UNISURV REPORT S24

DESIGN PRINCIPLES FOR LAND INFORMATION SYSTEMS

by

K. R. Bullock

Received August, 1983

SCHOOL OF SURVEYING
THE UNIVERSITY OF NEW SOUTH WALES
P.O. BOX 1
KENSINGTON, N.S.W. 2033
AUSTRALIA

National Library of Australia

CARD NO. and ISBN 0 85839 039 6

ABSTRACT

This study establishes principles for the design, implementation and operation of a computerised land information system (LIS). The LIS concept is formulated within the context of the evolution of cadastral systems, and the study views LIS development as the latest stage in this process. Based on a review and subsequent classification of cadastral systems in developed countries, the features of an efficient cadastral system are described. A major reassessment of the Australian cadastral survey system is proposed as a prerequisite for successful LIS development in the long term. The deficiencies of the present reform measures are identified and a new approach to the implementation of an integrated surveying and mapping system is suggested.

The major operational problems associated with the existing manually oriented land data organisation are outlined, and the ability of data base technology to overcome many of these deficiencies is explained. Based on these considerations, and on a review of LIS proposals overseas and in Australia, a conceptual model is formulated for a LIS designed to operate within the existing cadastral framework. The model envisages a centralised source of non-redundant property-based data which is created through the integration of separate land data systems.

Utilising this model, principles are established for the successful implementation and operation of an integrated LIS. The model is also used to establish principles for system design. In order for the LIS to efficiently perform its primary function of supporting land administration, legislative and administrative reforms are proposed in order to create the LIS Base File. A Valuation File, Register of Restrictions, and Unregistered Documents File are also proposed. Access via multiple reference keys contained in the Central and Peripheral Indexes is seen as essential for administrative applications. Design principles for planning applications are also discussed in terms of the ability of the LIS to process basic data into information for planning.

Design principles for each of the main LIS subsystems are described in detail. A primary identifier is chosen for the Central Index and Base File, and procedures are proposed for the creation of the Peripheral Indexes from existing data sources. Alternative methods for spatially referencing property-based data are reviewed and it is recommended that boundary, point and street segment references be made available through the Spatial Referencing System to ensure flexibility of system design. A flexible file design for the Digital Cadastral Data Base (DCDB) is formulated, and it is recommended that the DCDB serve as the base file for the Spatial Referencing System. A DCDB file creation procedure is devised which utilises spatial processing techniques to automatically create the necessary data linkages. The spatial referencing requirements for each of the land-related subsystems identified in the conceptual model are briefly discussed.

It is concluded that the development of an integrated LIS is technically feasible if existing data sources and administrative mechanisms are utilised, but that institutional problems are likely to be the major inhibiting factors to successful system development.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The writer would like to acknowledge the assistance and encouragement given by Dr.Bruce Forster in supervising this thesis, and to thank Mr.Ian Williamson, Mr.Lynn Holstein and Mr.David Close for their constructive criticism of the first draft.

Thanks are also extended to Ms.Gail Stebbings, Ms.Denise Gamble and Ms.Rosemary Flett for typing portions of the thesis.

1. THE EVOLUTION OF CADASTRAL SYSTEMS

1.1 Introduction

The central theme of this thesis is the fundamental relationship between man and the land, and the urgent need for contemporary society to understand and develop this relationship more fully by improving its existing public mechanisms for the provision of land information. As SIMPSON (1976) expressed it:

> "Land is the source of all material wealth. From it we get everything that we use or value, whether it be food, clothing, fuel, shelter, metal or precious stones. We live on the land and from the land, and to the land our bodies or our ashes are committed when we die. The availability of land is the key to our human existence, and its distribution and use are of vital importance".

Cadastral systems can be broadly defined as that machinery of government which records and maintains data about the location, extent, value, ownership and physical attributes of individual parcels of land, in support of efficient land administration. A parcel of land can be simply defined as a single, self-contained and continuous piece of land bounded throughout by other similar contiguous land parcels (see DOWSON & SHEPPARD, 1956). The principal subsystems of any cadastral system can be viewed as those agencies concerned with:

- the recording of basic descriptive information concerned with the valuation and assessment of land parcels
- the registration of ownership rights in land
- the delimitation and mapping of land parcels.

Cadastral systems throughout the world vary considerably in the degree of sophistication of these subsystems and in the organisational structures in which they operate. Irrespective of these differences and for the purposes of this thesis,

> "....it is important to establish that whatever the form and the character of the [cadastral system], its existence in an organized society is indispensible and that there are two powerful forces supporting it: the state as such, which must know the individual land owners or users for the purpose of managing the country and its resources, and the individual land owners or

> *users* who are looking for a clear and effective definition and protection of their property rights" (BLACHUT , 1973).

For nearly two centuries, existing cadastral systems have adequately fulfilled their traditional function with only minor reforms to long established procedures. In recent times, however, the pressure of accelerated population growth has intensified the competition for available land and in turn, has begun to focus attention on the capacity of existing cadastral arrangements to meet the requirements of contemporary planning and administration. Public administrators and planners are currently confronted with the dilemma of, on one hand, the need to exploit available land resources in order to satisfy the population's expectations for maintaining and improving its standard of living in material terms and on the other hand, the need to protect the environment from the effects of this process and from the effects of increasing urbanisation. The destruction of prime agricultural land for housing; the flooding of wilderness to provide power for industry; and the pollution of air and water by industrial and domestic waste are indicative of this dilemma.

In order to achieve better utilisation of land, the prompt provision of more reliable land information is required so that alternative plans can be formulated for the use of land, their expected results evaluated, and the approved plan successfully implemented. The degree to which better information gives rise to better planning is open to question. For example, DALE (1976) warns against assuming that the provision of better land information will necessarily lead to a better environment,

> "....partly because the decision making process may be concerned only to a limited extent with the factual possibilities and may be more concerned with political and social requirements.... The justification for better land information lies in the needs of land management and in the implementation of planning decision."

Nonetheless, the need for better information to service administration and planning has had two major impacts on the existing governmental data organisation.

Firstly, these demands have seriously restricted the ability of the cadastral system to efficiently perform its traditional function of providing basic information in support of land assessment and land transfer. Increasing reliance of governments on land taxation as a major revenue source and the exponential growth of land dealings since the second world war have placed enormous pressures on the efficiency of existing cadastral procedures. Increased governmental participation in the control of land use has also resulted in new restrictions being placed on the use of land which have further complicated these traditional procedures.

Secondly, the implementation of post war planning policies has given rise to a proliferation of governmental agencies each with a defined statutory function, and each collecting and maintaining its own data required to carry out its specific statutory responsibility. Data include not only details of the land itself, but on the individuals and activities associated with the land. Faced with increasing pressure "to utilize the total available information in his decision making" (TESSARI, 1974b) the public administrator must attempt to integrate these diverse data sources and coordinate data gathering processes. However, government agencies have tended to use and organise data according to their use or function, reflecting the particular responsibility of interest of each department. This conventional data organisation has resulted in many parallel data systems, each limited to the requirements it serves, and giving rise to data incompatibility and data duplication, both of which seriously restrict data integration and coordination.

