. 6-19.

Fig. 6-19 Framework of the points
The result is a file with the following format.

```
X  Y
X  Y + 100
X  Y + 200
```

The next step is to calculate the elevation of each above point. Fig. 6-20 depicts the idea of determining the elevation of a network point from known values of elevations points derived from the topographic map.

The necessary computer program was developed for the determination of the elevation of the network points using the file containing the elevation data of all contour points. The procedure is that for each point of the network file, the four closest points from the distance point of view are found. For example, point P is the point whose elevation should be calculated, and P1, P2, P3, P4 are the four closest points to it.
P (X, Y, Z=?)  (Z=? because the elevation of point P is unknown in this stage)

The known points are:

P1 (X1, Y1, Z1), P2 (X2, Y2, Z2), P3 (X3, Y3, Z3), P4 (X4, Y4, Z4)

The distances are calculated as:

\[ d1 = \sqrt{(X - X1)^2 + (Y - Y1)^2} \]
To calculate the elevation of point P using these 4 points, the inverse distance with a power of one is used. Other powers were examined, but a power of one resulted in the best approximation. The principle of the method is to calculate the elevation of an unknown point using other points. The shorter the distance the greater the weight.

The equations 6-1 and 6-2 is used to calculate the unknown elevation.

\[ D = \frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4} \]  

\[ Z = \frac{d_1}{D} \cdot Z_1 + \frac{d_2}{D} \cdot Z_2 + \frac{d_3}{D} \cdot Z_3 + \frac{d_4}{D} \cdot Z_4 \]

Where \( Z \) is the elevation of point P. The source code of the program is given in Appendix II.

Fig. 6-21 is the result of the original data and Fig. 6-22 is the result of the newly generated file for the network of Fig. 6-20.
Fig. 6-21 Original contour map
Fig. 6-22 Contour map resulted from MAKE NETWORK program

This artificial file will be used to find the elevation of any new point. The procedure of calculating the elevation is the same as before, and the coordinates of four required points are determined as follows:

\[ X1 = \text{integer} \left( \frac{X}{100} \right) \times 100 \]
\[ Y1 = \text{integer} \left( \frac{Y}{100} \right) \times 100 \]
\[ X2 = X1 + 100 \]
Y2 = Y1
X3 = X1
Y3 = Y1 + 100
X4 = X1 + 100
Y4 = Y1 + 100

Where X and Y are the coordinates of the point whose elevation is needed. Again the inverse distance method can be used to calculate the elevation of the required points.

6.4.2 OTHER DATA

In addition to topographic data, there are other sources of data such as geological, soil, demographic, heritage, existing roads, rivers, dams, lakes, and so on. Any source of data can be categorized into three groups. These three groups are points, lines, and polygons.

As an example for each group, dams, important buildings, trees, and monuments can be regarded as point features. Rivers and roads can be considered as line structures, and lakes, soils, and geology can be assumed as polygons. For this project, all these three categories needed to be polygons, and therefore points and line groups should be changed to polygons. For this purpose, according to the importance of the feature, a buffer area around or alongside that feature is considered as a polygon feature.

Figs. 6-23, 6-24, and 6-25 illustrate the idea.
Fig. 6-23 Rivers in the study area (line form)
Fig. 6-24 Buffered area
Fig. 6-23 is the map of some rivers in the study area. In order to design a road the following information is needed. Firstly, the width of the river at the intersection of the road and the river, and secondly, the angle between the road and the river at
the intersection point. Because preliminary road location is considered herein, all the
same class of rivers are considered as the same width.

Fig. 6-24 is an example, which shows the boundary of the rivers with a 100m buffer.
Fig. 6-25 shows the result of overlaying the two other figures. In order to find the
angle between the road and river, the data file containing the information concerning
rivers is used, and to find out the length of the possible bridge either the river data set
or the buffered river data set can be used. The program RIVER-CROSS given in
Appendix II contains the source code of the operation.

6.5 THE GIS PACKAGE USED, AND ITS FEATURES

Because of the diversity of data models, GIS has developed as a loose consortium,
with little standardization. While ESRI's ARC/INFO and TYDAC's SPANS are
among the most developed of the analytically oriented packages, they represent very
different approaches and architectures (Goodchild, 1993).

In order for a GIS system be able to process spatial information, it should have the
following capabilities:

Create digital abstractions of the landscape (ENCEODE);

Efficiently handle these data (STORE);

Develop new insights into the relationships of spatial variables (ANALYSE); and

Create "human-compatible" summaries of these relationships (DISPLAY).
Four classes of primitive operations can be identified from a GIS system, which are:

Reclassifying maps, Overlaying maps, Measure distance and connectivity, and Characterize cartographic neighborhoods.

Fundamentally three perspectives are important for GIS:

A functional perspective concerning what applications a GIS is used for, or the nature of GIS use.

A procedural perspective concerning how a GIS works with regard to the various steps in the process to perform this work, or the nature of GIS work flow.

A structural perspective concerning how a GIS is put together with regard to various components, or the nature of GIS architecture.

6.6 SUMMARY AND CONCLUSION

This chapter endeavours to picture the study area and its specifications. The noise and air pollution resulting from the road traffic vehicles, as the result of Chapter 3, will be used in the computer program directly. The ability of GIS to summarize the vast amount of diverse data is shown in this Chapter. The different properties of each point and assignment of a unique resistance factor, which can be used as the final resistance factor in further processing, are based on the data in this Chapter. If a route with the minimum accumulated resistant factor is determined, which is the result of the computer programs written by the author, it is most likely to be
the optimum road path. The full discussion will be carried out in Chapters 7, 8 and 9.
CHAPTER SEVEN

DESCRIPTION OF THE ROAD

LOCATION AND DESIGN PROGRAMS

7.1 INTRODUCTION

To determine the optimum road path between two terminal points according to descriptions discussed in previous chapters, a computer program was written to perform the task. The program uses different data sets to produce the final map (as discussed in previous chapters) and uses the information in the final map to determine the optimum road path. To this end the program uses six functions to perform the task. The result of Chapter 6 was a combined map of the study area, containing the combined information about different areas with their relative resistance factors. The first operation of the computer program is to determine the areas with unsuitable resistance factors and exclude them from the map. In other words, the computer program assumes that these areas are not to belong to the area, and unless there is no other area available any part of the road would pass these areas. As mentioned previously, the approach in this thesis is the use of a searching method. The length of each segment of the road is quite arbitrary and depends on the designer's point of view. The best value for the length of each
segment in this project was determined as 100 m after a series of execution of the
computer program (Appendix II).

However, the first interactive step is to input the length of each segment of the
road (l) and any value can be entered. The final output of the designed road
follows from 100 m as the entry for each road segment. The data input is:

"Enter the width of the road"

The location and coordinates of terminal points (starting and ending points) are
needed to start the design of the location of the road procedures. For this purpose
the next interactive data input are the coordinates of these terminal points. These
data inputs are:

The Range of Easting is between 295000 + 1 and 305000 - 1

"Enter the Easting of the starting point"

The Range of Northing is between 6153000 +1 and 6166000 - 1

"Enter the Northing of the starting point"

The Range of Easting is between 295000 + 1 and 305000 - 1

"Enter the Easting of the ending point"

The Range of Northing is between 6153000 +1 and 6166000 - 1

"Enter the Northing of the ending point"

where l is the length of each road segments.
CHAPTER 7: DESCRIPTION OF THE ROAD LOCATION AND DESIGN PROGRAMS

Determine any unsuitable areas in the study area

Calculate segments of the road (all 19 directions)

Determine the polygon(s) each segment is inside that

Eliminate any segment in unsuitable areas

Determine the environmental issues of that section

Determine the severance problems

Determine the overall weight of each segment

Select the segment with the minimum weight

Continue?

Yes

Optimum road location

Fig. 7-1 Flowchart of road location and design
The next information the computer program needs is the type of road, which governs the maximum acceptable slope of the road. Depending on the type of road the user chooses, the appropriate maximum acceptable slope is assigned to that type of road. One of the following choices should be made at this stage.

Highway = 1

First order road = 2

Second order road = 3

Third order road = 4

"Enter the type of the road"

A maximum slope of 5%, 8%, 11% and 15% is assigned to each road category, respectively.

The average cost of construction per meter normally is a predefined value for any project. The next data input assigns the relative value of construction costs per meter to its appropriate variable in the program. The data input is:

"Enter the average cost of construction per meter"

This value can be expanded to a wider range of inputs if required.

The next data input is the average cost of cutting and filling per cubic meter which is introduced to the program as:

"Enter the average cost of cutting per square meter"
"Enter the average cost of filling per square meter"

With these sets of information, the calculation of the optimum road path can be performed. Before describing the main program, the functions the main program employs to perform the task are described.

7.2 THE FUNCTIONS

There are several functions that are called by the main program for the design of optimal road location. These functions will be discussed here in details.

7.2.1 Function Findz (x, y)

This function interpolates the elevation of the point with x and y coordinates using the four closest points in the grid (as discussed in Chapter 6). For convenience these points are numbered from 1 to 4, counterclockwise starting from the lower left (Fig. 7-2).
The simplest interpolation in two dimensions is a bilinear interpolation on the grid square. Its formulas are:

\[ t = \frac{d_{11}}{d_1} \]  \hspace{1cm} 7-1

\[ u = \frac{d_{21}}{d_2} \]  \hspace{1cm} 7-2

(so that \( t \) and \( u \) each lie between 0 and 1), and
where \( z_A \) is the elevation of the desired point.

Bilinear interpolation is frequently close enough for road design purposes as the interpolating point wanders from grid square to grid square; the interpolated function value changes continuously. The source code of the computer program is given in Appendix II.

7.2.2 Function Azimuth \((x1, y1, x2, y2)\)

This function calculates the azimuth of each line where two points of that line are known.

The general equation for the calculation of azimuth is:

\[
\text{Azimuth} = \arctan \left( \frac{dx}{dy} \right)
\]

where \( \arctan \) is the arc tangent, and \( dx \) and \( dy \) are the differences in easting and northing of the two points.

The first azimuth is the azimuth from starting point to ending point (terminal points)(Fig. 7-3).
CHAPTER 7: DESCRIPTION OF THE ROAD LOCATION AND DESIGN PROGRAMS

7.2.3 Function Distance \((x_1, y_1, x_2, y_2)\)

This function calculates the distance between two points using the equation:

\[
\text{Distance} = \sqrt{dx^2 + dy^2}
\]

Fig. 7-3 Description of azimuth between two points

This azimuth is the same one with the first road segment. On each side of this line eight different lines with 10° decrement will be the azimuths of the other directions.

The best road segment at this stage provides the required information for the next sets of azimuths.
7.2.4 Function Point_inside_polygon (x, y)

One of the important functions in the program is the "point_inside_polygon" function which determines what polygon any required point is in, or simply is that point in any unwanted area. As mentioned previously in Chapter 6, the whole area will be divided into different polygons with an assigned number as a resistance factor. This function will determine the position of any point in any of those polygons and will assign a suitable number to that. The algorithm of the function to find the polygon is to draw two lines one horizontally and another vertically from the required point (one end of the line is that point), and find the polygon(s) with an odd number of intersections with the line as the required polygons. The points located on the boarder of two polygons could be assigned to either of them.

7.2.5 Function Parallel_pol()

This function is useful when a road around an area is required. As an example, if the designed road from point A to point B had to service a intervening town, this function can be used. For this purpose the function will turn the required polygon with a predefined distance and continue the normal design procedure after turning the polygon. This function is useful for designing bypasses around the cities. Fig. 7-4 shows a designed road using the normal program execution (without using Parallel_pol function) and an unsuitable polygon for design purposes. The road divides the polygon into two smaller polygons ABCD and ADEFG. The function computes the perimeter of each polygon and finds the shorter one (ABCD here). From the last point before entering the polygon (n + 2) (the distance from the last
point and the polygon is less than 100 here, but if necessary it can be assigned any other value as well) the road will change direction parallel to the unsuitable area towards the other end from the shorter side. This action will be finished 100 meters outside the other side of the polygon on the line from last point and the end point (Fig. 7-5). The process of design will be back to normal from this point. The idea is depicted in Fig 7-4 and Fig 7-5.

Fig. 7-4 Normal location of designed road
7.2.6 Function Prep(x_start, y_start, x_end, y_end, x1, y1)

This function finds the distance between a point and a line. To perform this task, first the intersection point between the line containing x_start, y_start, x_end, y_end and the line crossing point (x1, y1) which is perpendicular to the above line will be found, and second, the distance between point x1, y1, and this intersection point will be calculated using the distance Function.
The coordinates of intersection point I (Fig. 7-6) can be calculated as:

\[ x_1 = \frac{(m_1 \cdot x_{\text{end}} - m_2 \cdot x_1 + y_1 - y_{\text{end}})}{m_1 - m_2} \]  
7-6

\[ y_1 = m_1(x_1 - x_{\text{end}}) + y_{\text{end}} \]  
7-7

where:

\[ m_1 = \frac{\Delta y}{\Delta x} \]  
7-8

\[ m_2 = \frac{-1}{m_1} \]  
7-9
7.2.7 Function Bridge ()

Another function, which is used in design of the location of the road, is Bridge ().
The aim of this function is to determine the possible location of bridges, their
length and the angle of them to the rivers or other roads.

In order to determine the approximate cost of a bridge for the road design
purpose, the following parameters that define a bridge for this purpose are
described.

1) Entire length of bridge measured along the center-line of the bridge

2) The distance between end supports measured along the center-line

3) The number of spans

4) The width of the bridge

5) The angle between the center-line and the normal to the obstacle

6) The total height of piers, abutments etc used to support the bridge

The most simple mathematical model used to estimate the cost of a bridge
is simply (Ostler, 1978)

\[
\text{Cost} = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6
\]

where \( x_1 \) to \( x_6 \) are the six above bridge parameters.
a_i are the equation constants differing from one type of bridge to another and from one country to another. For example, the constants for an in situ concrete bridge is different from a pre cast one.

To solve the Equation 7-10 and find the best values for x_i in that equation, the equation is expanded as follows.

\[
\text{Cost}_1 = a_{10} + a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + x_{15} + a_{16}x_6
\]

\[
\text{Cost}_2 = a_{20} + a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 + x_{25} + a_{26}x_6
\]

\[
\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \]

The above equations can be represented in a general matrix form as follows.

\[
L = A \cdot X \quad \Rightarrow X = A^{-1} \cdot L
\]

Where:

\[
X = \begin{bmatrix}
X_1 \\
X_2 \\
X_3 \\
X_4 \\
X_5 \\
X_6
\end{bmatrix}
\]

\[
A = \begin{bmatrix}
a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\
a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66}
\end{bmatrix}
\]
and

\[
L = \begin{bmatrix}
\text{cost}_1 - a_{10} \\
\text{cost}_2 - a_{20} \\
\vdots \\
\text{cost}_n - a_{n0}
\end{bmatrix}
\]

A is an \( n \) row by 6 column matrix and inverse cannot be found. To deal with this situation a least squares method is employed to solve the equation. The appropriate form of the least square method for this particular equation can be represented as follows.

\[
X = (A^T A)^{-1} A^T L
\]

7-12

The \((A^T A)^{-1}\) is a 6 by 6 matrix and can be inverted.

In order to solve the above equations at least six cost prices and the bridge specification for each type of material should be known. The larger the amount of data, the more accurate the cost estimation.

For the preliminary road location design that is the concern of this thesis, the above parameters are treated as follows:

- Entire length of bridge measured along the centerline of the bridge

This property is obtained in the execution of the program.
The distance between end supports measured along the center-line and the number of spans are considered as dependent on the entire length of the road and is not considered separately.