This thesis argues that the measures currently being employed to improve the efficiency of the cadastral system can be made to form the basis of a public information system designed to intergrate other data sources outside the cadastral system, thereby overcoming many of the problems currently being experienced in the provision of land information. In preparation for the development of this land information system (LIS) cadastral reform measures must be implemented to transform the existing cadastral system (which is already an indispensible component of government machinery in its traditional role) into a more flexible and adaptable system. These reforms will include the automation of cadastral and other land records to enable the creation of a central property base file separate from existing cadastral records (but designed to operate within the existing cadastral framework) as the first stage of LIS development. Automation of cadastral maps is an important later stage of this development.

This chapter presents the development of land information systems as the latest stage in the evolution of cadastral systems. The land information system itself is viewed as one of several measures required to provide better land information, and is formulated within the framework of the need for more efficient land information management. It is not put forward as a total solution. The thesis adopts the view of McLAUGHLIN (1975) that the character and function of any cadastral system are a product of geographic, economic, biological, technical and socio-cultural factors such as agricultural development, the size and distribution of the population, the climate and the system of inheritance; and therefore that it is necessary to assess the transferability of cadastral operations from this viewpoint. It also adopts the view that cadastral systems are dynamic and that cadastral arrangements change in response to the changing needs of society. As DALE (1978) expressed it:

> "Cadastres and cadastral surveys are concerned with land, law and people. The relationship between these areas of concern is most apparent by the historical perspective where one may observe the evolution of the landscape through changes in land use and the adaption of laws and the attitudes of people to the changing times and conditions".

A classification of Western cadastral systems is presented in 1.2 to provide a framework for an assessment of the efficiency of the Australian cadastral system. The evolution of the European cadastral system towards a more multi purpose usage is presented in 1.3 as a model for the reform of the Australian cadastral system. Cadastral reform and LIS development in Europe, Britain, North America and Australia are also briefly reviewed. The purpose and format of the thesis are formally presented in 1.4.

1.2 A Classification of Cadastral Systems

1.2.1 Early Land Record Systems

From the moment that man first began to cultivate the land and to depend upon selected plots of ground for his very survival, a new and more intimate relationship between man and the land was formed - one in which the right to use this land for specific purposes began to emerge. These rights and privileges were also usually accompanied by certain duties and responsibilities including the payment of taxes levied on the base of the land itself. The first agricultural settlements in the Nile Valley and Tigris-Euphrates provide the earliest examples of the official, public recording of tenurial rights and privileges, and duties and responsibilities relating to the land. These early records usually included the name of the proprietor and a description of the land (TOMS, 1976).

Although they afforded some degree of protection for the users of the land, their primary purpose was to provide a satisfactory basis for taxation and therefore were created principally for the benefit of the State.

The later Greek and Roman Empires also developed extensive land record systems based on survey and demarcation of boundaries in support of colonisation, and to provide the basis for a uniform taxation system. Comprehensive taxation systems based on surveys of the extent, productivity and ownership of land were also in existence in China in the 7th and 11th centuries (SIMPSON, 1976). The Domesday Book of Norman England, systematically compiled between 1085 and 1086, is perhaps the most famous of all these early fiscal surveys, even though, like its predecessors, it was never revised in full. Several centuries later, sporadic attempts were being made on the Continent to create rudimentary land records for fiscal purposes. DOWSON & SHEPPARD (1956) cite examples in France in the 14th and 15th centuries and in Wurttemburg in 1514. Several notable efforts were also made in France and Sweden and the Austrian Empire during the late 17th and early 18th centuries (SIMPSON, 1976). However, these records were either relatively limited in their extent or, in the case of national programmes, the survey description was not based on a sound geometrical basis as was the case of the Austro-Hungarian Empire Survey of 1785-89 (RINNER, 1969). These deficiencies, together with the general failure to institute some effective means of updating, meant that these efforts produced no permanent results.

1.2.2 The European Cadastre

Present day cadastral systems in Western societies have their origins in the early to mid 19th century. However, it is the operations associated with the Napoleonic cadastre, originating in Europe at the turn of the 19th century, which are of immediate interest. In its historical context, the European cadastre can be defined as:

> "a public register of the quantity, value and ownership of the immovable property in a country, compiled to serve as a basis for taxation" (SIMPSON, 1976).

A brief description of the Napoleonic cadastre follows.

The end of the French Revolution saw the abolition of all manorial rights and feudal institutions in France and the consolidation of feudal taxes into a single tax on land. This latter reform stemmed from the economic principles of the 18th century physiocrats, that "land was the basis of all riches, so that funds for the maintenance of society should be obtained mainly by taxing landed property" (HENSSEN, 1975). These reforms created an urgent need for an equitable basis for taxation based on a more precise, detailed knowledge of individual land parcels and their owners. In 1790, the creation of a national cadastre was ordered by Napoleon. In 1807, a Commission was appointed to draw up a scheme for the systematic survey, classification, evaluation and assessment of over 100 million parcels. The scheme was approved and begun in 1808 and completed in 1850. The first manual of French cadastral practice appeared in 1811 and incorporated over 1000 articles which defined specifications by which each parcel was to be located, plotted, described and valued. The principal steps in the compilation of the cadastre are described in full by DOWSON & SHEPPARD (1956). These steps can be summarized as follows:

- a local triangulation network was established
- a provisional list of owners was drawn up, with the assistance of the tax list and by information gained "in situ", and parcels delineated
- a parcel was defined as a portion of the earth's surface undivided by any physical boundary and subject to the same land use and encumbrances and owned by the same person
- owners were notified and invited to attend the survey of their holdings. This detail survey was made by planetable after alignments had been run between the triangulation stations
- parcels were uniquely numbered on a plan compiled on a scale of 1:1250 to 1:2500. Index maps at 1:5000 - 1:10000 were also compiled
- parcel areas were computed
- an index of parcels was compiled showing the owner's name and address, the parcels owned by him and the nature of the cultivation and other details such as

buildings and pumps etc

- notification of the results of survey was given and any complaints were invited, investigated and corrections made where necessary
- each parcel was then classified according to land use, its value assessed and the amount of tax for each parcel computed
- an index of owners was then compiled under the names of the owners in alphabetical order
- initially, the parcel and owner indexes were updated annually from lists supplied by the deeds register.

It was with the Napoleonic operations that the term "cadastre" was first introduced to modern parlance, being a French word, derived from the medieval Greek term "katastichon" meaning notebook or, literally, "line by line" (SIMPSON, 1976). However, the significance of the Napoleonic cadastre was more than simply terminological. It represented a major departure from earlier efforts in several respects, in particular the unique socio-political environment in which it was implemented and the sound technical and administrative procedures on which it was based.

Firstly, the French Revolutionary conquests and subsequent occupation of large areas of Europe meant that, between 1794 and 1814 most of Europe came under French domination or influence providing a unique environment for the widespread adoption and promulgation of Napoleonic principles on a scale which would otherwise not have been possible. It is to the Napoleonic cadastre "that most of the cadastral systems of Western Europe owe, if not their origin, at least their inspiration and development" (SIMPSON, 1976).

Secondly, the extensive nature of the survey and the need for a uniform basis for assessment demanded an integrated view of land parcellation based on a sound geometrical basis for parcel location and description. It was the Napoleonic cadastre, with its need for a uniform and continuous series of maps and large scales based on precise survey which introduced the practice of connecting surveys to the national or regional triangulation network. The fiscal nature of the survey also meant that structures and other physical detail became an integral part of the cadastral survey in addition to the parcel boundaries and parcel numbers.

BLACHUT (1975b) identifies two other important features of the European cadastre:

- the introduction of the land parcel as the basic land unit on which the cadastre was built
- and the public utilisation of the survey records and maps.