- The width of the bridge is considered the same value for all bridges.
- The angle between the centerline and the normal to the obstacle
- The total height of piers, abutments etc, used to support the bridge

This amount can be calculated according to the average distance between spans, the length of the road and the average difference between natural ground elevation and the actual design. Therefore the following mathematical estimation can be used to estimate the cost.

\[
\text{Cost} = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4
\]

7-13

If the computer program encounters any potential bridge location, firstly it avoids that direction. If all directions find the same situations, the most cost-effective direction will be chosen, otherwise the direction without any bridge location will be set as the suitable direction. The first optimum direction encountered with any bridge will be marked, for the reason if at any time the other selected direction needs a bridge-making consideration, that could be compared with the optimum one. Fig. 7-7 describes the idea. The aim is to design a road location from point labeled 1 towards point labeled 7. The normal design procedure picks up the direction from point 2 towards point 3. This direction has to cross the river therefore direction from point 2 to point 4 will be considered at this stage. If this
direction is continued towards point 7, it has to cross the river between point 6 and point 7. At this stage the computer program comes back to point 2 and picks up the direction towards point 3 as the optimum road path.

Fig. 7-7 Application of function Bridge ()

### 7.3 LIMITATIONS OF METHOD

The limitation of such a method is that even though the program is designed to search the area in order to find the optimum road segments, only a limited number of alternatives in any stages can be saved due to the limitation of memory and time. Consider that a short road of 10 km is needed to be designed, and the optimum segment is set to 100 m with a 90° searching angle. In this case the number of all
possible alternatives will be $17^{100}$, which is $3 \times 17^{100}$ numbers (three coordinates for each point). If each 17 directions of a road segment consume one second using a normal desktop PC, $3 \times 16^{100}$ seconds ($15^{93}$ years) is needed for the calculation time. Further research to overcome this limitation of the search method could be a good future topic.

A dynamic programming technique, which is able to reduce the number of possible solutions in a variety of situations, is not suitable for this particular problem. To discuss the reason, consider the characteristics of dynamic programming problems according to Hillier and Lieberman (1990).

1. The problem can be divided into stages, with a policy decision required at each stage.

2. Each stage has a number of sub-stages associated with it.

3. The effect of the policy decision at each stage is to transfer the current state into a state associated with the next stage (possibly according to a probability distribution).

4. The solution procedure is designed to find an optimal policy for the overall problem, i.e., a prescription of the optimal policy decision at each stage for each of the possible states.

5. Given the current state, an optimal policy for the remaining stages is independent of the policy adopted in previous stages. (This is the principle of optimality for dynamic programming.)
6. The solution procedure begins by finding the optimal policy for the last stage. The optimal policy for the last stage prescribes the optimal policy decision for each of the possible states at that stage. The solution of this one-stage problem is usually trivial.

7. A recursive relationship that identifies the optimal policy for stage n, given the optimal policy for stage (n+1) is available.

8. When this recursive relationship is used, the solution procedure moves backward stage by stage (each time finding the optimal policy for that stage) until it finds the optimal policy starting at the initial stage.

In summary, to solve a problem using a dynamic programming solution, the designer starts from the last stage, and uses recursive relationships that enable him or her to move backwards stage by stage until the starting point is reached.

To illustrate the procedure considers the problem in Fig. 7-8. The aim is to find the best solution with minimum resistance factor from point A to point K. The resistance factors are the numbers associated with each line connecting two points of the network. The total number of possible solutions is large (27) and having to calculate the total cost for each possible solution is not an appealing task. A dynamic programming approach (Fig. 7-8) can provide a solution with much less effort.
Fig. 7-8 Example of a typical dynamic programming problem solution

This particular example consists of four stages, and the final possible solution in the fourth stage \((n = 4)\) is:

\[
\begin{array}{c|c|c}
 s & f_4(s) & x_4^* \\
 H & 3 & K \\
 I & 5 & K \\
 J & 4 & K \\
\end{array}
\]

where

\(n = \) label for current stage \((n = 1, 2, 3, \ldots, N)\).

\(s_n = \) current state for state \(n\).

\(x_n = \) decision variable for stage \(n\).

\(x^*_n = \) optimal value of \(x_n\) (given \(s_n\)).

\(f'_n(s) = \min f_n(s, x_n) = f_n(s, x^*_n)\).
\[ f_n(s, x_n) = \text{immediate cost (stage } n) + \text{minimum future cost (stages } n + 1 \text{ onwards)} = c_{x_n} + f'_{n+1}(x_n). \]

\[ f'_n(s) = f_n(s, x'_n). \]

Similarly for the stage 3 \((n = 3)\) the procedure is:

<table>
<thead>
<tr>
<th>(s)</th>
<th>(x_3)</th>
<th>(f'<em>3(s, x_3) = c</em>{x_3} + f'_{34}(x_3))</th>
<th>(f'_3(s))</th>
<th>(x'_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>7</td>
<td>7</td>
<td>H or J</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>11</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>9</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>12</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>11</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In stage 2 \((n = 2)\) it would be:

<table>
<thead>
<tr>
<th>(s)</th>
<th>(x_2)</th>
<th>(f'<em>2(s, x_2) = c</em>{x_2} + f'_{23}(x_2))</th>
<th>(f'_2(s))</th>
<th>(x'_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>12</td>
<td>10</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>14</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>14</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>13</td>
<td>11</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>
And the final stage (n = 1), it would be:

<table>
<thead>
<tr>
<th></th>
<th>$x_1$</th>
<th>$f_1(s, x_1) = c_{x_1} + f_2(x_1)$</th>
<th>$f_1'(s)$</th>
<th>$x^*_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>15</td>
<td>17</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

If the problem is to find the best road from point A to K with minimum resistance factor, the answer according to these four stages will be; $A \rightarrow D \rightarrow E \rightarrow H \rightarrow K$ or $A \rightarrow D \rightarrow E \rightarrow J \rightarrow K$ (both sections from H or J to K will result in the same resistance factors.

In this particular approach used in this thesis, the possible stages are not known beforehand. The final stage is available only when the previous stage is known. Unlike the solutions on grid based problems, which introduce possible solutions in any stage that are independent of other stages, in the particular approach described herein there are no differentiable sub-stages as could be seen in the previous example.

Consequently, the method proposed herein is considered to be a systematic approach to determination of optimum road location. Fig. 7-9 represents the structure of the whole program that determines the optimum location of a road regarding the criteria discussed earlier in this thesis. The different functions employed are not included in the flowchart in detail and only the name of the function is mentioned whenever it is needed.
These data are needed to start up the program:
- \( I \) = The length of each road segment
- \( x_{\text{start}}, y_{\text{start}} \) = Coordinates of starting point
- \( x_{\text{end}}, y_{\text{end}} \) = Coordinates of ending point
- \( s \) = Maximum acceptable slope
- \( \text{road_width} \) = Width of the road
- \( \text{cost\_construction} \) = Average construction cost per meter
- \( \text{cost\_cutting} \) = Average cutting cost per cubic meter
- \( \text{cost\_filling} \) = Average filling cost per cubic meter

Interactive input of the following variables:
- \( I \)
- \( x_{\text{start}}, y_{\text{start}} \)
- \( x_{\text{end}}, y_{\text{end}} \)
- \( s \)
- \( \text{road\_width} \)
- \( \text{cost\_construction} \)
- \( \text{cost\_cutting} \)
- \( \text{cost\_filling} \)

Invalid input data?  

No \[zz[i]\]

Put all elevation of points in network into a vector \([zz[i]]\) for faster computation

Compute the elevation for terminal points using function \(\text{findz}\) and set to \(h_{\text{start}}, h_{\text{end}}\)

The function \(\text{findz}\) has the following format:
\[ h = \text{findz}(x, y) \]

Compute the distance of two terminal points using function \(\text{distance}\) and assign to \(\text{tmp}\)

The function \(\text{distance}\) has the following format:
\[ d = \text{distance}(x1, y1, x2, y2) \]

\(\text{tmp} > I \) ?

No

Yes

Compute the azimuth of the two terminal points (start to end) and assign to \(g1\) using \(\text{azimuth}\) function

The azimuth function has the following format:
\[ g = \text{azimuth}(x1, y1, x2, y2) \]

\(k = 90\)
\[ g2 = g1 = g1 - k \]
CHAPTER 7: DESCRIPTION OF THE ROAD LOCATION AND DESIGN PROGRAMS

\[ i = 0 \]

\[ i < \text{Branch?} \]

\[ \text{Yes} \]

\[ dh = h\text{.start} - h[i] \]

\[ \text{slope} = dh / l \]

\[ \text{slope} < \text{slope.maximum?} \]

\[ \text{Yes} \]

\[ a[i][4] = 0 \]

\[ \text{No} \]

\[ \text{slope} < 0? \]

\[ \text{Yes} \]

\[ mm = l \cdot (\text{slope}\cdot\text{slope.maximum}) \]

\[ a[i][6] = \text{road\_width} \cdot l \cdot mm \cdot \text{cost\_filling} / 2 \]

\[ \text{min} = 10^9 \]

\[ j = 0 \]

\[ j < \text{BRANCH?} \]

\[ \text{Yes} \]

\[ |a[i][6] - a[i][5]| < \text{min?} \]

\[ \text{Yes} \]

\[ \text{min} = a[i][3] \]

\[ \text{No} \]

\[ a[i][4] = \text{min} \]

\[ \text{No} \]

\[ ++j \]

\[ j < \text{BRANCH?} \]

\[ \text{Yes} \]

\[ |a[i][7] - a[i][5]| \cdot \text{min?} \]

\[ \text{Yes} \]

\[ \text{min} = a[i][3] \]

\[ \text{No} \]

\[ a[i][4] = \text{min} \]

\[ ++j \]

\[ \text{No} \]

\[ \text{weight}[i] = a[i][3] + a[i][4] + a[i][8] \]

\[ ++i \]
Fig. 7-9 General flowchart of the program that performs the selection of the optimum road path
CHAPTER EIGHT

EXAMPLE OF DETERMINATION OF LOCATION OF ROADS USING ROAD LOCATION PROGRAM

8.1 INTRODUCTION

Previous chapters described the procedure of road location design and the computer programs written to perform the task. This chapter shows the result of the previous chapters in an example. The overlaying techniques, different maps used for this purpose, the computational algorithms, weighting, and resistance factor procedures are discussed at the end of this chapter. This chapter is the basis of the computer programs written and used in this thesis, which has been described in full detail in Chapter 7. It explains the procedure of preparing overlaying maps, the weighting and resistance factor values and other steps of procedure in an example. Some maps are depicted for comparison purposes. One map depicts the designed road using the program only concerning the physical constraints as described in Chapter 4. The resulting road location is mapped on
map depicts the designed road using the program only concerning the physical constraints as described in Chapter 4. The resulting road location is mapped on the top of the noise sensitive areas to show that it does not comply with the requirement of that map. And finally the design road using all constraints discussed herein is depicted in two maps. The final map is the result of application of all information and constraints to produce an optimum road path.

8.2 OVERLAYING MAPS FOR PRELIMINARY ROUTE SELECTION

Before the final stage of the design which includes the running of the optimization program, in order to determine the optimum road path, the process of constructing the combined map from the production of other maps should be carried out.

The following maps were used to make the final map.

1. The map which shows the residential areas, consisting of residential areas and non-residential areas.

2. The map describing the area around the residential areas which could be possibly affected by the traffic noise. This map is classified into two areas; noise sensitive areas and other areas.

3. The map showing the location of other roads in the area. The roads and their right of way are assumed to be 40m wide.
4. The map depicting the route of rivers and the width of rivers, each is assumed to be 50m wide. These areas need to be considered as possible bridge crossings.

5. The map showing the location of wetlands, lakes and dams.

6. The ground cover of the area from a forestry point of view. In this case the area is classified into three groups; dense timber, scattered timber and no vegetation.

7. The places of interest such as historical buildings, cultural heritage, aboriginal heritage, and landmarks.

8. The map showing the location of beaches.

9. The map of sea showing the coastline.

10. The geological map, which consists of the formations given previously in Chapter 7.

In the case of the Kiama region, it is concluded from the geological map and reports of the area, that the main geological features of the area include the distinctive volcanic flows of basalt contained in the hill slopes west and north of Kiama, and the quaternary alluvial soil deposits in the flood plain of the Minnamurra River and its tributaries. There are also isolated belts of overlaying sandstone.

Geology is important due to difficulties or constraints imposed on earthworks. Moving of hard rock, such as basalt will have a significant construction time and
cost compared with sandstone or compact clays if that section of road is located in a cutting. The main difference in price is due to rock blasting costs. On the other hand hard rock normally requires less compaction than sandstone and clays. Side slopes in hard rock are much sharper than in softer materials, thereby reducing the amount of cut required.

For the purpose of preliminary design, the geological map is generalized into eight groups according to the hardness of the formation. Table 8-1 describes the general resistance factor range applied in this thesis. It consists of seven categories. Any map entities has been assigned a value between 0 and 20. The equivalent weighting system is the opposite values except for value -1 that means unsuitable for the design purpose and should be excluded from the data sets.

Table 8-2 is the range of weighting in this thesis. The same procedure is applied to geological information to obtain the resistance factor range. Table 8-3 describes the idea according to Table 8-1.

Table 8-1 Range of resistance factor

<table>
<thead>
<tr>
<th>Resistance Factor</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>Ideal</td>
</tr>
<tr>
<td>3-5</td>
<td>Excellent</td>
</tr>
<tr>
<td>6-8</td>
<td>Very good</td>
</tr>
<tr>
<td>9-11</td>
<td>Good</td>
</tr>
<tr>
<td>12-14</td>
<td>Moderate</td>
</tr>
<tr>
<td>15-17</td>
<td>Poor</td>
</tr>
<tr>
<td>18-20</td>
<td>Very poor</td>
</tr>
</tbody>
</table>
Table 8-2 Range of weighting

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-20</td>
<td>Ideal</td>
</tr>
<tr>
<td>15-17</td>
<td>Excellent</td>
</tr>
<tr>
<td>12-14</td>
<td>Very good</td>
</tr>
<tr>
<td>9-11</td>
<td>Good</td>
</tr>
<tr>
<td>6-8</td>
<td>Moderate</td>
</tr>
<tr>
<td>3-5</td>
<td>Poor</td>
</tr>
<tr>
<td>2-0</td>
<td>Very poor</td>
</tr>
<tr>
<td>-1</td>
<td>Excluded</td>
</tr>
</tbody>
</table>

Table 8-3 Geological information and their relative resistance factors.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>General name</th>
<th>Hardness</th>
<th>Resistance Factor Filling</th>
<th>Resistance Factor Cutting</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qt, Cbs</td>
<td>Talus</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>Can be removed by machinery</td>
</tr>
<tr>
<td>Qa</td>
<td>Alluvium</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>Can be removed by machinery</td>
</tr>
<tr>
<td>Pi</td>
<td>quartz -lithic sandstone carbonaceous claystone and coal</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>Can be removed by heavier machinery</td>
</tr>
<tr>
<td>Psb</td>
<td>siltstone to fine sandstone</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>Very hard to removed by machinery</td>
</tr>
<tr>
<td>Psg</td>
<td>volcanic sandstones</td>
<td>5</td>
<td>4</td>
<td>10</td>
<td>Normally needed explosion if not subject to weathering</td>
</tr>
<tr>
<td>Rh, Rnz, Rnk</td>
<td>Quartzose Sandstone</td>
<td>6</td>
<td>3</td>
<td>12</td>
<td>Normally needed explosion</td>
</tr>
<tr>
<td>Sa, Pipm</td>
<td>Volcanic agglomerate</td>
<td>7</td>
<td>2</td>
<td>14</td>
<td>Explosion needed</td>
</tr>
<tr>
<td>bb, Psgd, Psgc, Psgs, Psgb, Psgh</td>
<td>Igneous and Volcanic Rocks (Basalt)</td>
<td>8</td>
<td>1</td>
<td>17</td>
<td>Heavy explosion needed</td>
</tr>
</tbody>
</table>

These ten maps, in addition to the topographical map, provide the required information needed to design the optimum road location. Each map has a resistance factor according the importance of the map. The greater the resistance...
factor, the less the suitability for the road location. Each entity in the map has also another resistance factor depending the importance of the entity inside the map. In order to produce the final map, these resistance factors should be assigned. A range of numbers, which is quite arbitrary, should be assigned to each entity in the maps. The best way to do this is to write down all entities and decide the minimum, maximum and the value for each of the entities. The idea is shown in Table 8-4.

Table 8-4  Resistance factor for whole entities in the combined map

<table>
<thead>
<tr>
<th>Entity</th>
<th>Description</th>
<th>Resistance Factor</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>residential areas</td>
<td>Urban areas</td>
<td>-1</td>
<td>Not suitable</td>
</tr>
<tr>
<td>noise sensitive areas</td>
<td>150m buffer around</td>
<td>9</td>
<td>Good</td>
</tr>
<tr>
<td>roads</td>
<td>40m wide</td>
<td>10</td>
<td>Good</td>
</tr>
<tr>
<td>rivers</td>
<td>50m wide</td>
<td>12</td>
<td>Moderate</td>
</tr>
<tr>
<td>other wetlands</td>
<td>Watercourses</td>
<td>16</td>
<td>Poor</td>
</tr>
<tr>
<td>dense timber</td>
<td>Dense timber</td>
<td>14</td>
<td>Moderate</td>
</tr>
<tr>
<td>scattered timber</td>
<td>Scattered timber</td>
<td>5</td>
<td>Excellent</td>
</tr>
<tr>
<td>no vegetation</td>
<td>Bare lands</td>
<td>0</td>
<td>Ideal</td>
</tr>
<tr>
<td>places of interest</td>
<td>National and aboriginal heritage</td>
<td>-1</td>
<td>Not suitable</td>
</tr>
<tr>
<td>beaches</td>
<td>Beaches</td>
<td>-1</td>
<td>Not suitable</td>
</tr>
<tr>
<td>coast lines</td>
<td>Coast lines</td>
<td>-1</td>
<td>Not suitable</td>
</tr>
<tr>
<td>Qa</td>
<td>Alluvium, gravel, beach and dune sand</td>
<td>F=7</td>
<td>C=4</td>
</tr>
<tr>
<td>Qt, Cbs</td>
<td>Talus</td>
<td>F=8</td>
<td>C=2</td>
</tr>
<tr>
<td>sa, Pigm</td>
<td>Volcanic agglomerate</td>
<td>F=2</td>
<td>C=14</td>
</tr>
<tr>
<td>bb, Psgd, Psgc, Psgs, Psgb, Psgh</td>
<td>Basalt</td>
<td>F=1</td>
<td>C=17</td>
</tr>
<tr>
<td>Rh Rnz, Rnk</td>
<td>Quartzose sandstone</td>
<td>F=3</td>
<td>C=12</td>
</tr>
<tr>
<td>Pi</td>
<td>quartz -lithic sandstone, carbonaceous claystone and coal</td>
<td>F=6</td>
<td>C=5</td>
</tr>
<tr>
<td>Psg</td>
<td>Volcanic sandstones</td>
<td>F=4</td>
<td>C=10</td>
</tr>
<tr>
<td>Psb</td>
<td>Siltstone to fine sandstone</td>
<td>F=5</td>
<td>C=8</td>
</tr>
</tbody>
</table>
The above eighteen groups of information allow the construction of the final map, which is the basis of selection of the optimum route. The final map might have other classes as well; the reason will be discussed later.

Using the above ten maps in SPANS GIS and using the INDEX overlaying and editing procedure the template results in the following indexing overlay input files. The first index overlay uses the resistance factors of the cutting section of the Table 8-3. The resulting map (Fig. 8-1) summarizes the idea and if a section of the road is in a cutting situation (Chapter 4), the information on this map is used. The other information on this map is the information in Table 8-3. If the above index template apply to the maps, another map which shows the different values for different positions of the land will be produced. Fig. 8-1 shows the resulting map.

```
: Indexing Overlay Input File
:---------------------------------------------
: new mapid & title : roadsuit road suitability map
:---------------------------------------------
: no of Input Maps : 10
: Input Maps (Id Max Colour)
    beachesr 1 builbufr 1 buildups 1 forestr 3 geor
    16 national 1 river 1 roads m 1 sea 1 waterr 1
: Format = Weight Map ID Title
:---------------------------------------------
10.000 beachesr : only beaches
:---------------------------------------------
: Beaches - 0: 0
: Beaches - 1: -1
:---------------------------------------------
10.000 builbufr : only buffered areas
:---------------------------------------------
: Buffered - 0: 0
: Buffered - 1: 9
:---------------------------------------------
10.000 buildups : only buildups areas
:---------------------------------------------
: Buildups - 0: 0
: Buildups - 1: -1
:---------------------------------------------
10.000 forestr : forest complete
:---------------------------------------------
: D-Timb - 0: 0
: S-Timb - 1: 14
: Nothing - 2: 5
:---------------------------------------------
```
## Example of the Determination of Location

### Geology

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ga</td>
<td>Generalised geology only</td>
<td>0</td>
</tr>
<tr>
<td>Qt</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>sa</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>bb</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Rh</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Rnz</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Rnk</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Pi</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Pipm</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Psgd</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Psgc</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Psgs</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Psgb</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Psgh</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Psg</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

### National Heritage

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nat-Her</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

### Rivers

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>rivers</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

### Roads

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

### Sea

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

### Watercourses

<table>
<thead>
<tr>
<th>Code</th>
<th>Legend</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watercou</td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>
Fig. 8-1 Road suitability map (Cutting)

The same procedure with some different weights produces Fig. 8-2, which is called road suitability map (filling). It should be mentioned that filling and cutting added to the map suitability does not mean only physical consideration which described in Chapter four. It means those two maps are the result of combination of all information described previously. If the road segment needs
cutting use the information in the map labelled cutting, otherwise (when filling required) use the data base related to the map that represents filling.

<table>
<thead>
<tr>
<th>Map ID Title</th>
<th>Format</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.000 beachesr: only beaches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:Beaches</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:buffered</td>
<td>-</td>
<td>1: -1</td>
</tr>
<tr>
<td>10.000 bulbufr: only buffered areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:buffered</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:Buildups</td>
<td>-</td>
<td>1: 9</td>
</tr>
<tr>
<td>10.000 buildups: only buildups areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:Buildups</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:Nothing</td>
<td>-</td>
<td>1: -1</td>
</tr>
<tr>
<td>10.000 forestr: forest complete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:D-Timb</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:S-Timb</td>
<td>-</td>
<td>1: 14</td>
</tr>
<tr>
<td>:Nothing</td>
<td>-</td>
<td>2: 5</td>
</tr>
<tr>
<td>10.000 geor: generalised geology only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:Qa</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:Qt</td>
<td>-</td>
<td>1: 4</td>
</tr>
<tr>
<td>:sa</td>
<td>-</td>
<td>2: 2</td>
</tr>
<tr>
<td>:bb</td>
<td>-</td>
<td>3: 14</td>
</tr>
<tr>
<td>:Rh</td>
<td>-</td>
<td>4: 17</td>
</tr>
<tr>
<td>:Rnz</td>
<td>-</td>
<td>5: 12</td>
</tr>
<tr>
<td>:Rnk</td>
<td>-</td>
<td>6: 12</td>
</tr>
<tr>
<td>:Pi</td>
<td>-</td>
<td>7: 12</td>
</tr>
<tr>
<td>:Pipm</td>
<td>-</td>
<td>8: 5</td>
</tr>
<tr>
<td>:Psgd</td>
<td>-</td>
<td>9: 14</td>
</tr>
<tr>
<td>:Psgc</td>
<td>-</td>
<td>10: 17</td>
</tr>
<tr>
<td>:Psga</td>
<td>-</td>
<td>11: 17</td>
</tr>
<tr>
<td>:Psgs</td>
<td>-</td>
<td>12: 17</td>
</tr>
<tr>
<td>:Psgb</td>
<td>-</td>
<td>13: 17</td>
</tr>
<tr>
<td>:Psgh</td>
<td>-</td>
<td>14: 17</td>
</tr>
<tr>
<td>:Psg</td>
<td>-</td>
<td>15: 10</td>
</tr>
<tr>
<td>10.000 national: only national heritage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:Nat-Her</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:rivers</td>
<td>-</td>
<td>1: -1</td>
</tr>
<tr>
<td>10.000 river: only river in 50m buffer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:rivers</td>
<td>-</td>
<td>0: 0</td>
</tr>
<tr>
<td>:rivers</td>
<td>-</td>
<td>1: 12</td>
</tr>
</tbody>
</table>
CHAPTER 8: EXAMPLE OF THE DETERMINATION OF LOCATION...

10,000 roads: only roads in 40m buffer
: - : 0 : 0
: Roads : 1 : 10

10,000 sea: only sea
: - : 0 : 0
: Sea : 1 : -1

10,000 water: only watercourses
: - : 0 : 0
: Water : 1 : 16

---

Fig. 8-2 Road suitability map (Filling)
The same technique is employed to produce the road suitability map for filling. Fig. 6-23 depicts the result.

### 8.2.1 COMPUTATIONAL ALGORITHM

The average score is calculated as follows:

- All negative scores are rounded to the nearest integer.

- For areas where there is a negative score, the average score equals the minimum of the negative scores.

- For areas where all scores are non-negative, the average score equals:

  \[ \text{SUM}_i = \frac{\text{score}_i \cdot \text{weight}_i}{\text{SUM}_i} = 1 \text{ to n}^{(\text{weight}_i)} \]

  Where the equation to be solved used iteration method.

- The average scores are rounded to the nearest integer.

- The maximum individual score is assigned class 1. All average scores are assigned classes relative to this class.

### 8.3 THE WEIGHTING

As mentioned earlier, the principle of using GIS to design road locations depends on the use of weights or resistance factors. In this thesis, the resistance factor concept is used. In order to apply the appropriate resistance factors, two sets of numbers should be assigned to each part of the road. The first resistance factor
was discussed in Chapter 3 and was the resistance factor due to the length and earthwork of the different road segments. The result was equation (4-5) which was the basis for further resistance factor determination procedures in equations (4-8) to (4-11). The same concept can be applied to the other properties of land at each point on the basis of equation (4-5). For example, the price of land, buildings, geological features that increase construction expenditures, soil properties of the land and its importance in agriculture and so on, should be considered for each road segment. The final digital map, which is the composite map for all of this information, consists of different polygons and is used for the second resistance factor assignment. The final map consists of different polygons. Each of these polygons represents a unique resistance factor. The main computer program (written by the author) detects each of these polygons and their associated resistance factors simultaneously, and adds to the result of equation 3-5, which is the resistance factor due to the road length and earthwork. According to the associated resistance factor of each polygon, which represents its importance in the road design procedure, the computer program decides to cross or avoid or turn that polygon. Crossing a polygon means that it is a suitable polygon for the road design purpose. Avoiding a polygon means that the polygon is not suitable for the design purpose, and it should be determined in the earthwork stage of road location and design. Turning a polygon means that the polygon is not suitable for the design purpose but the road should pass an area near that polygon (for example a road connecting two places should cover another place in the middle). The result of the final road path would be the optimum road
location design. The full descriptions of all computer programs used in this thesis have been discussed in Chapter 7.

8.4 DESIGN PROCEDURE

In order to demonstrate the design procedure of the road location computer program, two locations were picked up as the terminal points in the Kiama region.

The coordinate of terminal points were as follows:

<table>
<thead>
<tr>
<th>Point</th>
<th>Easting</th>
<th>Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting (A)</td>
<td>303000</td>
<td>6165500</td>
</tr>
<tr>
<td>Ending (B)</td>
<td>302200</td>
<td>6158300</td>
</tr>
</tbody>
</table>

In this stage the road location computer program has been run with different constraints.

8.4.1 FIRST STEP OF DESIGN PROCEDURE

The first version of the designed road is just to consider the optimum length and earthwork. It is also assumed that the cost of cutting is the same regardless of the place and also the cost of filling is the same as well. The result is depicted in Fig. Appendix II contains designed roads maps with different road segments of 50,
100, 200 and 500 meters, from and to the same terminal points according the optimum length and optimum earthwork concept. From these designs the 100-meter segments have been chosen as the optimum road segments. The designed road depicted in Fig. 8-3 is the result of equations discussed in Chapter 4 that resulted in the optimum road regarding the optimum amount of earthwork and length together.

![Legend](image)

**Fig. 8-3 Designed road only considering earth work**

### 8.4.2 SECOND STEP OF DESIGN PROCEDURE

Even though the designed road, depicted in Fig. 8-3, fulfils the optimum length and optimum earthwork requirements, if it is mapped against the residential areas,
it can be seen that it needs some modifications to avoid crossing the residential area.

The background map in Fig. 8-4 shows some of the residential areas of the study area, and a noise sensitive buffer associated with that. As can be seen from the Fig. 8-4, the designed road has crossed some part of the residential areas. Normally the road location procedure requires the crossing of such areas and some other areas of interest to be avoided. To maintain these requirements, the program determines these areas and avoids them as far as possible.

Fig. 8-4 Designed road, residential and noise sensitive areas
The second version of the designed road using the same terminal points were examined for this purpose, and the result is depicted in Fig. 8-5, which shows this new road R2 plotted against the previous one, R1.

Fig. 8-5 Designed road considering the residential areas and noise pollution

8.4.3 FINAL STEP OF DESIGN PROCEDURE

If the second version of the road is mapped against other factors discussed earlier in this thesis, the same problem will occur, which is that some (or sometimes all) parts of the road need to be modified. The road design program can do all the
necessary modifications and produce the final map according to the data sets described earlier. These data sets were:

- Topography
- Location of sea
- Location of beaches
- Residential areas
- Ground coverage
- Geology
- Soil
- Places of interest
- Location of other roads
- Location of watercourses
- Location of rivers
- Noise and air pollution

To perform the task of the design of the optimum road, using all the parameters discussed in Chapter 6 and listed briefly here, two sets of data are used according to Figs. 8-1 and 8-2. Both figures are derived from Table 8-4. Firstly, the common resistance factor (first eleven rows) and the cutting characteristics of the geology resulted in Fig. 8-1. Secondly, the filling characteristics of the geology, in addition to the same common resistance factors, namely the first eleven rows, resulted in Fig. 8-2. These two maps and data sets associated with them are used to design the final road herein. The procedure is to use one of these maps in any design stage. If the road segment needs cutting the data sets of Fig. 8-1 are used. If the road segment needs filling the data sets of Fig. 8-2 are used. The final road is a single road, which satisfies the design requirements of the constraints
discussed in this thesis. For example consider that two consecutive coordinates of a road segment (AB) are as follow:

\[ X_A = 500, \ Y_A = 500 \]
\[ X_B = 600, \ Y_B = 500 \]

If the ground elevations of the point A and B are 500m and 510m respectively, and the project elevations for the same points are 500m and 505m respectively for the same points. In this case that segment of the road needs to be cut and therefore the data set of Fig. 1 should be used. The result will be that section of the road satisfies the other requirements of the design procedure and considered as needed to be cut. Alternatively if the natural elevations of the same points are 500m and 490m respectively and the project elevations are designed to be 500m and 505m for the same points, that segment of the road needs to be filled and therefore the data set of Fig. 2 should be used. It means that in addition to general requirements of road design should meet, the data set of Fig. 2 should be used since the section is in a filling section. Therefore depends on the position of ending point of each road segment, the suitable data sets for further operations should be selected. The final designed road is depicted in Figs. 6 and 7 which are the larger scale of the partial maps of Figs. 1 and 2 that contains the final designed road.
Fig 8-8 Final designed road (Cutting) in bigger scale
Fig 8-7 Final designed road (Filling) in bigger scale
CHAPTER 8: EXAMPLE OF THE DETERMINATION OF LOCATION...

8.5 SUMMARY AND CONCLUSION

This Chapter endeavours to picture the study area and its specifications, and how the computer program can use the information to design the optimum path. The noise pollution resulting from the road traffic is considered separately with an independent computer program, and the result of Chapter 3 is used in the computer program directly. Air pollution is regarded as a variable of the length of the road, and given weight according to this. The ability of GIS to summarize the vast amount of diverse data is shown in this Chapter. The different properties of each point are gathered together and are assigned a unique resistance factor for each of their aspects. The composite map can be used as the final resistance factors in further processing. If a route with the minimum accumulated resistance factor is determined, which is the result of the computer program, it is called the optimum road path. The optimum road path is pictured against the road suitability map (cutting) and road suitability map (filling), respectively, in the last two maps.