Finally, unlike previous efforts, mechanisms for keeping the maps and records up to date were also provided, although, in the case of the French cadastre, the original provisions for the updating of the maps proved to be inadequate (SIMPSON, 1976).

Removing the cadastre from its historical context, the essence of classical cadastral operations have been summarised by DOWSON & SHEPPARD (1956) as:

- it is a systematic operation,
- it is the classification and valuation of the different categories of land,
- it is the cojoint delimitation and mapping of parcels, together with the investigation into, and record of, ownership and other real rights to and over such parcels,
- it is continually kept up-to-date.

1.2.3 A Comparison of Cadastral Systems

The importance of European cadastral operations in the reform of cadastral systems generally is discussed in 1.3. For the present purpose of classification of systems, it is important to note that few Western societies outside Europe possess any cadastral subsystem which is comparable to the cadastre. Although rating lists or valuation rolls tend to serve the same functions as the cadastre in these countries, they are rarely comprehensive or complete; are not updated on a continuous basis; and are not closely linked with cadastral surveying and mapping operations. As a consequence of various social, political and geographic factors different from those which helped form the Napoleonic cadastral operations, land registration systems form the basis of the cadastral systems in Britain, North America and Australia. For the purposes of this thesis, land registration is taken to mean the registration of ownership rights in land, which is established primarily for the benefit of the land owner to provide some degree of security of tenure and to facilitate land transfer. In these jurisdictions cadastral survey operations have originated (and continue to function) primarily in support of the land registration process.

Land registration systems developed in response to the deficiencies of private conveyancing (conveyancing without recourse to any public records). In earlier times when communities were small and relatively stable, the transfer of interests in land by public and symbolic actions performed in front of witnesses was sufficient to safeguard the parties involved. With increasing population and greater mobility of society, oral enquiries and the memories of local land owners could no longer prove ownership adequately enough to ensure security of title. Public ceremony eventually gave way to the signing of a written document (a private deed) by the parties involved in the exchange. The transfer took place without public notice, record, verification or supervision. The solicitor merely described the land and its history for at most 40 years in an "abstract of title". No survey was required for issuing the deed. The main deficiencies of private conveyancing, which are a consequence of the secrecy associated with land dealings, are that it is slow, costly, inconclusive and lends itself to serious fraud.

For the purposes of this thesis it is possible to classify land registration systems into 2 broad categories: -

- *deed registration :* conveyancing conducted with the assistance of the public record of deeds affecting land
- *title registration :* conveyancing in which the state establishes title by declaring under guarantee that the land is vested in a person subject to the specified encumbrances.

In deed registration, title is established by repeated, imperfect and costly examination of deeds. In title registration, title is determined as a fact rather than inferred by the collection and assessment of evidence. As the land is the subject of registration in title registration, and not the action between individuals, transactions are registered against the parcel, the entry in the register becoming proof of ownership. For these and other reasons, title registration is generally recognised as a more efficient and more secure method of land registration and land transfer. Consequently, it is found that in many jurisdictions, title registration has been introduced specifically to replace the existing deed registration system. However, it is important to recognise that the distinction between the two systems is not a precise demarcation.

> "Each is not a single system, but rather is composed of different alternatives, and the combined alternatives form a continuum. The major variable in this continuum is the extent of the affirmation made by the [State] of the existence and ownership of interests. Other differences among different forms of the systems, such as the arrangements for indexing the records, and control of descriptions, plans and surveys are not inherent, and are often the results of chance" (ONTARIO LAW REFORM COMMISSION, 1971).

Within this continuum, it is possible to further differentiate land registration systems into at least 5 categories:

- rudimentary deed registration
- title deed registration
- Continental title registration
- English title registration
- Torrens title registration

Differentiation is based on several criteria:

- the jurisdictions in which they currently operate
- the nature and simplicity of legal statutes under which they operate
- the administrative procedures associated with registration
- survey methods employed to identify land subject to registration
- compulsion of registration

- state guarantee of ownership
- state guarantee of boundaries.

The opportunity is now taken to briefly describe the cadastral systems in Europe, Britain, North America and Australia in terms of the interaction between the valuation, land registration, and surveying and mapping subsystems. An attempt has been made to identify the main factors which have shaped these systems, and several of the more significant features of these systems are described in detail and drawn upon in later chapters of the thesis. Considerable detail has been drawn from the comparative studies of DOWSON & SHEPPARD (1956), KONECNY (1970), SIMPSON (1976) and TOMS (1976).

Continental Europe

DOWSON & SHEPPARD (1956) claim that the practice of deeds registration was in evidence in Europe as early as the 12th century, while public registration of deeds was introduced in Denmark and Norway in the late 17th century in order to counteract the increasing trend towards private conveyancing. In general, registration was not compulsory but gave priority to registered documents. Registration was a function of the judiciary and the registers were usually maintained in the lower courts. The introduction of large scale cadastral mapping inevitably lead to these clear and concise parcel descriptions being used to describe land referred to in deeds recorded in the deeds register (which had always been operated independently of the earlier fiscal cadastres). Today, *title deed registration* systems are operated in most Western European countries. In these jurisdictions, no land transaction is valid unless it is recorded in a public register. The registration includes ownership, servitudes, mortgages, mineral rights, leases, contracts and restrictions and is checked for correctness by the registrar. Registration cannot be executed until a survey has been completed according to cadastral specifications. Each survey is checked. Despite their theoretical shortcomings, these systems operate efficiently, owing to the skill, knowledge and integrity of the government appointed local conveyancing lawyers, through whom land dealings must be conducted. Fraud and mistakes are rare and there is a close working relationship between the Cadastre and deed registries (SIMPSON, 1976).

In Central and Eastern Europe it was gradually recognised that an efficient fiscal cadastre which is kept up to date by recording changes in ownership and in parcel boundaries mutation, could also serve as the basis for an authoritative record of ownership. As DOWSON & SHEPPARD (1956) explained:

> "...any well-ordered and well-administered land tax records precisely and dependably linked with the units of land taxed tend progressively to develop and to crystallise the rights of the taxpayers to the use, occupancy and ultimate ownership of the land in respect of which they are taxed. So that there was a natural tendency for these local parcellation plans and land tax records to develop insensibly into informal proprietary records enjoying general confidence whenever they were reliably and systematically kept up-to-date. Statutory recognition, following appropriate opportunity for challenge and judicial investigation, finally converted such of these records into the "livres fonciers" of Switzerland, Austria, Hungary and Germany, which embrace the functions of land tax records and of registers of title to the ownership of the land".

The "livres fonciers" of the *Continental title registration* systems generally contain details of the property description, owner's name(s), easements, leases, rights and restrictions and charges, relating to each land parcel. Compilation of the new title registers usually involved a systematic adjudication, monumentation and survey of parcel boundaries with the costs of survey being met by the state. The systematic upgrading of the cadastral survey to a requisite degree of accuracy sufficient for the establishment of boundaries, combined with the simplicity of Code Law under which the boundaries are monumented and maintained have enabled the state to guarantee the validity of survey records for the reestablishment of boundaries. Legislation also sets specifications for all legal surveys and requires connection of surveys to the control network. It is also mandatory in most countries to send all field notes taken during any surveying activity to a central surveying authority to ensure their use in the production and updating of maps (ZIEMANN, 1970). Cadastral surveys are used to update the cadastral map series, generally published at scales of 1:500 to 1:1000 for urban areas. Maps usually show parcel boundaries, buildings, fences, road and river edges, and parcel numbers.