The main advantages of this procedure of designing the location of roads using such a technique is the ability of considering all of the required parameters at almost one stage. The environmental issues can be integrated into other physical elements in one stage. In addition, many alternatives road segments are tested against each other to determine the optimum road location than is carried out by conventional methods (Oblesby, 1982), (Behbahani, 1983), (Lay, 1990). The design road in this example avoided crossing the residential areas, places of interests, noise sensitive areas, and has used the best location according to Figs. 8-6 and 8-7, and optimum length and earthwork. This designed road does not
require any bridges, and therefore did not use the bridge program. The whole idea is depicted in Fig. 8-8.

Fig. 8-8 General idea of designing road using GIS
CHAPTER NINE

CONCLUSION AND RESULTS

This thesis consists of nine chapters. The general idea has been to develop a model, which is able to perform computerised road location and design. Some of author's ideas were programmed, and further ideas can be added to the program to make it more complete. With some minor modifications, the program can be used for other transportation route design such as pipelines and railways locations. Of course, determination of the relative importance of each layer, as discussed in Chapter 6 in the final composite digital map, is a complicated task to achieve. It requires teamwork from members of a design team with different expertise, and probably the application of some special methods developed for the road design purpose.

One important factor in determining the optimum road path was the length of the road. The cost of construction plays an important role in determining the optimum road path. The meaning of construction cost here relates to the construction of the road surface, such as, sub-base, base, and so on, regardless the earthwork expenses, which are dealt with as a different matter. The optimum road path used in this thesis indicates that even though the shortest road can satisfy the design standards, it might not be the best solution. Therefore, the aim was not to introduce the shortest road between terminal points from
this point of view, as long straight sections of roads are not suitable from a driver's point of view. These long straight sections cause driver fatigue and can result in serious accidents. Some sort of optimum road path which considers different design requirements such as cost, environment care, safety and so on, were taken in to consideration in this thesis, which resulted in an optimum road location rather than the shortest one. The length of the road was the basis of the resistance factor assignments, and all other assignments followed this part of the design procedure.

The amount of earthwork was another important aspect of road path design in this thesis. Depending on the average natural slope of each road segment and the maximum permitted slope according to the type of the road, the average earthwork was calculated for different directions, and according to that, the appropriate resistance factors were assigned to each relevant road segment.

To perform the task of design of a road, all the parameters discussed in Chapter 6 were used in the road location program. Environmental issues regarding the air pollution caused by emissions of motor vehicles, which were briefly discussed in Chapter 3, have been included in the road location program as being dependent on the length of the road.

The program developed herein can determine the optimum road path using all the factors discussed in previous chapters. It firstly divides the area from starting point towards the finishing point into smaller road sections, and chooses the most suitable direction towards the finishing point. Each stage of determining a road segment will result in a
new starting point and the procedure of design continues. At the same time, the designed road is checked for environmental considerations, bridge locations and geological constraints. The procedure for the determining these properties is achieved by using a complex map resulting from SPANS GIS software.

Each point of the complex map is assigned a number as its resistance factor. According to that number a point is classified from “not suitable for road location” to “excellent point for road location”. Fig 9-1 describes in flowchart form the general procedure of designing the location of a road based on using digital information and GIS techniques, as described in previous chapters.

The important advantage of using such a technique to design a road path is that the whole procedure of road design (physical and environmental) can be carried out in one stage. Instead of designing a road and then considering the environmental issues, such as those mentioned in previous chapters, the designer is able to take into account all information simultaneously by putting it into GIS systems the way he or she wishes to handle the design.

Like any other approach to road design, this procedure has some advantages and few disadvantages. An advantage is the speed of the procedure compared with the traditional methods. If digital data is available for entering the GIS package, a one-week operation is enough for a normal project to enter the data into the package and produce the required maps and data sets that the road design program requires for operation. In addition, the
result of this stage is that the digital form of the ground and its attributes is a good source for any other civil works at that area. The time needed for determining a road segment using the road design program is less than a second for a normal design using a common PC computer.

More importantly, the environmental considerations, which are of great concern nowadays, can be carried out concurrently with the other design requirements. This is because the program knows the sensitive areas beforehand, and can exclude or include them in the various design stages.

In addition, the results of the individual and combined maps, which are available in digital format for the computer processing, can be converted to hard copy such as maps, charts and so on for other interested parties and future developments.

As for any other methods of designing a road, there are a few drawbacks of using such a method. One of them was described in Chapter 7 as the difficulty to examine all possible variants. Another drawback is if the data required for determining the road design using the method discussed in this thesis is not available in digital format, the production of producing such data sets incurs high cost for large projects.

The approach carried out in this thesis is different from all other approaches discussed earlier in Chapter 2. In contrast, the approach proposed herein neither uses the gird-based techniques, nor leaves the subjective part of the design to the designer
for a different stage. The approach employs a GIS technique, which enables the
designer to introduce all his ideas and experiences with appropriate weights to
produce suitable map or maps and associated data sets. Each map is unique for the
desired purpose, and each point on the map has a weight associated to that purpose.
This map or maps, besides the contour map, can be used to produce the optimum
road alignment. The result can be used in other packages, such as MOSS or Mac
Road, to design the horizontal, vertical, transition curves and extent of earthwork,
and any other design requirements.
CHAPTER 9: CONCLUSION AND RESULTS

Fig. 9-1 Flowchart of road location and design
REFERENCES


REFERENCES


REFERENCES


Cuff, D. J. and Mattson, M. T., (1982). "Thematic maps, their design and production." Methuen, USA.


REFERENCES


REFERENCES


Goodchild, M. F. and Kemp, K. K., (1990). "Introduction to GIS." NCGIA Core Curriculum National Centre for Geographic Information and Analysis, University of California, Santa Barbara, USA.


REFERENCES

In I. Moffatt and A. Webb (eds.). Conservation and Development Issues in Northern Australia. Australian National University, Darwin.


REFERENCES


Department of Geography, School of Geoscience, University of Wollongong, Australia.


REFERENCES


Prisley, S. P., (1986). "Commercial GIS's for natural resources managements: what a manager needs to know." GIS Workshop April 1-4, Atlanta, Georgia, USA.


REFERENCES


REFERENCES


APPENDIX I

Designed road using Road Design Program with different length of road segments for comparison. Only minimum length and earthworks are considered here since the other factors are the same for all designed roads.

Fig. AI-1 Designed road using road design program with 50 m segments
Fig. AI-2 Designed road using road design program with 100 m segments
Fig. Al-3 Designed road using road design program with 200 m segments
Fig. AI-4 Designed road using road design program with 500 m segments
INTRODUCTION

In order to demonstrate the ideas discussed in previous chapters, a computer program was written to perform the design of the location of the road. To apply the program for this particular approach, the Kiama region of NSW, Australia was used, and some data files needed to be prepared prior to the execution of the program. In some stages the program needs to access the elevation of required points, and to speed up the procedure some grid techniques employed. To construct the required grid database in 100 by 100 meters, using a large number of random points, a normal 486 33 MHz computer used, which took 48 hours of computation. The same program took 24 hours with a 486 100 MHz computer, and around 14 hours with a 686 133 MHz computer with the same configurations. The road location program takes less than one second for each road segment in the Kiama region example. It means that the whole run time of the program is less than a minute using a 686 133 MHz computer. The most time consuming aspect for using such a program is the preparation of data. The different information data sets should be organized and planned carefully to result in a correct combined map. The order of combining the maps is important to get the correct results as described in Chapter 6.
The general flowchart of the program is depicted at the end of Chapter 9. A detailed flowchart is shown in Chapter 7 where the program and some of its important functions are described. The full flowchart of all functions would be very lengthy, and it is not included in the thesis.

The first part of the following sets of programs is the road location program itself followed by some of the important functions. Again, some of the complementary programs are not included, and only the results of those, which have formed the different data sets, are included.

The first function after the main program is the findz function. This program uses a network of 100 by 100 meters as coordinates. The required data file consists of 13100 sets of x, y and z coordinates. The first 20 lines of data are shown below as an example.

```
295000.000 6153000.000 40.000
295000.000 6153100.000 40.000
295000.000 6153200.000 40.000
295000.000 6153300.000 40.000
295000.000 6153400.000 40.000
295000.000 6153500.000 40.000
295000.000 6153600.000 40.000
295000.000 6153700.000 40.000
295000.000 6153800.000 40.000
295000.000 6153900.000 49.500
295000.000 6154000.000 50.000
295000.000 6154100.000 50.000
295000.000 6154200.000 50.000
295000.000 6154300.000 60.000
295000.000 6154400.000 60.000
295000.000 6154500.000 60.000
295000.000 6154600.000 65.358
295000.000 6154700.000 74.574
295000.000 6154800.000 80.000
295000.000 6154900.000 80.000
```

The next function, sort, is a part of the previous function findz. This function sorts the four elevations of the four closest points to the points whose elevation is needed.

The next function is called point_inside_polygon, which is one of the most important functions in this program. Any point can be determined within a polygon, which is
placed using this function, therefore the appropriate resistance factor can be assigned accordingly regarding the importance of the particular property that the polygon may have.

Two other functions that are used frequently are azimuth and distance functions.

Another function (input), which was used to input the initial data, is next. These data include the coordinates of terminal points. Even though this part could be included in the main program, it is more flexible to make a separate function for this purpose.

Another important function is, parallel_pol, which turns any polygon when the road reaches a certain distance in that polygon. To do this task two other functions are introduced that are prep and max distance functions. With these two function the designer is able to turn any polygon at any distance he decides. For example, they enable the designer to place the road location at a certain distance from a residential area and turn it.

The next program is called noise program. This program is able to calculate the noise due to motor vehicle traffic. To reduce the time of such an operation, another program that is called, cross, is used to determine the areas around residential areas, which if avoided, the designer can be sure that there is no need to calculate any relevant noise. If the road happens to cross any part of this buffered area, the calculation of the noise for the affected area could be carried out for those segments that might be responsible for the excessive noise, and further commitment can be considered. Finally, the river program determines the possible bridge locations and other parameters discussed in Chapter 7.
ROAD LOCATION PROGRAM (MAIN PROGRAM)

// This program finds the location of the road with respect to minimizing the earth works and distance.

// Declaration of variables

// a[i][1] = easting of points
// a[i][2] = northing of points
// a[i][3] = horizontal weight due to the length of the road
// a[i][4] = vertical weight due to the elevations
// a[i][5] = cost of overall construction in any segment
// a[i][6] = cost of cutting in any segment
// a[i][7] = cost of filling in any segment
// weight[i] = the overall weight
// h[i] = the height of points
// x_start, y_start, h_start, x_end, y_end, h_end = the coordinates of terminal points
// cost_construction = average cost of construction per meter
// cost_cutting = average cost of cutting per cubic meter
// cost_filling = average cost of filling per cubic meter
// slope_maximum = maximum slope allowed for the road regarding its class
// road_width = width of the road
// outf.txt is the data file contains the information of elevation.
// minl0.txt is the file contains the coordinates of optimum road.

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <graphics.h>
#include <conio.h>
#include <iostream.h>
#include <ctype.h>
#include <time.h>
#include <string.h>

#define BRANCH 19
#define PI 3.14159257

FILE *fl, *f2, *f3;
float x_start, y_start, h_start, x_end, y_end, l, road_width;
float cost_construction, cost_cutting, cost_filling, zz[15000];
float xint, yint, x100, y100, w;
int s;
char si[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];

void inputs();
void sort (float final[4][4]);
float Findz (float x, float y);
float azimuth (float xl, float yl, float x2, float y2);
float distance (float xl, float yl, float x2, float y2);
float point_inside_polygon (float x_start, float y_start);
void maxlOO (float xmax, float ymax, float xint, float yint);
void parallel_pol ();
float prep (float x_start, float y_start, float x_end, float y_end, float x1, float y1);

main()
{
    float a[BRANCH][8], weight[BRANCH], h[BRANCH], x, y, z;
    float h_end, dx, dy, dh;
    float xM, yM, l1, l2, l12;
    float slope, slope_maximum;

}
float k, gk, /*w,*/ gl, g2;
float tmp, tmp1, tmp2, mm, min;
int i, j, m, p, q;

f1 = fopen("outf.txt", "r");
f3 = fopen("minlO.txt", "w");

inputs();

switch (s) {
    case 1:
        slope_maximum = .05; // Maximum slope acceptable for highways
        break;
    case 2:
        slope_maximum = .08; // Maximum slope acceptable for first class road
        break;
    case 3:
        slope_maximum = .11; // Maximum slope acceptable for second class road
        break;
    case 4:
        slope_maximum = .15; // Maximum slope acceptable for third class road
        break;
}

for (i=0; i<13100; i++)
    fscanf(f1, "%f %f %f\n", &x, &y, &z);

h_start = findz(x_start, y_start);
h_end = findz(x_end, y_end);
fprintf(f3, "%3f %.3f %.3f\n", x_start, y_start, h_start);
printf("x=%.3f y=%.3f z=%.3f\n", x_start, y_start, h_start);

tmp = distance (x_start, y_start, x_end, y_end);
while (tmp > 1)
    {
        // Searching area is 90 degree on each side of the aiming line.
        gl = azimuth (x_start, y_start, x_end, y_end);
        for (i=0; i<BRANCH; ++i)
            {a[i][1] = x_start+i*sin(gl); a[i][2] = y_start+i*cos(gl);}
        gl *= PI/180; // Degree to radian
        a[i][3] = 3*(sqrt(12+112-2*ll*l*cos(gk)))+l-ll)/sqrt(12+112)+l-ll;
        a[0][3] = a[18][3] = 3;
        a[i][5] = (sqrt (12+112-2*ll*l*cos(gk)) + l) * cost_construction;
        a[i][8] = point_inside_polygon(a[i][1], a[i][2]);
        gl = g2+i+1;
\[ k = 90 - (i+1) \cdot 10; \]

for \( i = 0; i < \text{BRANCH}; ++i \)
{
    \[ dh = h_\text{start} - h[i]; \]
    \[ \text{slope} = dh / 1; \]
    
    if (fabs(slope) <= \text{slope maximum})
        \[ a[i][4] = 0; \]
    else
        if (slope < 0)
            \[ mm = 1 \cdot (-\text{slope maximum} - \text{slope}); \]
            \[ a[i][6] = \text{road width} \cdot 1 \cdot mm \cdot \text{cost filling} / 2; \]
            \[ \text{min} = 10e10; \]
            
            for (j = 0; j < \text{BRANCH}; ++j)
            {
                if (fabs(a[i][6] - a[j][5]) < \text{min})
                    \[ \text{min} = a[j][3]; \]
            }
            \[ a[i][4] = \text{min}; \]
        else
            \[ mm = 1 \cdot (\text{slope} - \text{slope maximum}); \]
            \[ a[i][7] = \text{road width} \cdot 1 \cdot mm \cdot \text{cost cutting} / 2; \]
            \[ \text{min} = 10e10; \]
            
            for (j = 0; j < \text{BRANCH}; ++j)
            {
                if (fabs(a[i][7] - a[j][5]) < \text{min})
                    \[ \text{min} = a[j][3]; \]
            }
            \[ a[i][4] = \text{min}; \]

    \[ \text{weight}[i] = a[i][3] + a[i][4] + a[i][8]; \]
}

\[ w = \text{weight}[0]; \]

for (i = 1; i < \text{BRANCH}; ++i)
{
    if (\text{w} < \text{weight}[i])
        \[ w = \text{weight}[i]; \]
}

if (\text{w} >= 10)
{
    \text{parallel_pal}();
    \[ \text{tmp} = \text{distance} (x_\text{start}, y_\text{start}, x_\text{end}, y_\text{end}); \]
}
else
{
    \[ w = \text{weight}[0]; \]
    \[ m = 0; \]
    for (i = 1; i < \text{BRANCH}; ++i)
    {
        if (\text{w} > \text{weight}[i])
        {
            \[ w = \text{weight}[i]; \]
            \[ m = i; \]
        }
    }

    \[ x_\text{start} = a[m][1]; \]
    \[ y_\text{start} = a[m][2]; \]
    \[ h_\text{start} = h[m]; \]

    \text{printf}("\text{direction}=%d\n", (9-m)*10);
    \[ \text{tmp} = \text{distance} (x_\text{start}, y_\text{start}, x_\text{end}, y_\text{end}); \]
    \text{fprintf(f3,"%.3f %.3f %.3f\n", x_\text{start}, y_\text{start}, h_\text{start});}
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```c
printf("x=%.3f y=%.3f z=%.3f\n",x_start,y_start,h_start);
}
}
fprintf(f3,"%.3f %.3f %.3f\n",x_end,y_end,h_end);
printf("x=%.3f y=%.3f z=%.3f\n",x_end,y_end,h_end);
fclose(f1);
fclose(f2);
return(0);
```
FINDZ FUNCTION

// This function finds the elevation of a point x, y and return the value to the main
// program.

float findz(float x, float y)
{
    int i;
    long m, n;
    long a[4], weight[4], c[4];
    float v, z, x1, y1, w[4], f[4][4];
    if (x>304800 || y<6153200)
        z = 0;
    else
    {
        m = x / 100;
        n = y / 100;
        f[0][0] = m * 100;
        f[0][1] = n * 100;
        f[1][0] = f[0][0];
        f[1][1] = f[0][1] + 100;
        f[2][0] = f[0][0] + 100;
        f[2][1] = f[0][1] + 100;
        f[3][0] = f[0][0] + 100;
        f[3][1] = f[0][1];
        for (i=0; i<4; ++i)
        {
            a[i] = (f[i][0]-295000)/100*131 +(f[i][1]-6153000)/100;
            f[i][2] = zz[a[i]]
            weight[i] = pow((f[i][0] - x) ,2);
            c[i] = pow((f[i][1] - y), 2);
            f[i][3] = sqrt(weight[i] + c[i]);
        }
        sort(f);
        v = 0;
        if (f[0][3] < 0.001)
            z = f[0][2];
        else
        {
            for (i = 0; i < 4; i++)
            {
                v = v + 1 / f[i][3];
                z = 0;
            }
            for (i = 0; i < 4; i++)
            {
                w[i] = 1 / f[i][3] / v;
                z = z + w[i] * f[i][2];
            }
        }
    return z;
    //-----------------------------------------------------------------------------------
SORT FUNCTION

// This function sorts the final array ascending according to last column elements
void sort(float final[4][4])
{
    int i, j, k;
    float temp[4];
    for (j = 0; j < 4; j++)
        for (k = j + 1; k < 4; k++)
            if (final[j][3] > final[k][3])
                for (i = 0; i < 4; i++)
                    temp[i] = final[j][i];
                final[j][i] = final[k][i];
                final[k][i] = temp[i];
}

//---------------------------------------------------------------
POINT_INSIDE_POLYGON FUNCTION

// This function determine whether a point is inside or outside a polygon.

float point_inside_polygon(float x_start, float y_start)
{
    int nol, no2, set, i, j, f;
    char s1[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];
    float x, y, x1, x2, x3, x4, y1, y2, y3, y4;
    float m, ml, m2, dx1, dx2, dy1, dy2, w;
    FILE *fl, *f2;

    fl = fopen("buildup.vec","r");
    f2 = fopen("buildup.veh","r");

    fscanf (fl,"%s \n", s1);
    //printf("%s\n", si);
    fscanf (f2,"%s %s %s %s %s %s
", s1, s2, s3, s4, s5, s6);
    //printf("%s %s %s %s %s %s\n", si, s2, s3, s4, s5, s6);
    fscanf (f2,"%s %s
", si, s2);
    //printf("%s %s\n", si, s2);
    fscanf (f2,"%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    //printf("%s %s %s %s %s %s\n", si, s2, s3, s4, s5, s6);
    fscanf (f2,"%s %d
", si, iset);

    x1 = x_start;
    y1 = y_start;
    x2 = x1;
    y2 = y1+100;
    for (i=0; i<iset; i++)
    {
        f = 0;

        fscanf (fl,"%d %d %s %s %s %s %s %s %s %s
", &nol, &no2, s1, s2, s3, s4, s5, s6, s7);
        //printf("%d %d %s %s %s %s %s %s %s %s
", nol, no2, s1, s2, s3, s4, s5, s6, s7);
        fscanf (f2,"%f %f
", x3, &y3);
        for (j=0; j<no2-1; j++)
        {
            fscanf (f1,"%f %f\n", &x4, &y4);
            dx1 = x2-x1;
            dy1 = y2-y1;
            dx2 = x4-x3;
            dy2 = y4-y3;
            m = dx1*dy2-dy1*dx2;
            if (m != 0)
            {
                ml = x1*dy1-y1*dx1;
                m2 = x3*dy2-y3*dx2;
                x = (dx1*m2-dx2*ml)/m;
                y = (dy1*m2-dy2*ml)/m;
                if ((x>=x3 && x<x4 && y>y3 && y<y4) ||
                    x=x3 && x=x4 && y>y3 && y<y4) ||
                    x>x3 && x=x4 && y<y3 && y=y4) ||
                    x=x3 && x=x4 && y<y3 && y=y4) &&
                    y<y1)
                {
                    f = f+1;
                }
            }
        } x3 = x4;
        y3 = y4;
    }
if ( (f%2) != 0 )
{
    w = 10.0;
    i = set;
}
else
    w = 0.0;

    //printf("w=%.0f\n", w);
    fclose(f1);
    fclose(f2);
    return w;

//-------------------------------------------------------------------------------
DISTANCE FUNCTION

// This function finds the distance between two points when the coordinates of both points
// are known.
float distance (float x1, float y1, float x2, float y2)
{
    float dist;
    dist = sqrt (pow ((x1-x2), 2) + pow ((y1-y2), 2));
    return (dist);
}

//---------------------------------------------
INPUTS FUNCTION

// This function inputs the required initial information into the main program

void inputs ()
{
    cout << "The Range of Easting is between 295100 and 304900.\n";
    cout << "Enter the Easting of the starting point : ";
    do
    {
        cin >> x_start;
        if (295100 >= x_start || x_start >= 304900)
            cout << "Out of Range! Try again : ";
    }
    while (295100 >= x_start || x_start >= 304900);
    cout << "The Range of Northing is between 6153100 and 6165900.\n";
    cout << "Enter the Northing of the starting point : ";
    do
    {
        cin >> y_start;
        if (6153100 >= y_start || y_start >= 6165900)
            cout << "Out of Range! Try again : ";
    }
    while (6153100 >= y_start || y_start >= 6165900);
    cout << "The Range of Easting is between 295100 and 304900.\n";
    cout << "Enter the Easting of the ending point : ";
    do
    {
        cin >> x_end;
        if (295100 >= x_end || x_end >= 304900)
            cout << "Out of Range! Try again : ";
    }
    while (295100 >= x_end || x_end >= 304900);
    cout << "The Range of Northing is between 6153100 and 6165900.\n";
    cout << "Enter the Northing of the ending point : ";
    do
    {
        cin >> y_end;
        if (6153100 >= y_end || y_end >= 6165900)
            cout << "Out of Range! Try again : ";
    }
    while (6153100 >= y_end || y_end >= 6165900);
    cout << "Enter the distance for any two points : ";
    cin >> 1;
    cout << "\n";
    cout << "1 = Highway\n";
    cout << "2 = First order road \n";
    cout << "3 = Second order road \n";
    cout << "4 = Third order road \n\n";
    cout << "Enter the type of the road: ";
    do
    {
        cin >> s;
        if ( s!=1 && s!=2 && s!=3 && s!=4 )
            cout << "Not a correct selection! Try again: ";
    }
    while ( s!=1 && s!=2 && s!=3 && s!=4 );
    cout << "Enter the width of the road : ";
    cin >> road_width;
cout << "Enter the average cost of construction per meter : ";
cin >> cost_construction;

cout << "Enter the average cost of cutting per cubic meter : ";
cin >> cost_cutting;

cout << "Enter the average cost of filling per cubic meter : ";
cin >> cost_filling;
cout << "n";
cout << "n";

//------------------------------------------------------------------------------------------
PARALLEL_POL FUNCTION

// This function makes a (part of) polygon parallel to the sides of another polygon

void parallel_pol ()
{
    int nol, no2, set, i, j, jj, k, kk, kkk, kkkk, no[5][2];
    int start1, end1, start2, end2, p1, p2;
    char s1[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];
    float x, y, x3, x4, y3, y4, max, ymax, ymax, cross[10][2];
    float m, ml, m2, dxl, dyl, dy2, g, d1, d2, d3, d4;
    float xtemp, ytemp, xetemp, yetemp, xstart, ystart, x4temp, y4temp, temp;
    float temp0[4][2], temp1[4][1], pol[100][2], pol1[100][2], pol2[100][2];
    float dist, dist1, dist2, x4temp, ytemp, h_start;

    FILE *fl, *f2;
    fl = fopen ("buildup.vec", "r");
    f2 = fopen ("buildup.veh", "r");

    fscanf (fl, "%s\n", s1);
    printf ("%s\n", s1);
    fscanf (f2, "%s %s %s %s %s %s\n", s1, s2, s3, s4, s5, s6);
    printf ("%s %s %s %s %s %s\n", s1, s2, s3, s4, s5, s6);
    fscanf (f2, "%s %d\n", s1, &set);
    k = 0;
    kkk = 0;
    for (i=0; i<set; i++)
    {
        kk = 0;
        fscanf (fl, "%d %d %s %s %s %s %s %s %s\n", inol, &no2, si, s2, s3, s4, s5, s6, s7);
        fscanf (fl, "%f %f\n", 4x3, 4y3);
        printf ("%f %f\n", x3, y3);
        dxl = x_end-x_start;
        dyl = y_end-y_start;
        for (j=0; j<no2-1; j++)
        {
            fscanf (fl, "%f %f\n", 4x4, 4y4);
            dx2 = x4-x3;
            dy2 = y4-y3;
            m = dx1*dy2-dy1*dx2;
            if (m != 0)
            {
                ml = x_start*dyl-y_start*dx1;
                m2 = x3*dy2-y3*dx2;
                x = (dx1*m2-dx2*ml)/m;
                y = (dyl*m2-dy2*ml)/m;
                xstart = x_start;
                ystart = y_start;
                xetemp = x_end;
                yetemp = y_end;
                xtemp = xstart;
                ytemp = ystart;
                x3temp = xetemp;
                y3temp = yetemp;
                x4temp = x4temp;
            }
        }
    }
}
y4temp = y4;
if (xstemp > xetemp)
{
    temp = xstemp;
    xstemp = xetemp;
    xetemp = temp;
}
if (ystemp > yetemp)
{
    temp = ystemp;
    ystemp = yetemp;
    yetemp = temp;
}
if (x3temp > x4temp)
{
    temp = x3temp;
    x3temp = x4temp;
    x4temp = temp;
}
if (y3temp > y4temp)
{
    temp = y3temp;
    y3temp = y4temp;
    y4temp = temp;
}
if (x >= xstemp && x <= xetemp && y >= ystemp && y <= yetemp &&
    x >= x3temp && x <= x4temp && y >= y3temp && y <= y4temp)
{
    cross[k][0] = x;
    cross[k][1] = y;
    if (k==0)
    {
        tempO[0][k] = x3;
        tempO[1][k] = y3;
        tempO[2][k] = x4;
        tempO[3][k] = y4;
        printf("%f
",tempO[0][k],tempO[1][k]);
        printf("%f
",tempO[2][k],tempO[3][k]);
    }
    if (k==1)
    {
        tempO[0][k] = x3;
        tempO[1][k] = y3;
        tempO[2][k] = x4;
        tempO[3][k] = y4;
        printf("%f
",tempO[0][k],tempO[1][k]);
        printf("%f
",tempO[2][k],tempO[3][k]);
    }
    k += 1;
    kk += 1;
    kkk = kk;
    if (kk == 2)
    {
        no[kkk][0] = no1;
        no[kkk][1] = no2;
        xstemp, xetemp,
        ystem, yetemp,
        x3temp, x4temp,
        y3temp, x4temp,
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```c
kkk += 1;
    i = no2;
}
    x3 = x4;
    y3 = y4;
}

if (kkk>1)
    kkk = 0;
    rewind (f1);
    rewind (f2);
    printf ("%d %d\n", no[0][0], no[0][1]);
    printf ("%d\n", kkk);
    fscanf (f1,"%s \n", s1);

while (kkk < 1) // 1 should be changed by 5 later.
    for (i=0; i<set; i++)
    s2, s3, s4, s5, s6, s7);
    fscanf (fl,"%d %d %s %s %s %s %s %s
", &nol, &no2, s1,
    printf ("nol-%d no2-%d\n", noi, no2);
    for (j=0; j<no2; j++)
    {
        fscanf (fl,"%f %f\n", &x3, &y3);
        if (no[kkk][0] —  noi)
        pol[0][0] = noi;
        pol[0][1] = no2;
        if (j==0)
            printf ("%.0f %.0f\n", pol[0][0],
        pol[j+1][0] = x3;
        pol[j+1][1] = y3;
        printf ("%.3f %.3f %.3f %.3f\n", pol[j-1][0],pol[j-1][1], pol[j][0],
        pol[j][1]);
    }
    kkk += 1;

    dist = 0;
    for (j=1; j<pol[0][1]; j++)
    dist += distance (pol[j][0], pol[j][1], pol[j+1][0], pol[j+1][1]);
    printf ("%d\n", dist);
    printf ("%.3f %.3f %.3f %.3f\n", pol[j-1][0],pol[j-1][1], pol[j][0],
    pol[j][1]);

for (j=1; j<=pol[0][1]; j++)
    {  if (tempO[3][0]==pol[j][0] && tempO[3][1]==pol[j][1])
        start2 = j;
    else
        end2 = j;
    printf ("start2=%d end2=%d\n", start2, end2);
    }
    for (j=1; j<pol[0][1]; j++)
    {  if (tempO[2][0]==pol[j][0] && tempO[3][0]==pol[j][1])
        start1 = j;
    else
        end1 = j;
    printf ("start1=%d end1=%d\n", start1, end1);
    }
```

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for (j=start1; j<pol[0][1]; j++)
    for (j=start1 & & j<=end1)
        i++;
        pol[i][0] = pol[j][0];
        pol[i][1] = pol[j][1];
    }  
    }  
    }  
    if (start2<end2)
    {
        for (j=start1; j<pol[0][1]; j++)
            for (j=start2 & & j<=end2)
                k++;
                pol2[k][0] = pol[j][0];
                cout << "\n pol2=" << pol2[k][0] << " pol=" << pol[j][0];
                pol2[k][1] = pol[j][1];
                cout << "\n pol2=" << pol2[k][1] << " pol=" << pol[j][1];
        }  
        }  
        }  
        else
        {
            for (j=start2; j<pol[0][1]; j++)
                for (j=start2 & & j<=end2)
                    k++;
                    pol2[k][0] = pol[j][0];
                    cout << "\n pol2=" << pol2[k][0] << " pol=" << pol[j][0];
                    pol2[k][1] = pol[j][1];
                    cout << "\n pol2=" << pol2[k][1] << " pol=" << pol[j][1];
            }  
            }  
            }  
            
            pol2[0][0] = i+1;
            pol2[0][1] = k+1;
            pol2[1][0] = cross[0][0];
            pol2[1][1] = cross[0][1];
            pol2[i+1][0] = cross[i][0];
            pol2[i+1][1] = cross[i][1];
            pol2[2][0] = cross[0][0];
            pol2[2][1] = cross[0][1];
            pol2[3][0] = cross[0][0];
            pol2[3][1] = cross[0][1];
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\[
pol2[k+1][0] = cross[1][0];
pol2[k+1][1] = cross[1][1];
\]

for (i=0; i<=poll[0][1]; i++)
    printf ("%f %f
", poll[i][0], poll[i][1]);

for (k=0; k<=pol2[0][1]; k++)
    printf ("%f %f
", pol2[k][0], pol2[k][1]);

dist1 = 0;
for (j=1; j<poll[0][1]; j++)
dist1 += distance (pol[j][0], pol[j][1], pol[j+1][0], pol[j+1][1]);

printf ("dist1=%.3f\n", dist1);
dist2 = dist - dist1;

printf ("dist2=%.3f\n", dist2);

pl = poll[0][1];
p2 = pol2[0][1];
d1 = distance (x_start, y_start, poll[1][0], poll[1][1]);
d2 = distance (x_start, y_start, poll[pl][0], poll[pl][1]);
d3 = distance (x_start, y_start, pol2[1][0], pol2[1][1]);
d4 = distance (x_start, y_start, pol2[p2][0], pol2[p2][1]);

if (dist1<=dist2 && d1<=d2)
    for (i=1; i<poll[0][1]; i++)
        temp=distance (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);

    if (i==1 || i==(poll[0][1]-1))
        temp += 100;
    else
        temp += 200;

    g = azimuth (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);

    g *= PI/180;
x_start += temp*sin(g);
y_start += temp*cos(g);
h_start = findz (x_start, y_start);

printf (f3, "%.3f %.3f %.3f\n", x_start, y_start, h_start);

printf ("==> x=%.3f y=%.3f
", x_start, y_start, h_start);