Present day cadastral arrangements in Europe are characterized by the interaction between the Office of the Cadastre and the Land Registries (title or deed registers). The practices of both agencies are usually regulated by national standards and the operations of both are highly decentralized through local cadastral offices and land registries. Close coordination between these agencies is required because of their interdependence in the processes of land subdivision and transfer. On one hand, the Land Registry is dependent on the Cadastre for its survey and parcel identification requirements. Historically the Registry maintains no plans and exercises no control over survey methods or standards. These are solely the function of the Cadastral Office. Therefore when any dealing or transfer requires the demarcation of new boundaries, the conveyancing lawyer must apply to the Cadastral Office for permission to subdivide and then either the Cadastral Office carries out the survey with its own personnel, or the survey is carried out by a licenced surveyor contracted privately by the conveyancing lawyer, who then forwards his survey to the Cadastral Office. The Cadastral Office incorporates these changes into its sheets (which are eventually used to update the large scale cadastral map series), allocates new parcel numbers and then forwards this information to the Land Registry. Here, records are amended and the new cadastral designation used for subsequent transfer of the same parcels. Conversely, the Cadastral Office is dependent on the Land Registry for notification of changes in ownership which do not affect boundaries. In this case, the Registry periodically notifies the Cadastral Office of any changes in ownership of whole parcels so that the cadastral record can be amended accordingly.

Britain

Britain presents "the paradox of an economically powerful country operating administratively for 900 years without recourse to a system even of a general registry of deeds to land parcels, let alone a form of registry of title" (TOMS, 1976). DOWSON & SHEPPARD (1956) see different social and economic factors as an explanation for the lack of a general cadastral survey in Britain. Unlike the small, privately owned plots in Europe with whom the state needed to deal with directly, Britain has pre-eminently been a country of large landlords of agricultural land with whom the state could deal without knowledge of tenants' holdings.

DOWSON & SHEPPARD also ascribe four main reasons for the generally high standard of security of land tenure in Britain, despite the widespread continued practice of private conveyancing:

- the customary nature of these processes
- the high professional standards and integrity of conveyancing lawyers
- the practice of exclusive rights of inheritance which avoided the repeated fragmentation of land into smaller parcels on death
- the exceptionally stable and stably marked pattern of the countryside which sets physical barriers to petty encroachments.

Under the influence of these alleviating conditions, it was not until 1830 that a Royal Commission needed to be established to enquire into the confusion and insecurity in land dealing which had begun to emerge under private conveyancing. Title registration legislation was first introduced in 1862 but conversion of land to title registration was ineffective until the introduction of selective compulsion and simplified land law in the 1925 Land Registration Act which is still in force. Title registration practice is presently controlled by Her Majesty's Land Registry (HMLR) and operations are decentralised through nine offices. The records are only open to those persons with a proven interest in the land. An insurance fund compensates anyone suffering monetary loss through any error in the registration process.

A unique feature of the English system is the organisation of the cadastral survey system and the survey methods used to define boundaries for registration purposes. HMLR is dependent on the national topographic mapping agency (the Ordnance Survey) for the maps upon which land is identified for registration purposes; and for ad hoc surveys where the identity of the parcel is uncertain. The existence of a comprehensive uniform, accurate, continuously revised, large scale (1:1250 in urban areas) topographic map series which clearly depicts the physical boundaries of all land parcels (hedges, walls, fences etc) has enabled boundaries to be defined by their physical evidence, the exact position of the boundary within a fence, wall etc. being left undetermined. The principles of "general boundaries" are discussed further in chapter 3. In effect, cadastral survey in Britain has been a two stage process in which a systematic state funded, integrated topographic survey has been followed by a sporadic, privately initiated adjudication and delineation of ownership boundaries.

North America

In contrast to the relatively stable and densely settled landscapes of Europe and Britain, the North American continent at the turn of the 19th century presented a vast, unexplored territory in which the prime concern of land administration was the granting of land to the new settlers to facilitate the rapid development of the interior. Limited survey resources were necessarily devoted to the survey of land grants and there existed little scope for the creation of the extensive control networks necessary for the production of uniform cadastral maps. Neither was there a need for the uniform assessment of land for taxation purposes.

Cadastral operations have changed little in the last two centuries, with most jurisdictions in the United States and in the Atlantic Provinces of Canada continuing to operate *rudimentary deed registration* systems which only offer the interested land owner the opportunity of registering a land parcel in a publicly operated land register. The registrar receives copies and files deeds without checking the validity of their contents and does not accept any responsibility in this regard. Because registration is not compulsory, no parcel index exists. Deeds are recorded and filed chronologically and retrieved by reference to alphabetical grantor/grantee name index. The inclusion of plans as part of the deed description is not common and it is generally not mandatory to record all property surveys and plans. Property descriptions used in deeds are often inadequate, faulty and misleading and these descriptions are used repeatedly long after they have become invalid. Once filed, documents are open to public inspection. The system of recording deeds is designed to establish priority of rights in land dealings and to protect the buyer from hidden liens (charges for debt or duty) and transfer. Registration is not compulsory but is considered prudent practice. Because the recording of the deed is not proof of its legality, it is necessary to search, assemble and evaluate recorded title information in public records in order to prove ownership, tracing the history of the parcel back to the original state grant or 'patent'. This laborious process must be repeated for each successive transfer or mortgage. Searches are therefore time consuming and costly, and the system has been described by those familiar with its operation as "archaic, expensive, inefficient and an insult to the intelligence" (ROZOVSKY, 1969).

In the United States, few states prescribe or demand high standards of quality and practice of surveyors and quality is largely a matter of professional conscience and self imposed standards (GREULICH, 1977). There are (with limited exceptions) no survey and plan checking procedures and no truly satisfactory method of correlating and controlling survey operation.

In order to provide some degree of title security in the United States, private title insurance companies have been established each maintaining its own title plants. These records are, in effect, a duplication of the public record but generally better organised, documents being indexed against the parcel. The title insurance policy, however, is not a guarantee of title (SCHMIDT, 1971).

Australia

As with the North America, the rapid settlement of the Australian continent by a relatively small population precluded a systematic approach to cadastral operations.

From the time of settlement, the fuedal principle of English law applied that all land for which no subject could show title, belonged to the Crown. The early practice of granting freehold title to private individuals was supported by the recording of all such Crown grants. However, having received a land grant, any person was then free to dispose of the land as they desired. Conveyances of alienated land were subject to the existing English property law with no official records of land transactions kept. A rapidly developing land market and the growing insecurity caused by secret conveyancing saw the introduction of the first registry of deeds in 1818 (HALLMAN, 1973). Similar arrangements were introduced in the other states under their own legislation and continue to operate today. Although these arrangements functioned adequately while the colonies remained small and relatively stable, the rapid development of the continent in the middle of the 19th century began to place pressures on the deeds system which soon gave rise to serious delays and insecurity in the land transfer process.