}

else if (dist1<=dist2 && d1>d2)
    for (i=poll[0][1]; i>0; i--)
        temp=distance (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);

    if (i==1 || i==(poll[0][1]-1))
        temp += 100;
    else
        temp += 200;

    g = azimuth (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);

    g *= PI/180;
x_start += temp*sin(g);
y_start += temp*cos(g);
h_start = findz (x_start, y_start);

printf (f3, "%.3f %.3f %.3f\n", x_start, y_start, h_start);

printf ("==> x=%.3f y=%.3f
", x_start, y_start, h_start);

}

else if (dist1>dist2 && d3<d4)
    for (i=1; i<pol2[0][1]; i++)
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```c
pol2[i+1][1]);
if (i==1 || i== (pol2[0][1]-1))
    temp += 100;
else
    temp += 200;
g = azimuth (pol2[i][0], pol2[i][1], pol2[i+1][0],
pol2[i+1][1]);
g *= PI/180;
x_start += temp*sin(g);
y_start += temp*cos(g);
h_start = findz (x_start, y_start);
fprintf (f3, "%.3f %.3f %.3f
", x_start, y_start, h_start);
printf("====> x=%.3f y=%.3f
",x_start,y_start,h_start);
```

```c
else if (dist1>dist2 && d3>d4)
    for (i=pol2[0][1]; i>0; i--)
    {
        temp=distance (pol2[i][0], pol2[i][1], pol2[i+1][0],
pol2[i+1][1]);
        if (i==1 || i==(pol2[0][1]-1))
            temp += 100;
        else
            temp += 200;
g = azimuth (pol2[i][0], pol2[i][1], pol2[i+1][0],
pol2[i+1][1]);
g *= PI/180;
x_start += temp*sin(g);
y_start += temp*cos(g);
h_start = findz (x_start, y_start);
fprintf (f3, "%.3f %.3f %.3f
", x_start, y_start, h_start);
printf("====> x=%.3f y=%.3f
",x_start,y_start,h_start);
```
PREP FUNCTION

// This function finds the distance between a point and a line.

float prep (float x_start, float y_start, float x_end, float y_end, float xl, float yl)
{
    float dxl, dyl, ml, m2, dist;
    int i;
    dxl = x_end-x_start;
    dyl = y_end-y_start;
    ml = dyl/dxl;
    m2 = -1/ml;
    xint = (ml*x_end-m2*xl+yl-y_end)/(ml-m2);
    yint = ml*(xint-x_end)+y_end;
    dist = distance (xint, yint, xl, yl);
    return (dist);
}

//-------------------------------------------------
MAX100 FUNCTION

// This function finds a point a certain meter from the function parallel_pol (100 meters
// here).

void max100 (float xintx, float yintx, float xm, float ym)
{
    float m, max;
    printf ("##xintx»%f ##yintx*%f\n", xintx, yintx);
    printf ("$$xm»%f $$ym~%f\n", xm, ym);
    max = distance (xm, ym, xintx, yintx);
    printf ("$$max=%f\n", max);
    m = (ym-yintx)/(xm-xintx);
    x100 = sqrt ((pow (max, 2)+10000)/(pow (m,2)+1))+xintx;
    y100 = m*(x100-xint)+yintx;
    //parallel_pol (x_start, y_start, x100, y100);
}

//........................................................................................................

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CROSSI PROGRAM

// This program finds the intersection point of the road and the buffered residential // areas.

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <graphics.h>
#include <conio.h>
#include <iostream.h>
#include <ctype.h>
#include <time.h>
#include <string.h>

#define PI 3.14159257


int lines (FILE *file);

main()
{
    int nol, no2, set, i, j, j1, k;
    int NULL, p1, p2;

    char s1[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];

    double x, y, x3, y3, x4, y4, max, xmin, xmax;
    double m, ml, m2, dx1, dy1, dy2, w, g, d1, d2, d3, d4;

double xtemp, ytemp, x3temp, y3temp, x4temp, y4temp, temp;

double x_road[100], y_road[100], x_source[100], y_source[100];

    double xl, yl, xtemp, ytemp;

    fpl = fopen("buildbuf.vec","r");
    fp2 = fopen("buildbuf.veh","r");
    fp3 = fopen("lines.vec","r");
    fp4 = fopen("sourcel.txt","w");

    fscanf (fp2,"%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    printf("%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    fscanf (fp2,"%s %s
", si, s2);
    printf("%s %s
", si, s2);
    fscanf (fp2,"%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    printf("%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    fscanf (fp2,"%s %d
", si, &set);

    nil = lines (fp3);
    rewind (fp3);

    for (k=0; k<nll; k++)
    {
        fscanf (fp3, "%lf %lf
", &x3, &y3);
        x_road[k] = x3;
        y_road[k] = y3;
    }

    for (k=0; k<nll; k++)
    {
        dx1 = x_road[k+1]-x_road[k];
        dy1 = y_road[k+1]-y_road[k];

        for (i=0; i<set; i++)
        {
            fscanf (fpl, "%d %d %s %s %s %s
", &nol, &no2, s1, s2, s3, s4, s5, s6);
            printf("%d %d %s %s %s %s
", &nol, &no2, s1, s2, s3, s4, s5, s6);
            fscanf (fpl, "%lf %lf
", &x4, &y4);
            printf("%lf %lf
", &x4, &y4);
        }

        for (j=0; j<no2-1; j++)
        {
            fscanf (fpl, "%lf %lf
", &x4, &y4);
            printf("%lf %lf
", &x4, &y4);
        }
    }

    nll = lines (fp3);
    rewind (fp3);
}
\[
dx_2 = x_4 - x_3; \\
dy_2 = y_4 - y_3; \\
m = dx_1 * dy_2 - dy_1 * dx_2; \\
\]

if (m != 0) 
{ 
    \[
    m_1 = x_\text{road}[k] * dy_1 - y_\text{road}[k] * dx_1; \\
m_2 = x_3 * dy_2 - y_3 * dx_2; \\
x_1 = (dx_1 * m_2 - dx_2 * m_1) / m; \\
y_1 = (dy_1 * m_2 - dy_2 * m_1) / m; \\
x_\text{stemp} = x_\text{road}[k]; \\
y_\text{stemp} = y_\text{road}[k]; \\
x_\text{etemp} = x_\text{road}[k+1]; \\
y_\text{etemp} = y_\text{road}[k+1]; \\
x_3\text{temp} = x_3; \\
y_3\text{temp} = y_3; \\
x_4\text{temp} = x_4; \\
y_4\text{temp} = y_4; \\
\]

if (x_\text{stemp} > x_\text{etemp}) 
{ 
    \[
    \text{temp} = x_\text{stemp}; \\
x_\text{stemp} = x_\text{etemp}; \\
x_\text{etemp} = \text{temp}; \\
\]
}

if (y_\text{stemp} > y_\text{etemp}) 
{ 
    \[
    \text{temp} = y_\text{stemp}; \\
y_\text{stemp} = y_\text{etemp}; \\
y_\text{etemp} = \text{temp}; \\
\]
}

if (x_3\text{temp} > x_4\text{temp}) 
{ 
    \[
    \text{temp} = x_3\text{temp}; \\
x_3\text{temp} = x_4\text{temp}; \\
x_4\text{temp} = \text{temp}; \\
\]
}

if (y_3\text{temp} > y_4\text{temp}) 
{ 
    \[
    \text{temp} = y_3\text{temp}; \\
y_3\text{temp} = y_4\text{temp}; \\
y_4\text{temp} = \text{temp}; \\
\]
}

if (x >= x_\text{stemp} \&\& x <= x_\text{etemp} \&\& \\
y >= y_\text{stemp} \&\& y <= y_\text{etemp} \&\& \\
x >= x_3\text{temp} \&\& x <= x_4\text{temp} \&\& \\
y >= y_3\text{temp} \&\& y <= y_4\text{temp}) 
{ 
    \[
    \text{printf} (fp4, "%.3f %.3f\n", x_\text{road}[k]); \\
\]
}

\[
\text{printf} (fp4, "%.3f %.3f\n", x, y); \\
\text{cout} << x << "\t" << y << "\n"; \\
\text{printf} (fp4, "%.3f %.3f\n", x_\text{road}[k+1]); \\
\]

\[
x_3 = x_4; \\
y_3 = y_4; \\
\]

rewind (fp1);

rewind (fp2);

fclose (fp1);
APPENDIX II

ROAD LOCATION COMPUTER PROGRAMS

fclose (fp2);
fclose (fp3);
fclose (fp4);

fp4 = fopen ("source1.txt","r");
nll = lines (fp4);
rewind (fp4);

for (i=0; i<nll; i++)
{
    fscanf (fp4, "%lf %lf\n", &x, &y);
x_source[i] = x;
y_source[i] = y;
    cout << x << "\t" << y << "\n";
}
fclose (fp4);

fp4 = fopen ("source1.txt","w");

fprintf (fp4, "%.3f %.3f\n", x_source[0], y_source[0]);

for (i=1; i<nll; i++)
{
    k = 0;
    for (j=0; j<i; j++)
    {
        if (x_source[i]==x_source[j] && y_source[i]==y_source[j])
            k += 1;
    }

    if (k == 0)
    {
        fprintf (fp4, "%.3f %.3f\n", x_source[i], y_source[i]);
        //cout << x_source[i] << "\t" << y_source[i] << "\n";
    }

    fclose (fp4);
    return (0);
}

//----------------------------------------------------------------------------------
LINES FUNCTION

// This function counts the number of lines in a file.

int lines (FILE *file)
{
    long nl = 0, c;
    while ((c = getc(file)) != EOF)
    {
        if (c == '\n')
            ++nl;
    }
    return nl;
}
ANGLE PROGRAM

/* This program calculate the angle of two lines when the Easting and Northing of three points is known (one point is common).

   A | X1
   Y1

   B | X2
   Y2

   C | X3
   Y3

*/

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include <ctype.h>
#include <graphics.h>
#include <iostream.h>

define PI 3.14159257

double azimuth (double xl, double yl, double x2, double y2);

main()
{
    double angle, x3, y3;
    cin >> xl;
    cout << "enter the Easting of the corner point: ";
    cin >> yl;
    cout << "enter the Northing of the corner point: ";
    cin >> x2;
    cout << "enter the Easting of the second point: ";
    cin >> y2;
    cout << "enter the Northing of the second point: ";
    cin >> x3;
    cout << "enter the Easting of the third point: ";
    cin >> y3;
    cout << "enter the Northing of the third point: ";
    angle = fabs(azimuth(xl, yl, x2, y2) - azimuth(xl, yl, x3, y3));
    printf("angle=%3f %.3f %.3f\n", angle, azimuth(xl, yl, x2, y2), azimuth(xl, yl, x3, y3));
}

//---------------------------------------------------------------------

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**AZIMUTH FUNCTION**

/* The following function calculates the azimuth of each segment of the road. */

```
/*
   double azimuth (double xl, double y1, double x2, double y2)
{
   double dx, dy, g;
   dx = x2-xl ;
   dy = y2-y1 ;
   if (dy == 0 && x2 >= xl)
      g = 90 ;
   else
      if (dy == 0 && x2 < xl)
         g = 270 ;
      else
         g = atan(dx/dy) ;
         g *= 180/PI ;
         if ((g*dx) == 0)
            if ( dx==0 && y2 >= y1)
               g = 0 ;
            else
               g += 180 ;
         if ((g*dx) < 0)
            g += 180 ;
         if (g <= 0 && dx < 0)
            g += 360 ;
   return (g);
}
*/
```
CROSS_POLYGON PROGRAM

// This function determine whether a line cross a polygon or not.

#include <stdio.h>
#include <math.h>
#define PI 3.14

float xint, yint, x100, y100, xs, ys, xe, ye, z, zz[14000];

void sort(float final[4][4]);
float findz(float x, float y);
float azimuth(float xl, float yl, float x2, float y2);
float distance(float xl, float yl, float x2, float y2);
float prep (float xs, float ys, float xe, float ye, float xl, float yl);
void maxlOO (float xmax, float ymax, float xint, float yint);

main()
{
    int nol, no2, set, i, j, jj, k, kk, kkk, no[5][2], start1, end1, start2, end2;
    char si[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];
    float x, y, x3, x4, y3, y4, max, xmax, ymax, cross[10][2];
    float m, ml, m2, dx1, dx2, dy1, dy2, w, g;
    float xstemp, ystemp, xetemp, yetemp, x3temp, y3temp, x4temp, y4temp, temp;
    float tempo[4][2], tempi[4][1], pol[100][2], poll[100][2], pol2[100][2];
    float dist, distl, dist2, xtemp, ytemp, hs;
    FILE *fpl, *fp2, *fp3;

    fpl = fopen("buildup.vec","r");
    fp2 = fopen("outf.txt","r");
    fp3 = fopen("temp.dat","w");

    for (i=0; i<13100; i++)
    {
        fscanf(fp2, "%f %f %f\n", &x, &y, &z);
        z[i] = z;
    }

    fscanf (fpl, "%s \n", si);
    fscanf (fp2, "%s %s\n", si, s2);
    fscanf (fpl, "%s %s %s %s %s %s\n", si, s2, s3, s4, s5, s6);
    fscanf (fp2, "%s %d\n", si, &set);/*

    set = 21;
    xs = 300800;
    ys = 6153300;
    xe = 301300;
    ye = 6153250;
    k = 0;
    kkk = 0;

    for (i=0; i<set; i++)
    {
        kk = 0;
        fscanf (fpl, "%d %d %s \n", &nol, &no2, si);
        fscanf (fpl, "%d %d \n", 4x1, 4y1);
        dx1 = xe-xs;
        dy1 = ye-ys;
        for (j=0; j<no2-1; j++)
        {
            fscanf (fpl, "%f %f %n", 4x4, 4y4);
            dx2 = x4-x3;

            ...
\[
dy_2 = y_4 - y_3; \\
m = dx_1 \cdot dy_2 - dy_1 \cdot dx_2; \\
\]
if \( m \neq 0 \) \{
\[
ml = xs \cdot dy_1 - ys \cdot dx_1; \\
m2 = x3 \cdot dy_2 - y3 \cdot dx_2; \\
\]
\[
x = (dx_1 \cdot m2 - dx_2 \cdot ml) / m; \\
y = (dy_1 \cdot m2 - dy_2 \cdot ml) / m; \\
\]
xstemp = xs; \\
ystemp = ys; \\
xetemp = xe; \\
yetemp = ye; \\
x3temp = x3; \\
y3temp = y3; \\
x4temp = x4; \\
y4temp = y4; \\
\]
if \( xstemp > xetemp \) \{
\[
temp = xstemp; \\
xstemp = xetemp; \\
xetemp = temp; \\
\]
\}
if \( ystemp > yetemp \) \{
\[
temp = ystemp; \\
ystemp = yetemp; \\
yetemp = temp; \\
\]
\}
if \( x3temp > x4temp \) \{
\[
temp = x3temp; \\
x3temp = x4temp; \\
x4temp = temp; \\
\]
\}
if \( y3temp > y4temp \) \{
\[
temp = y3temp; \\
y3temp = y4temp; \\
y4temp = temp; \\
\]
\}
if \( x >= xstemp \&\& x <= xetemp \&\& y >= ystemp \&\& y <= yetemp \&\& x >= x3temp \&\& x <= x4temp \&\& y >= y3temp \&\& y <= y4temp \) \{
\[
cross[k][0] = x; \\
cross[k][1] = y; \\
printf("%f %f
", cross[k][0], cross[k][1]); \\
if (k==0) 
\{
\[
temp0[0][k] = x3; \\
temp0[1][k] = y3; \\
temp0[2][k] = x4; \\
temp0[3][k] = y4; \\
printf("%f
", temp0[0][k],temp0[1][k]); \\
printf("%f
", temp0[2][k],temp0[3][k]); \\
\}
\]
\}
if (k==1)
\}
APPENDIX II
ROAD LOCATION COMPUTER PROGRAMS

```c
{ temp0[0][k] = x3; temp0[1][k] = y3; temp0[2][k] = x4; temp0[3][k] = y4; printf("%f\n",temp0[0][k],temp0[1][k]); printf("%f\n",temp0[2][k],temp0[3][k]); } k += 1; kk += 1;

if (kk == 2) { no[kkk][0] = no1; no[kkk][1] = no2; /*printf ("Polygon detected!\n"); printf ("%.0f %.0f %.0f %.0f\n",ystemp, xetemp, yetemp, xetemp, xetemp, yetemp, yetemp); printf ("X=\%.0f Y=\%.0f\n", x, y);*/ kkk += 1; i = no2;
}

x3 = x4; y3 = y4;

} }

kkk = 0;
rewind (fpl);
rewind (fp2);
printf ("%d\n",kkk);*/
scanf (fpl,"%s \n",sl):

while (kkk < 1) /* 1 should be changed by 5 later. */ { for (i=0; i<set; i++) {
      fscanf (fpl,"%d %d %s\n", &nol, &no2, si);
      /*printf ("%.0f %.0f %.0f %.0f\n", x3temp, x4temp, y3temp, x4temp);
     printf ("\nX=\%.0f Y=\%.0f\n", x, y.rgb;
     i = no2;
      }

} }

x3 = x4; y3 = y4;

}

kkk += 1;
}

dist = 0;
for (j=1; j<pol[0][1]; j++)
    dist += distance (pol[j][0], pol[j][1], pol[j+1][0], pol[j+1][1]);
printf ("dist=\%.3f\n", dist);
for (j=1; j<pol[0][1]; j++)
```
if (tempO[2][0]==pol[j][0] && tempO[3][0]==pol[j][1])
    start1 = j;
if (tempO[0][1]==pol[j][0] && tempO[1][1]==pol[j][1])
    endl = j;
printf ("start1=%d endl=%d\n", start1, endl);
for (j=1; j<=pol[0][1]; j++)
    if (tempO[2][j]==pol[j][0] && tempO[3][j]==pol[j][1])
        start2 = j;
    if (tempO[0][0]==pol[j][0] && tempO[1][0]==pol[j][1])
        end2 = j;
printf ("start2=%d end2=%d\n", start2, end2);
pol1[0][0] = 1;
pol2[0][0] = 1;
i = 1;
k = 1;
for (j=1; j<pol[0][1]; j++)
    if (j>=start1 && j<=endl)
    {
        i++;
poli[i][0] = pol[j][0];
poli[i][1] = pol[j][1];
    }
for (j=1; j<pol[0][1]; j++)
    if (j>=start2)
    {
        k++;
pol2[i][0] = pol[j][0];
pol2[i][1] = pol[j][1];
    }
for (j=1; j<pol[0][1]; j++)
    if (j<=end2)
    {
        k++;
pol2[i][0] = pol[j][0];
pol2[i][1] = pol[j][1];
    }
pol1[0][1] = i+1;
pol2[0][1] = k+1;
pol1[1][0] = cross[0][0];
pol1[1][1] = cross[0][1];
pol1[i+1][0] = cross[1][0];
pol1[i+1][1] = cross[1][1];
pol2[1][0] = cross[0][0];
pol2[1][1] = cross[0][1];
pol2[k+1][0] = cross[1][0];
pol2[k+1][1] = cross[1][1];
for (i=0; i<=pol1[0][1]; i++)
    for (i=0; i<=pol2[0][1]; i++)
        dist1 = 0;
    for (j=1; j<pol1[0][1]; j++)
        dist1 += distance (pol[j][0], pol[j][1], pol[j+1][0], pol[j+1][1]);
printf ("dist1=4.3f\n", dist1);
dist2 = dist - dist1;
APPENDIX II

ROAD LOCATION COMPUTER PROGRAMS