In 1858 Sir Robert Torrens introduced registration of title into South Australia, the first jurisdiction (at least of jurisdictions using English land law) to establish such a system (SIMPSON, 1976). Legislation similar to the South Australian Real Property Act was enacted in the other States between 1861 and 1874. *The Torrens title registration* system requires that all land alienated from the Crown from and after a given date would be subject to the Act. From this date, original grants from the Crown were immediately entered in the Title Register in the Land Titles Office (LTO). The act of registration confers on the registered proprietor an absolutely secure title. A certificate of title is prepared, recording the name of the proprietor and complete details of the rights, charges and conditions affecting the land and bound in the register book. The certificate is conclusive evidence of ownership which is financially guaranteed by means of an insurance fund. Mutations or changes in the status of the title are recorded on the face of the certificate subject to examination of supporting documents by LTO staff. These documents include instruments of transfer, lease, mortgage etc. as well as maps and plans prepared by licenced surveyors for land being subdivided. These documents are registered separately from the title register. All transactions which result in mutation of a parcel are also recorded on the appropriate map or plan. All registered documents, including maps, plans and certificate of title are open to public inspection.

Since the earliest days of settlement, the primary purpose of cadastral survey in Australia has been the description and definition of parcel boundaries in support of the processes of alienation of Crown land and the subdivision and conveyance of freehold land. The present system of boundary definition in Australia can be described as an isolated survey system based on the placement of artificial monuments on or near corners and supported by the precise measurement of boundary lines. The lack of cultural features and the sporadic nature of land settlement have been given as reasons for the use of corner marking rather than linear boundary features to define boundaries as in Britain.

The Australian cadastral system is discussed in more detail in chapter 2.

1.2.4 A Classification of Cadastral Systems

The preceding description of the European cadastre and comparison of cadastral arrangements in Western jurisdictions, form the basis of a classification of cadastral systems and clarification of the terminology used in this regard. The functions of valuation and land registration, and the parcel delimitation and mapping operations associated with these functions can be classified on the basis of:

- who creates and administers them and for whose benefit,
- their primary purpose and usage,
- recording procedures and contents of the registers,
- survey procedures upon which the records are based.

This classification, based on SIMPSON (1976), is presented in figure 1.1.

As regards the difficulty associated with the terminology currently used to classify cadastral systems, PRIDDLE (1975) has commented:

> "It has become obvious that, in English, the term 'cadastre' means different things to different people... The problem of defining the term is somewhat like attempting to define a container by reference to its contents.... A satisfactory definition of the term is therefore difficult, if not impossible" (PRIDDLE, 1975).

Problems of definition stem from fact that the term "cadastre" has acquired a far wider connotation than the systematically compiled fiscal record of European origins. It has lost its specifically fiscal association in the adoption of classical cadastral principles (see 1.2.3) as a model for cadastral reform outside Europe. This recent phenomena is discussed in 1.3. Matters have been further complicated by the extension of these principles to describe any collection of immovable objects which can be systematically, comprehensively and accurately surveyed and recorded in an up to date register. For example, BRAASCH (1975) adopts a general definition of cadastre which embraces house, dike and sluice cadastres.

In this thesis, the use of the term "cadastre" will be confined to its classical European meaning, as a register of the quality, value and

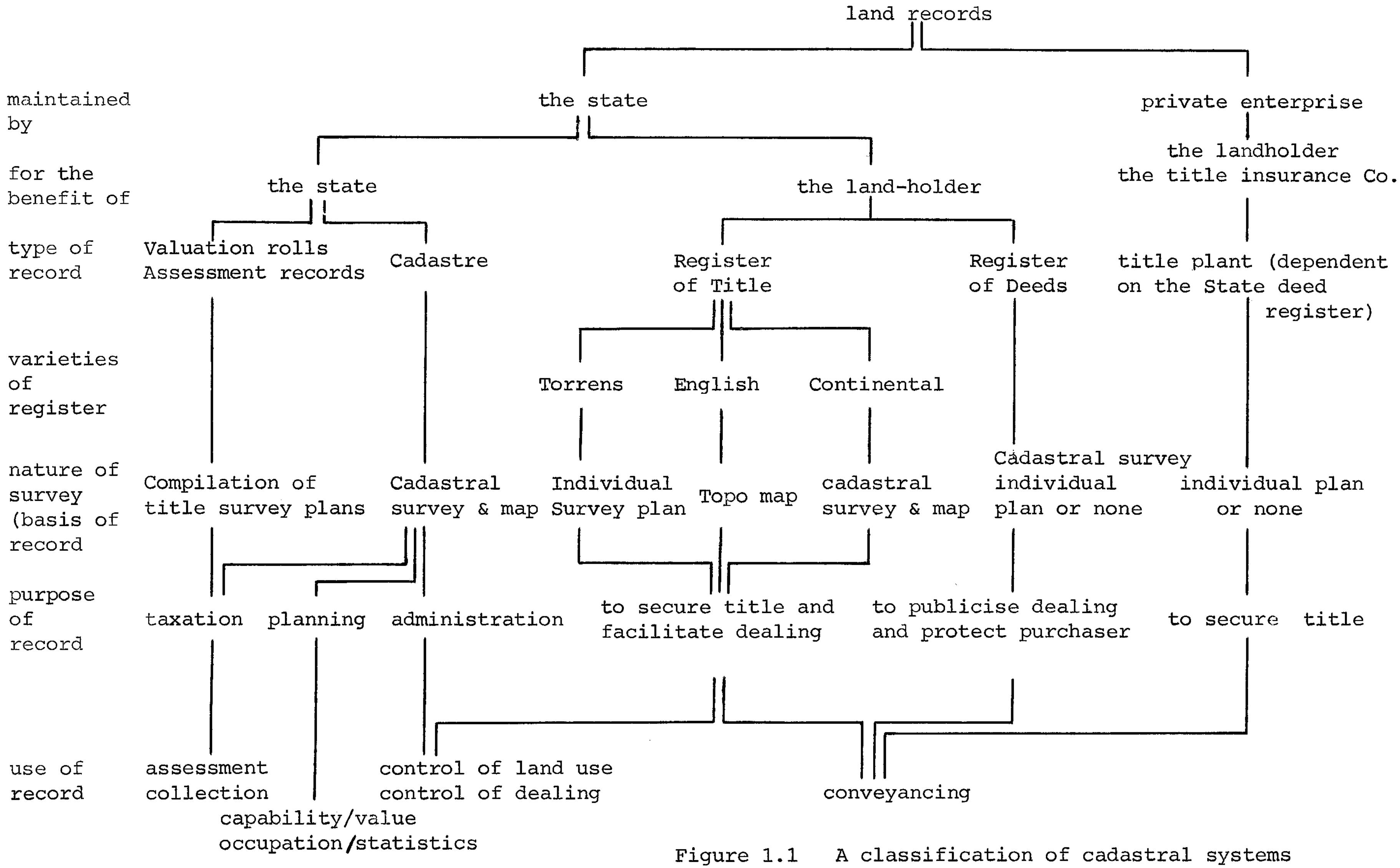


Figure 1.1 A classification of cadastral systems (after SIMPSON, 1976).

ownership of land originally compiled for taxation purposes and the contents of which are continually updated. The term "property register" and "land register" will be also used to denote the cadastre and the deed/title registers respectively in line with apparent current usage in Europe (see ANDERSSON, 1980). The term "cadastral system" will be used to denote any collection of land records systems within a jurisdiction (irrespective of the purposes for which they have been created and irrespective of their efficiency or completeness) which encompass the functions of valuation, land registration and parcel delimitation and mapping. An efficient cadastral system would be expected to exhibit most of the characteristics of cadastre, although it need not have been systematically compiled. These definitions permit the term "cadastral survey" to retain the meaning which it has already acquired in many jurisdictions, that of a survey of land parcel boundaries whether or not the survey has any connection with taxation. In Australia, the term has always exclusively been used to denote survey in support of land registration, and has lost any connection with a systematic process.