```c
printf("dist2=%3f\n", dist2);
if (dist1<=dist2) {
    for (i=1; i<poll[0][1]; i++)
        temp=distance (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);
    if (i==1 || i==(poll[0][1]-1))
        temp += 100;
    else
        temp += 200;
    g = azimuth (poll[i][0], poll[i][1], poll[i+1][0], poll[i+1][1]);
    g *= PI/180;
    xs += temp*sin(g);
    ys += temp*cos(g);
    hs = findz (xs, ys);
    fprintf (fp3, "%.3f %.3f %.3f\n", xs, ys, hs);
    printf("<== \(x=%.3f\ y=%.3f\ z=%.3f\n\),xs,ys,hs);
}
if (distl>dist2) {
    for (i=1; i<pol2[0][1]; i++)
        temp=distance (pol2[i][0], pol2[i][1], pol2[i+1][0], pol2[i+1][1]);
    if (i==1 || i==(pol2[0][1]-1))
        temp += 100;
    else
        temp += 200;
    g = azimuth (pol2[i][0], pol2[i][1], pol2[i+1][0], pol2[i+1][1]);
    g *= PI/180;
    xs += temp*sin(g);
    ys += temp*cos(g);
    hs = findz (xs, ys);
    fprintf (fp3, "%.3f %.3f %.3f\n", xs, ys, hs);
    printf("===> \(x=%.3f\ y=%.3f\ z=%.3f\n\),xs,ys,hs);
}
fclose (fp1);
fclose (fp2);
```
/This program finds four points which have the minimum distance to the point we are going to find the elevation. Data from the result of change program are used here.

#include <stdio.h>
#include <stdlib.h>
#include <math.h>

void sort(double final[4][4]);

long lines (FILE *file);

main()
{
    double final[4][4], temp[4], w[4];
    double a1, a2, a3, a4, b, v;
    double x, y, z, xm, ym, zm;
    long i, j, k, l, nil, nl2;
    FILE *fpl, *fp2, *fp3;

    fpl = fopen("out9.txt", "r");
    fp2 = fopen("out9.dat", "r");
    fp3 = fopen("min9.txt", "w");

    nil = lines(fpl);
    rewind(fpl);

    nl2 = lines(fp2);
    rewind(fp2);

    for (l = 0; l < nl2; l++)
    {
        fscanf(fp2, "%lf %lf
", &xm, &ym);
        for (i = 0; i < 4; i++)
        {
            fscanf(fpl, "%lf %lf %lf
", &x, &y, &z);
            b = sqrt(pow((x - xm), 2) + pow((y - ym), 2));
        }
        sort(final);
    }

    for (i = 4; i < nil; i++)
    {
        fscanf(fpl, "%lf %lf %lf
", &x, &y, &z);
        b = sqrt(pow((x - xm), 2) + pow((y - ym), 2));
        if (temp[3] < final[3][3])
        {
            for (ii = 0; ii < 4; ii++)
            final[3][ii] = temp[ii];
        }
    }

    sort(final);

    v = 0;

    if (final[0][3] < 0.001)
    zm = final[0][2];
    else
    {
        for (i = 0; i < 4; i++)
        {
            temp[i] = 1 / (pow(final[i][3], 2));
            v = v + temp[i];
        }
    }
}

\[
v = v + temp[i];
\]
\[
zm = 0;
\]
for (i = 0; i < 4; i++)
{
    \[
w[i] = temp[i] / v;
    \]
    \[
zm = zm + w[i] * final[i][2];
    \]
    \[
\]
    fprintf(fp3, "%.3f %.3f %.3f\n", xm, ym, zm);
    printf("%.3f %.3f %.3f\n", xm, ym, zm);
    rewind(fp1);
}
fclose(fp1);
fclose(fp2);
fclose(fp3);
return 0;

void sort(double final[4][4])
{
    int i, j, k;
    double temp[4];
    for (j = 0; j < 4; j++)
        for (k = j + 1; k < 4; k++)
            if (final[j][3] > final[k][3])
                for (i = 0; i < 4; i++)
                    \[
temp[i] = final[j][i];
final[j][i] = final[k][i];
final[k][i] = temp[i];
\]
}
long lines (FILE *file)
{
    long nl, c;
    nl = 0;
    while ((c = getc(file)) != EOF)
        if (c == '\n')
            ++nl;
    return nl;
}
NOISE PROGRAM

// This program calculates the noise around selected points of a road

#include "include.h"
#include "function.h"
#include "func.c"
#define PI 3.14159257
FILE *f1, *f2, *f3, *f4;
float b_n_l ();
int set_source_z ();
main()
{
    long Q;
    int i, j, nll;
    float basic_noise_level, d;
    float noise1, ii, g, gl, g2;
    float d_prime, dist_corr, dist;
    float z_source, z_source1, z_source2, z_noise, noise;
    float x_source, x_source1, x_source2, y_source, y_source1, y_source2;
    float x_noise, y_noise;
    f3 = fopen ("noise.txt", "w");
    if (!f3) cerr << "Cannot open noise.txt for output";
    set_elev ();
    basic_noise_level = b_n_l ();
    nll = set_source_z ();
    f4 = fopen ("source.txt", "r");
    if (!f4) cerr << "Cannot open source.txt for input";
    fscanf (f4, "%f %f %f\n", &x_sourcel, &y_sourcel, &z_sourcel);
    for (j=1; j<nll; j++)
    {
        fscanf (f4, "%f %f %f\n", &x_source1, &y_source1, &z_source1);
        g = azimuth (x_sourcel, y_sourcel, x_source1, y_source1);
        d = distance (x_sourcel, y_sourcel, x_source1, y_source1);
        g -= 90;
        if (g<0)
            g += 360;
        for (l=100; l<d; l+=10)
        {
            for (g2=g; g2<=g+180; g2+=10)
            {
                if (g1>360)
                    g1 -= 360;
                ii = gl*PI/180;
                x_noise = x_source1+l*sin(ii);
                y_noise = y_source1+l*cos(ii);
            }
z_noise = findz(x_noise, y_noise);
printf("%.3f %.3f %.3f\n", x_noise, y_noise, z_noise);

if (dist < 4)
    dist = 4;

d_prime = sqrt(pow((dist+3.5), 2)+pow((z_sourcel-
    if (d_prime <= 13.5)
        dist_corr = 0;
    else
        dist_corr = -10*log10(d_prime/13.5);

noise = basic_noise_level+dist_corr;
fprintf(f3, "%.3f %.3f %.3f %.3f\n", x_noise, y_noise,

x_sourcel = x_source2;
y_sourcel = y_source2;
fclose(f3);
fclose(f4);
return(0);
}:///---------------------------------------------
APPENDIX II

ROAD LOCATION COMPUTER PROGRAMS

BASIC_NOISE_LEVEL FUNCTION

// This function calculates the Basic Noise Level
float b_n_l ()
{
    long Q;
    int road_class, road_surface;
    float basic_noise_level, P, G, V, TD, mean_speed_corr;
    float bitum_corr, concr_corr, corr;

cout << "\n\n";
cout << "Enter the total 18-hour traffic flow:\t";
cin >> Q;
cout << "\n";
    basic_noise_level = 29.1+10*log10(Q);

cout << "
1 = Freeway
2 = Highway
3 = Main road
4 = Second class road
5 = Third order road
6 = Local road
";
cout << "Enter the type of the road:\t";
do {
    cin >> road_class;
cout << "\n";
    if ( road_class != 1 && road_class != 2 && road_class != 3 && road_class != 4 && road_class != 5 && road_class != 6)
cout << "Not a correct selection! Try again:\t";
} while ( road_class != 1 && road_class != 2 && road_class != 3 && road_class != 4 && road_class != 5 && road_class != 6);
switch (road_class)
{
case 1:
    G = 4; // Maximum grade acceptable for freeways
    V = 110; // Average speed on freeways
    break;

case 2:
    G = 7; // Maximum grade acceptable for highways
    V = 100; // Average speed on highways
    break;

case 3:
    G = 9; // Maximum grade acceptable for first class roads
    V = 90; // Average speed on main roads
    break;

case 4:
    G = 12; // Maximum grade acceptable for second class roads
    V = 80; // Average speed on second class roads
    break;

case 5:
    G = 14; // Maximum grade acceptable for third class roads
    V = 70; // Average speed on third class roads
    break;

case 6:
    G = 17; // Maximum grade acceptable for local roads
    V = 60; // Average speed on local roads
    break;
}
}
cout << "Enter the percentile of heavy vehicles:\t";  
cin >> P;  
cout << "\n";

mean_speed_corr = (0.73+(2.3-1.15*P/100))*P/100*G;  
V += mean_speed_corr;

bitum_corr = 0;  
concr_corr = 0;

if (V>75)  
{
    cout << "1 = Bituminous\n";  
    cout << "2 = Concrete\n";
    cout << "Enter the type of the surface of the road:\t";
    do  
    {
        cin >> road_surface;  
        cout << "\n";
        if (road_surface!=1 && road_surface!=2)  
            cout << "Not a valid choice. Try again:\t";
    }  
    while (road_surface!=1 && road_surface!=2);
    cout << "Enter the depth of the surface of the road (in centemeter):\t";  
cin >> TD;  
TD /= 100;  
cout << "\n";

    switch (road_surface)  
    {
        case 1:  
            bitum_corr = 10*log10(20*TD+60)-20;  
            break;
        case 2:  
            concr_corr = 10*log10(90*TD+30)-20;  
            break;
    }
}

corr = 33*log10(V+40+500/V)+10*log10(1+5*P/V)-68.8+0.3*G;

basic_noise_level += corr+bitum_corr+concr_corr-10;

cout << "basic_noise_level\t=\t" << basic_noise_level << "\tdB(A)";  
cout << "\n";
return (basic_noise_level);
RIVER PROGRAM

// This program finds the intersection point of the road and the rivers.
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <graphics.h>
#include <conio.h>
#include <iostream.h>
#include <ctype.h>
#include <time.h>
#include <string.h>
#define PI 3.14159257

int lines (FILE *file);
float azimuth (float x1, float y1, float x2, float y2);

main()
{
    int nol, no2, set, i, ii, j, jj, k;
    int nil, pl, p2;
    char si[20], s2[20], s3[20], s4[20], s5[20], s6[20], s7[20];
    double x, y, x1, x2, x3, x4, y1, y2, y3, y4, max, xmin, ymax;
    double m, m1, m2, dxl, dy2, dy2, w, d1, d2, d3, d4;
    double xttemp, ytemp, xttemp, ytemp, yt, xt, ytemp, ytemp, ytemps, temp;
    double xtemp, ytemp, angle, bridge_length;

    fpl = fopen ("rivers.vec", "r");
    fp2 = fopen ("rivers.veh", "r");
    fp3 = fopen ("lines.vec", "r");
    fp4 = fopen ("bridge.txt", "w");
    clrscr();
    fscanf (fp2, "%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    fscanf (fp2, "%s %s
", si, s2);
    fscanf (fp2, "%s %s %s %s %s %s
", si, s2, s3, s4, s5, s6);
    fscanf (fp2, "%s %d
", si, set);
    nil = lines (fp3);
    rewind (fp3);
    ii = 0;
    fscanf (fp3, "%.1f %.1f
", &x, &y);
    for (k=0; k<nl-1; k++)
    {
        fscanf (fp3, "%.1f %.1f
", &x, &y);
        rewind (fp1);
        fscanf (fp1, "%.1f
", sl);
        //printf ("%.1f\n", sl);
        dxl = x2-x1;
        dy2 = y2-y1;
        for (i=0; i<set; i++)
        {
            fscanf (fp1, "%.1f %.1f %.1f %.1f %.1f
", &nol, &no2, s1, s2, s3);
            fscanf (fp1, "%.1f %.1f
", &x3, &y3);
            for (j=0; j<no2-1; j++)
            {
                fscanf (fp1, "%.1f %.1f
", &x4, &y4);
            }
dx2 = x4-x3;
d2y = y4-y3;
m = dx1*dy2-dyl*dx2;

if (m != 0)
{
    ml = x1*dyl-y1*dxl;
    m2 = x3*dy2-y3*dx2;
    x = (dxl*m2-dx2*ml)/m;
    y = (dyl*m2-dy2*ml)/m;
    xstemp = xl;
    ystemp = yl;
    xetemp = x2;
    yetemp = y2;
    x3temp = x3;
    y3temp = y3;
    x4temp = x4;
    y4temp = y4;

    if (xstemp > xetemp)
    {  
        temp = xstemp;
        xstemp = xetemp;
        xetemp = temp;
    }

    if (ystemp > yetemp)
    {  
        temp = ystemp;
        ystemp = yetemp;
        yetemp = temp;
    }

    if (x3temp > x4temp)
    {  
        temp = x3temp;
        x3temp = x4temp;
        x4temp = temp;
    }

    if (y3temp > y4temp)
    {  
        temp = y3temp;
        y3temp = y4temp;
        y4temp = temp;
    }

    if (x >= xstemp && x <= xetemp && y >= ystemp && y <= yetemp && x >= x3temp && x <= x4temp && y >= y3temp && y <= y4temp)
    {  
        ii += 1;
        angle = fabs(azimuth(x,y,x3,y3) -
        printf(fp4, "%.3f %.3f \n", x, y);
        cprintf("The location of Bridge %d: \n", ii);
        cprintf("%.3fE %.3fN \n", x, y);
        textcolor(8);
        textbackground(7);
        cprintf("The angle between the river and the 
        if (180<angle && angle<=360)
        angle -= 180;
        printf("%.3fE \n", angle);
    }
}

azimuth(x,y,xstemp,ystemp));
angle *= PI/180;
bridge_length = /*river_width*/50/sin(angle);
textcolor(1);
textbackground(2);
cprintf("The length of the bridge:");
cprintf("%.3fm\n", bridge_length);
cprintf("\n");
}
x3 = x4;
y3 = y4;
}
x1 = x2;
y1 = y2;
}
return (0);

//--------------------
APPENDIX III

Road Traffic Noise-Overview

The importance of living and working in quiet areas and the awareness of the public concerning noise emission, especially by road transport systems, has resulted in applying regulations for highway planning and design. Although these regulations differ from one country to another, and even from one situation to another, the general idea is to reduce noise pollution to an acceptable level.

Australian Standard (AS 2702 1984) specifies the procedures to be used for the measurement of road traffic noise. The important variables which will determine the level of the noise from traffic are total vehicle flow rate; vehicle speed; percentage of heavy vehicles; gradient and surface of road; type of ground surface; presence of a barrier; reflection from nearby surfaces.

While there is no specific Australian regulation or standard, which specifies an acceptable level from traffic noise, The NSW State Pollution Control Commission has released some environmental goals. These specify a maximum $L(A10)(18 \text{ hours})$ of 60 dB(A) at 1m from a residential facade or other noise sensitive locations.

Here the only noise of concern is traffic noise and not the noise generated during road construction. To this end, two factors are of concern, the source vehicles of the noise
and the receiver that is normally a residential area. The existing level of noise, emitted from the road traffic, should be determined with regard to its traffic flow, the composition of vehicles (percentage of heavy vehicles), mean speed, gradient of the road and road surface. Any increase in noise level associated with future development such as increase in the amount of traffic volume should be taken into account as well.

The following stages are normally followed through to predict the noise level at a receptor point from a road scheme.

1. Divide the road into one or more segments such that the variation of noise within the segment is small.

2. Calculate the basic noise level for each of these road segments.

The basic noise level at a reference distance of 10 m away from the nearside carriage way edge may be calculated as indicated below. The distance of 10 m is arbitrary and can be changed to other distances with different numerical values of constants appearing in certain of the prediction equations.

Basic noise level is calculated when mean traffic speed \( V = 75 \text{ km/hr} \); percentage of heavy vehicles \( P = 0 \) and the gradient of road \( G = 0 \); from Eqs. 1 and 2;

\[
\text{Basic noise level} = L_{10} \text{ (hourly)} = 42.2 + 10 \log_{10} q \quad \text{(dB(A))} \quad (A3-1)
\]

(Calculation of Road Traffic Noise, 1988)

where \( q \) is the total hourly traffic flow.
Basic noise level = $L_{10} \ (18\text{-hour}) = 29.1 + 10 \log_{10} Q, \ (\text{dB}(A))$ \hspace{1cm} (A3-2)

(Calculation of Road Traffic Noise, 1988)

where $Q$ is the total 18-hour traffic flow.

The following correction should apply to the basic noise level to determine the actual basic noise level, depending on the mean traffic speed $V$, percentage of heavy vehicles $P$, and the gradient $G$, which are different from those mentioned above.

$\text{Correction} = 33 \log_{10} (V+40\left(\frac{500}{V}\right)) + 10 \log_{10} (1+\left(\frac{5P}{V}\right)) - 68.8 + 0.3G, \ (\text{dB}(A)) \hspace{1cm} (A3-3)$

(Calculation of Road Traffic Noise, 1988)

Therefore, the actual basic noise level is $L_{10} + \text{Correction}$.

Depending the class of road, suitable speeds are assigned to them.

Table 1 illustrates the road classifications and their traffic speed when $G = 0$ and $P = 0$. Any traffic speed between two limits can be assumed as the upper limit and further calculation can be carried out on that basis.
Table A3-1  Road classification scheme and the relevant speed (Calculation of Road Traffic Noise, 1988)

<table>
<thead>
<tr>
<th>Road classification</th>
<th>Mean traffic speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeways</td>
<td>110</td>
</tr>
<tr>
<td>Highways</td>
<td>100</td>
</tr>
<tr>
<td>Main roads</td>
<td>90</td>
</tr>
<tr>
<td>Second class roads</td>
<td>80</td>
</tr>
<tr>
<td>Third class roads</td>
<td>70</td>
</tr>
<tr>
<td>Local roads</td>
<td>60</td>
</tr>
</tbody>
</table>

If values other than $G = 0$ and $P = 0$ are used, the mean speeds from Table A3-1 require the following correction, $\Delta V$, and should be applied to the mean speed in Eq. (A3-3).

$$\Delta V = [0.73 + (2.3 - \frac{1.15P}{100}) \frac{P}{100}] G, \text{ (km/hr)}$$

(Calculation of Road Traffic Noise, 1988)

3. Road surface correction

When the speed of the vehicle is more than 75 km/hr, the following corrections apply.

For bituminous surfaces:

$$\text{Correction} = 10 \log_{10} (20 TD + 60) - 20, \text{ (dB(A))}$$
(Calculation of Road Traffic Noise, 1988)

For concrete surfaces:

\[
\text{Correction} = 10 \log_{10} (90 \text{ TD} + 30) - 20, \quad (\text{dB(A)}) \quad (A3-6)
\]

(Calculation of Road Traffic Noise, 1988)

where TD is the texture depth in meters.

For both surface types, when the speed is less than 75 km/hr, 1 dB(A) should be subtracted from the basic noise level, (Eqs. 1 or 2). For other road surfaces, 3.5 dB(A) should be subtracted from the basic noise level for all traffic speeds (Calculation of Road Traffic Noise, 1988).

4. Propagation

The effects of distance from the source line and the nature of the ground and screening from any intervening obstacles cause further correction to the basic noise level and the amount of noise received by the receiver.
A distance correction is calculated as:

\[
\text{Correction} = -10 \log_{10}(\frac{d'}{13.5}), \quad (\text{dB(A)})
\]  \hspace{1cm} (A3-7)

(Calculation of Road Traffic Noise, 1988)

where:
d' = the shortest slant distance from the source position (Fig A3-1).

\[ d' = \left( (d + 3.5)^2 + h^2 \right)^{\frac{1}{2}}, \quad (\text{dB(A)}) \quad (A3-8) \]

where \( d \) is the horizontal distance of receiver from the edge of nearest carriage way, 0.5 m above the road level (the height of the receiver) (Fig. A3-1).

This equation is valid for \( d \geq 4 \text{ m} \) (Fig. A3-1).

When \( d \) is less than 4 m, it is regarded as 4 m.

5. Potential barrier correction

Another correction that normally applies to the basic noise level is the potential barrier correction. The potential barrier correction applies when a barrier exists between effective source position and receiver.

Potential barrier correction = \( A = A_0 + A_1 x + A_2 x^2 + A_3 x^3 + \ldots + A_n x^n \) \quad (A3-9)

where \( x = \log_{10} \delta \) \quad (A3-10)

(Calculation of Road Traffic Noise, 1988)

and the path difference \( \delta \) is the difference in distance between the diffracted and direct rays in meters (\( \delta = a + b - c \)) as depicted in Fig. A3-2.
The coefficients $A_i$ in Eq. A3-9 can be obtained from Table A3-2. Table A3-4 provides the amount of A when $x$ is outside the range of validity in Table A3-2.

Table A3-2  Coefficients for potential barrier correction (Calculation of Road Traffic Noise, 1988)

<table>
<thead>
<tr>
<th></th>
<th>Shadow zone</th>
<th>Illuminated zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_0$</td>
<td>-15.4</td>
<td>0.0</td>
</tr>
<tr>
<td>$A_1$</td>
<td>-8.26</td>
<td>+0.109</td>
</tr>
<tr>
<td>$A_2$</td>
<td>-2.787</td>
<td>-0.815</td>
</tr>
<tr>
<td>$A_3$</td>
<td>-0.831</td>
<td>+0.479</td>
</tr>
<tr>
<td>$A_4$</td>
<td>-0.198</td>
<td>+0.3284</td>
</tr>
<tr>
<td>$A_5$</td>
<td>+0.1539</td>
<td>+0.04385</td>
</tr>
<tr>
<td>$A_6$</td>
<td>+0.12248</td>
<td></td>
</tr>
<tr>
<td>$A_7$</td>
<td>+0.02175</td>
<td></td>
</tr>
</tbody>
</table>

Range of validity for $x$: $-3 \leq x \leq +1.2$ for the illuminated zone and $-4 \leq x \leq 0$ for the shadow zone.
The shadow and illuminated zones, used in Table A3-2 and A3-3 are described as follows (Fig. A3-2):

Table A3-3 Potential barrier correction, outside the range of validity for x in Table A3-2 (Calculation of Road Traffic Noise, 1988)

<table>
<thead>
<tr>
<th>Shadow zone</th>
<th>Illuminated zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>For ( x &lt; -3 ) ( A = -5 )</td>
<td>For ( x &lt; -4 ) ( A = -5 )</td>
</tr>
<tr>
<td>For ( x &gt; 1.2 ) ( A = -30 )</td>
<td>For ( x &gt; 0 ) ( A = 0 )</td>
</tr>
</tbody>
</table>

Shadow zone: \[
\frac{h_o - h_s}{h_R - h_s} > \frac{D_{SO}}{D_{SR}} \] (Fig. A3-2)

Illuminated zone: \[
\frac{h_o - h_s}{h_R - h_s} < \frac{D_{SO}}{D_{SR}} \] (Fig. A3-2)

where \( h_s, h_R \) and \( h_o \) are the height of source, receiver and intervening object respectively. \( D_{SO} \) is the horizontal distance between the source and intervening object, and \( D_{SR} \) is the horizontal distance between source and receiver.

6. Correction for ground absorption

The correction for ground absorption as a function of horizontal distance from the edge of nearest carriage way \( d \) (the distance from the receiver to the edge of nearest carriage way), the average height of propagation \( H \), and the proportion of absorbent
ground I, are computed from the following equations, where all distances are measured in meters.

If \(0.75 \leq H < \frac{d + 5}{6}\)
\[
\text{Correction} = 5.2 \cdot I \cdot \log_{10}(\frac{6H - 1.5}{d + 3.5}), \text{(dB(A))} \quad (A3-11)
\]

If \(H < 0.75\)
\[
\text{Correction} = 5.2 \cdot I \cdot \log_{10}(\frac{3}{d + 3.5}), \text{(dB(A))} \quad (A3-12)
\]

If \(H \geq \frac{d + 5}{6}\)
\[
\text{Correction} = 0 \quad (A3-13)
\]

Valid for \(d \geq 4\) meters.

(Calculation of Road Traffic Noise, 1988)

The value of I varies between 0 and 1. When the ground cover is non-absorbent such as paved areas, rolled asphalt surfaces, water and so on, the value of I is 0 and no ground cover correction is applied. For areas with high ground absorbent ability, the value of I is set to 1. Areas covered with dense vegetation belong to this group. Other areas set the value of I somewhere between 0 and 1.

7. Calculation of combined noise levels

The final stage of the calculation process, to arrive at the predicted noise level, requires the combination of noise level contributions from all the source segments that
comprise the total road scheme. The combined noise level is given by the following equation (Calculation of Road Traffic Noise, 1988):

$$L = 10 \log_{10} \left[ \sum_{1}^{n} 10^{\frac{L_{n}}{10}} \right], \text{ (dB(A))} \quad (A3-14)$$

where $L_n$ is the noise level of the nth segment.

Other corrections, such as the angle of the inclination of the road and multiple screening, are not considered here.

To apply the above mentioned equations, the designer needs to know the regulations for highway planning and design regarding allowable noise levels. Table A3-4 and A3-5 are guidelines of such a noise from international textbooks. Table A3-4 describes the thresholds of acceptable highway noise abatement levels for the USA and Table A3-5 shows the abatement levels within buildings applies by Australia.
Table A3-4  Thresholds of acceptable highway noise abatement levels (Harris, 1979)

<table>
<thead>
<tr>
<th>Activity category</th>
<th>$L_{eq}$ (Exterior)</th>
<th>$L_{10}$ (Exterior)</th>
<th>Description of activity category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>57</td>
<td>57</td>
<td>Tracts of land in which severity and quiet are of extraordinary significance. Such areas include amphitheatres, particular parks, open spaces, or historic districts.</td>
</tr>
<tr>
<td>B</td>
<td>67</td>
<td>67</td>
<td>Picnic areas, recreation areas, playgrounds, active sports areas, parks which are not included in Category A, motels, hotels, public meeting rooms, schools, churches, libraries and hospitals.</td>
</tr>
<tr>
<td>C</td>
<td>72</td>
<td>72</td>
<td>Developed lands, properties, or activities not included in categories A or B above.</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>-</td>
<td>Undeveloped lands.</td>
</tr>
</tbody>
</table>

Table A3-5 Guidelines for acceptable noise levels within buildings (Nelson, 1987)

<table>
<thead>
<tr>
<th>Type of room</th>
<th>Background noise level dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential buildings:</td>
<td></td>
</tr>
<tr>
<td>Work area</td>
<td>30-40</td>
</tr>
<tr>
<td>Living room</td>
<td>30-35</td>
</tr>
<tr>
<td>Bedroom</td>
<td></td>
</tr>
</tbody>
</table>
### Table A3-6 Reduction in A-weighted sound level provided by various types of building structures (Harris, 1979)

<table>
<thead>
<tr>
<th>Building type</th>
<th>Window condition</th>
<th>Reduction dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Open</td>
<td>10</td>
</tr>
<tr>
<td>Light frame</td>
<td>Ordinary sash (closed)</td>
<td>20</td>
</tr>
<tr>
<td>Light frame</td>
<td>Storm windows</td>
<td>25</td>
</tr>
<tr>
<td>Masonry</td>
<td>Single glazed</td>
<td>25</td>
</tr>
<tr>
<td>Masonry</td>
<td>double glazed</td>
<td>35</td>
</tr>
</tbody>
</table>
Using Tables A3-4 and A3-5, and the previous equations, the designer is able to determine the appropriate road location resulting in a level of noise less than or equal to the acceptable threshold levels. In special cases, where the designed road cannot maintain the acceptable noise level and no other alternative variant is suitable, the construction of noise barriers is a feasible way to reduce the noise level. Well-designed barriers can provide a reduction of A-weighted sound level of 10 dB(A), and in some cases, 15 dB(A) or more (Harris, 1979).