1.3 Cadastral Reform : towards the development of land information systems.

1.3.1 The Multipurpose Cadastre

In the preceding classification of cadastral systems, the evolution of these systems in response to changing social requirements and attitudes is readily apparent. The independent development of the Continental, British and Torrens title registration systems represent the most significant cadastral reforms during the last century, although in the latter cases, initiation of the changes involved major new legislative measures which attracted concerted opposition when introduced. Undoubtedly the most significant development in cadastral processes during this century, and the development of prime concern to this thesis, has been the evolution of the European cadastre towards a more multipurpose use. Since the turn of the century, the cadastre has increasingly been adapted for use in land consolidation, land management and urban and regional planning. For example, KONECNY (1978) claims that after 1920, the German cadastre became primarily useful as a basis for recording property-based data for planning purposes.

The ability of the European cadastre to satisfy a wide variety of needs can be attributed to two factors:

Firstly, the cadastre provides an authoritative, public record of basic information on land and ownership rights in land upon which "all realistic planning and effective administration is dependent" (LARSSON, 1975). DENMAN (1974) explained the fundamental importance of ownership information in the planning process in the following terms:

> "No decision to develop land can effectively be taken outside the property right. No one can understand or analyse the pattern of land use without knowledge of the scope, incidence and manipulation of that power. Knowledge of it is essential to any planner who would be fully informed of all factors affecting development..... The rights and the land to which they pertain are the elements of a unit of decision-making which [can be] designated the proprietary land unit. The land use pattern of an area is, at any one moment, the outcome of decisions taken within the competence of particular property rights and within the confines of proprietary land units. Sanctioned by the property rights of a proprietary land unit, the land assets, the soil, its fixtures and improvements, are arranged and rearranged from time to time to give expression to the motives of him who holds the unit."

As well, the separation of the cadastre from the land register has enabled the expansion of the cadastral record to readily include data which is of interest to the planning process and some of which have been generated by planning legislation introduced since the original cadastral operations. For example, in addition to owner's name, parcel designation and value, the present German cadastre is also used to record:

- actual land use and zoning
- nature and quality of the soil for rural properties
- restrictions affecting the use of the parcel including the location of the parcel in water preservation areas, nature reserves, building conservation areas, building restrictions (HERZFELD, 1978).

Secondly, the cadastre has been able to integrate the data contained in other land records and maps outside cadastral system. The integration of other land records is possible:

> "Because such a great part of human life, human activities and human property have a meaningful connection with land. Inhabitants are located on a certain piece of land and buildings erected thereupon. The daily work is also, as a rule, bound up with specific land and buildings. The same can be said about taxes. It is therefore quite natural to tie together all data relating to land,

> buildings, people, enterprises, property, taxes, etc., in an integrated system. This system must have one or several identification keys that trace all data back to a common base. One such key is the numbered piece of land, registered in the cadastre" (LARSSON, 1975).

ZIEMANN (1976b) expressed the integrating role of the land parcel in these terms:

> "If governmental data requirements are to be integrated, a small unit... must be found, that is, a small geographical entity capable of representing a rather stable and unique common denominator - an anchor to which various files can be related."

The utility of the cadastral map for purposes other than land assessment and land registration became apparent at an early stage in its development. As BLACHUT (1975b) explained:

> "The systematic coverage of the land by a cadastral map, the map accuracy and content that included the main planimetric features of the earth's surface (man-made and natural), and which was continually updated as alterations occurred on the ground, made the cadastral map a surveying and cartographic product of a much more universal and technically oriented usefulness than the initial purpose of its creation would suggest. Already in Napoleon's time, the cadastral map started to be used for other than taxation and legal purposes."

In addition to providing an up to date inventory of cadastral and environmental information, the large scale map, particularly in urban areas, provides a uniform framework for the correlation, storage, presentation and analysis of all information of a social, cultural, economic and technical nature. For example, the map can be used to:

- record and analyse all information about landscape germane to planning considerations, e.g. geology, soils, climate
- plan and execute layouts for roads and building development
- record services such as sewers, drains, street lighting
- record land use including shops, offices, industries, recreation areas
- record rating assessments and payment of rates
- record and plan all public works projects and their relation to government and private property (DALE, 1976).

Given the long and successful history of cadastral operations in Europe, and their proven adaptability to contemporary planning requirements, it is understandable that jurisdictions outside Europe, particularly those with rudimentary cadastral arrangements such as in North America, would look to the European cadastre as a model for cadastral reform. The ultimate goal of these reforms is not simply to improve the process of land administration but to produce an efficient cadastral system which has the capacity to bring together all land-related information in a data compatible form. The reform measures ultimately find their expression in the creation of the LIS. It is also important to establish the relationship between the LIS and the cadastral system. The LIS is developed as a separate entity within existing cadastral operations, and draws on the cadastral system for its basic data and for the updating of its contents. As BLACHUT (1975b) explains:

> "a multi-purpose [cadastral system] does not mean that it should be the responsibility of the [cadastral system] to collect and maintain all the variety of information that may be considered. What is, however, expected is that the cadastral data be in a form and of a quality suitable for use by a wide circle of users and for different data files."

BLACHUT (1969, 1971b, 1975b) has identified the main technical and administrative requirements of an efficient cadastral system which is to serve as the basis of a land information system:

- the system must be based on technically sound surveying (field or photogrammetric) of parcels in a nation-wide coordinate system of precisely specified accuracy.
- the control network on which the system is based must be permanently monumented and maintained.
- the results of surveying must be converted into large scale maps (1:1000 in urban areas) or stored in a form suitable for instantaneous conversion into maps. The maps must be relatively complete and must include all buildings and other structures and the natural features of importance in addition to parcel boundaries.
- integrated descriptive parcel records must be compiled consisting of size, value, mortgages, easements etc. Common identifiers and reference keys

must permit an instantaneous identification and correlation of data on the maps and in the registers.

- These identifiers must identify files outside the cadastral system which contain land-related information.
- Cadastral records (including survey data maps and the registers) must be final at any given moment and must have legal validity, i.e. the state must guarantee their contents.
- To achieve finality, the records and maps must be continuously and automatically updated. This also includes any changes in the physical features depicted on the map.
- To form the basis of a land information system, the cadastral system should lend itself to the automated processing of the recorded data.

1.3.2 The Modern Era of Cadastral Reform

It is only in relatively recent times that problems in the provision of land information have become sufficiently acute, and technology sufficiently advanced, for LIS development to be considered an economically viable proposition. The modern era of cadastral reform can be viewed as commencing in most Western countries in the mid to late 1960s. MITCHEL (1976) in a dissertation on information technologies and government processes, sees striking similarities between the present social and technological environment, and those conditions which gave birth to the Napoleonic cadastre. According to MITCHEL, two significant features of the Napoleonic cadastral operations were "the peculiar set of social, economic and political conditions which generated the program and the technical capability which made it feasible."

> "the Napoleonic cadastre will be seen as a major technological and administrative response to the profound challenges arising from equally profound changes within a society."

> "the Cadastre, perhaps as well as any other evidence, marks the emergence of France as an industrial society. It also reflects the growth of private wealth and property, the identification of individual rights as apart from the prerogatives of the State, and a growing bureaucracy using technology to deal with those to be taxed, regulated, and served."

> "Barring the disruptive influence of a major catastrophy such as nuclear war, we are in the process of and witnessing a change in geographic and cartographic technology surely as significant as that promulgated by Napoleon, and for the same basic reasons: ground swells in the demands placed on governments for programs and services, and a concomitant increase in technologic capability. We are witnessing the initial period of a third era marking the confluence of government and technology " (MITCHEL, 1976).

The new technologies to which MITCHEL refers are those concerned with data processing which he defines as the "automated manipulation, storage, and transmission of symbols through chemical, optical and electronic processes." Electromagnetic distance measurement, photogrammetric block triangulation and (more recently) intertial survey systems and satellite positioning systems, will enable the rapid acquisition of the coordinate framework within which cadastral survey operations will function. Other technologies available for the creation and maintenance of the cadastral maps and records include:

- photogrammetry and associated map production techniques including orthophotography,
- digitization which converts graphical coordinate values from a map data automatically into computer readable form,
- computers with their capability to receive, store, manipulate and reproduce data in digital form including interactive computer graphics and data base management systems,
- telecommunications - the mechanisms by which digital values are transmitted electronically including the capacity for the networking of individual computer systems.

The nature and extent of cadastral reform measures will be determined to a large degree by existing cadastral arrangements. In those jurisdictions lacking dependable and up to date registration of land, KONECNY (1978) proposes a four phase programme for cadastral reform:

1. the establishment of geodetic control down to 4th order including monumentation of reference points to which all ground surveys can be economically tied.

2. large scale mapping to establish a coordinate reference for land on a graphical numerical or digital basis
3. the introduction of a compulsory land registration system involving legislation for updating the cadastre consisting of a property description (e.g. map parcel) and a property file (e.g. owner, mortgages, land use etc.)
4. the expansion of the cadastre into a land information system.

This approach deliberately parallels the processes involved in the creation and evolution of the European cadastre. At present, Europe is only concerned about the automation of phases 2 and 3 and about phase 4. As a model for jurisdictions outside Europe, its main deficiency is that it does not consider the positive aspects of existing cadastral arrangements upon which a new system could build. Its appropriateness for these jurisdictions is therefore difficult to assess.

The final phase of this process, the gradual development of the LIS, can be achieved through the automation and integration of cadastral and other records and maps. The application of automated data processing technology to cadastral records systems commenced in the early 1960s and was generally designed to enable the cadastral system to continue to perform its traditional administrative functions more efficiently, in response to the increasing demands which were being placed on the system. The use of the computer to assist in production and maintenance of cadastral maps was not seriously undertaken until the late 1970's when the technology had become sufficiently advanced to permit the complete digitization of maps. These developments, and the automation of administrative files within local government were also seen by many planners as providing the necessary infrastructure on which an information system for planning could be based. Such developments took place during the 1970's, usually independently of cadastral reform programmes.

A review of cadastral reform measures and LIS development in western countries follows.

In contrast to the earlier comparison of cadastral systems (see 1.2.3) this review attempts to highlight the similarities between approaches to cadastral reform and between the conceptual LIS models which these approaches have produced. Several of the more successful property-based planning information systems are also reviewed for two reasons. Firstly, many of the techniques used in their creation are applicable to LIS development and secondly, because a future LIS may need to incorporate these systems in order to satisfy the needs of administrative and strategic planning purposes.

Continental Europe

Cadastral reform and LIS development in Europe has been characterised by a "gradual development towards a more diversified use, but without any major changes having so far occurred in the actual content of the cadastre" (LARSSON, 1977a). Initially, reform concentrated on the renewal of existing maps and records in an attempt to gradually improve the quality of the cadastre. For example, since the late 1950's, many European countries began to show contour lines and main topographical features on cadastral maps in order to make them more useful for general planning purposes, and for the production and maintenance of topographical maps (KURANDT, 1958).

Other reform measures are aimed at the reorganisation and coordination of cadastral data flows. The separation of the Cadastre and Land Register has long been recognised as detrimental to the efficient operation of the cadastral system generally. As HENSSEN (1975b) explains, the continual interchange between separate organisations which may often be a considerable distance apart, has created unnecessary delays in land transactions and has slowed down the record updating process so that discrepancies inevitably occur. As well, data referring to the same land parcel has been duplicated in both registers, thereby raising the costs of maintenance of both systems. This continued separation is largely traditional, reflecting the respective public and private interests that the Cadastre and Land Register are designed to serve. Alternatively, it could be argued that the separation of the legal matters of land registration from the predominantly technical matters of the Cadastral office is a positive aspect of the present cadastral arrangements. The ability to crosscheck the independently maintained records may also be an advantage.

HENSSEN proposes that, from the point of view of cost and efficiency, it would appear preferable to either combine the two agencies, or, at best, bring about a closer coordination of their activities. This has been achieved to some degree in Switzerland where four of the 25 cantons have combined both agencies under the control of the Cadastral Office (DOWSON & SHEPPARD, 1956).

However, it is the introduction of automatic data processing to cadastral operations which has provided the impetus for more recent reforms. One of the earliest applications of automatic data processing was in connection with land consolidation or reallotment (the process by which small agricultural holdings are equitably redistributed to form larger, more economical units). The successful use of the computer in the more tedious and complicated tasks of area calculation, optimization analysis and automated drafting, although limited in its extent, no doubt influenced the move toward the automation of all cadastral records and maps (see GASTALDI 1974, POLMAN 1974). Since the early 1960's, cadastral records were being computerised in West Germany largely to assist in routine administrative tasks (BASTIAN, 1980). However, it was in Sweden that the first formal recognition was made of the possibility of cadastral automation, not only integrating the functions of the property register and land register, but also forming the basis of a much broader land information system and it has been the Swedish proposals which have most influenced European and overseas LIS development.

In Sweden registers containing data on population and taxation, enterprises and owners of enterprises, real estates, land utilization, establishment of various kinds and motor vehicles, are maintained by various government agencies. The data recording environment, however, was far from perfect.

> "The method of registering data is unsatisfactory because the technical and organisational design is inefficient, registration is split into a multitude of register systems, most registers are incomplete, registration by administrative area hampers efficient planning later when different areas are to be considered at one time, and there is considerable duplication" (WALLNER, 1969).

Problems also existed in the cadastral system in both the property and land title registers. The old land registers were large books, difficult to handle and in which entries were made manually, while the property registers in urban and rural districts employed different recording procedures.

In response to these problems, a cadastral-reform Committee was established in 1964.

> "Quite early during the investigation, it was decided that the important part played by the real estate registration should be recognised and that a base register should be built up on the principle that it fit into a uniform integrated network of information systems"
>
> (WALLNER, 1969).

Acting on these proposals, the Swedish Central Board for Real Estate Data (CFD) was established in 1968, and given the task of implementing the recommendations of the committee, which were that:

- one register should be created including the present two cadastres and the land register
- the contents of the register should be extended and improved in reliability and completeness to serve the needs of community planning
- the new register should hold basic data including identification, area, location, ownership, rights, official restrictions and planning regulations
- supplemental data should be added when available (including buildings and use of soil)
- every parcel should be spatially referenced by one or more geodetic point coordinates, contained in a separate coordinate register
- the new register should be organised as a computer-based public information system (WALLNER, 1969).

In 1970 it was also decided that the land register be automated and the following year the two reforms were coordinated under the CFD to provide a uniform system for the whole country.

The progress of the Swedish land data bank can be traced in WALLNER (1969, 1971), ANDERSSON (1974, 1975, 1977) and RYSTEDT (1977a, 1977b). The design concepts of the Swedish Land Data Bank clearly show that the feature which transforms a reform of the existing cadastral system into a activity of major consequence is the ability of the cadastre to integrate diverse data records through the use of a common key - the property identifier. Integration was possible because many of the existing public records were already computerised and many contained the property identifier or personal number. Consequently, one of the first reforms of the Swedish project was to create a uniform identification system for all properties to replace the two different systems (one in towns and one for rural districts) which had been in use since the turn of the century. This task required the introduction of one million (30%) new notations (WALLNER, 1969). This property designation is used as the primary key in the land data bank.

The nature of cadastral arrangements in Europe, in which the land register relies on the cadastre for the survey and identification of parcels, ensures that the uniformity of parcel definition and identification (essential to the mechanics of integration) is maintained.

Britain

The case for the creation of local cadastres in Britain along European lines has been put forward by DENMAN (1974) as a vital necessity for the formulation of fiscal land policy and for land use planning, both of which have traditionally been carried out without an adequate knowledge of ownership and proprietary rights. The creation of these cadastres and their maintenance are clearly dependent on the eventual completion of the land register and would require the ongoing participation of Her Majesty's Land Registry (HMLR). However, such developments seem unlikely in the short term.

Despite the substantial land law reforms of 1925, registration of title progressed slowly until the 1950's and 1960's when a large number of local authorities applied to have the selective compulsion provisions apply in their respective areas. In the late 1960s a systematic and sustained attempt was made to bring all land onto the title register sponsored by Central Government by 1975 (RUOFF, 1968), but failed due to manpower problems. According to MAINTHORPE (1979) approximately half of all parcels remained unregistered so that the total cadastral picture is still far from complete. However, even if land registration is completed in the near future, the development of national cadastre would still require considerable legislative reform to enable the HMLR to participate in its maintenance. As DENMAN (1974) points out, there does not appear to be any intention on behalf of government at this time to view the machinery of land registration as anything more than a means of facilitating conveyancing, even though "all the parts are there for the creation of a national cadastre."

In the absence of adequate cadastral arrangements, local authorities have begun to develop their own computerised property-based information systems, based on local rating lists but lacking any input from HMLR. The catalyst for planning information system development in Britain came with the 1968 Town Planning Act which required local authorities to collect more detailed information to assist in the monitoring of land use change. In 1972, the Department of the Environment (DOE) in association with several local authorities, produced the General Information System for Planning (GISP) Report (JOINT LOCAL AUTHORITY STUDY TEAM, 1972) which outlined the structure of a comprehensive information system designed to fulfill the requirements of the Planning Act. The GISP philosophy recognised the need for a central computerised property file built around the rating lists in urban areas and was clearly influenced by reports of the Swedish land data bank (WILLIS, 1978). Although GISP as conceptually outlined in its report was never fully implemented, most of the developments (both at and since that time) utilised its findings, and the principles still remain the objectives of all information systems development in Britain (BARNES, 1980).

GISP recommended that to ensure each property was referenced uniquely and unambiguously and in order to avoid duplication of effort, a national organisation must be given responsibility to maintain a National Gazetteer. Acting on this recommendation, a Gazetteer Working Party (GWP) was set up in 1971 whose terms of reference were to examine the feasibility, form and content of a National Gazetteer. The GWP recommended that the minimum contents of a gazetteer should be:

- postal address and post code
- property number (identifier code)
- locational reference
- land use description.

In 1972 the National Gazetteer Pilot Study (NGPS) was established to ascertain the costs and benefits of gazetteers to local government and to establish procedures for gazetteer creation which would be suitable for work on a national basis. The gazetteer was successfully completed in 1976 with interim progress published in several technical memoranda. The recommendations of NGPS were published in a final report (DEPARTMENT OF THE ENVIRONMENT, 1979). The main achievements of NGPS were seen as the successful development of a property numbering system that managed to link administrative to planning data, and the establishment of procedures for updating the system from rating records and other administrative sources (WILLIS, 1978).

Simultaneously with these projects, developments were taking place in several local governments in the establishment of corporate management information systems. These developments represented change of direction from gazetteer creation towards information systems which satisfied planning and administrative requirements in a single approach, with an emphasis on file integration. This approach to the creation of property based information systems is exemplified by the Local Authority Management Information System (LAMIS) which is a system package specifically designed to be adapted by all local authorities. LAMIS is built around a hub file containing a register of all properties referenced by a unique property reference number. HARRISON (1976, 1977, 1979) describes the progress of LAMIS in Britain.

North America

As described in 1.2.3, the rudimentary cadastral arrangements in the United States and Eastern Canada had remained little changed over the past 200 years. However, by the early 1960's an awareness of the costs incurred by the public and by government in the continued reliance on a cadastral system based on a highly fragmented system of public and private deeds recording, conducted without recourse to an adequate system of large scale cadastral or topographic maps. Increasing costs and difficulties and delays began to be experienced in even the basic administrative processes of conveyancing and real estate assessment, and existing arrangements were unable to readily provide basic information for use in urban planning, environmental protection and land management.

In the early 1960's, proposals for reform of the cadastral system began to be put forward. In the United States, these early reform measures focussed on the need to improve the system of deed recordation in an effort to reduce conveyancing costs. These reforms favoured the introduction of new technology and new recording procedures but required only minor legislative changes and were to be implemented without the need to produce a uniform large scale cadastral/topographic map series. However, beginning in 1967, a series of meetings were held including those at Fredericton (KONECNY, 1969c), Atlanta (MOYER & FISHER, 1973), Ottawa (BLACHUT, 1975a) and culminating in a National Conference in Washington (PHILIPS, 1975).

At these meetings, proposals began to emerge from surveyors, lawyers and other professions concerned with the reform of existing cadastral systems, which recognised the broader implications of these reforms. Although it was agreed that the land parcel was most suitable as a building block for a modern computerised system of land records, it was decided that study of title search procedures alone was not sufficiently broad and that the solution would necessitate careful consideration of all aspects of land records. This need to have all land-related data tied together led to the 'total system' approach towards the modernization of land data systems. According to McLAUGHLIN & CLAPP (1977) two schools of thought have emerged as to how modernization of land data systems should be effected. One can be described as the mechanistic approach, exemplified by the Comprehensive and Unified Land Data System (CULDATA) model and the other as the institutional approach which has been adopted in the Maritime Provinces of Canada.

The mechanistic approach is characterised by the systematic application of computer technology, recent developments in surveying and photogrammetry and automated cartography to existing land record and survey systems. The basic characteristics of the CULDATA system can be defined as:

- the basic building block of the system is a land ownership parcel - the unit of land included within a legal description in a deed
- the system is based on a modern system of land titles records (deeds) indexed by parcels as well as by owners
- use of a unique code number for each parcel indicative of its location
- use of the same parcel code numbers for land title, taxation, land use, and land planning records
- land descriptions are based on a plane coordinate system tied to the national control network and which meet recognised legal standards for land descriptions
- a system of large scale maps should be maintained for urban and rural areas at scales of 1:500 and 1:2500 respectively, and based on the same plane coordinate system as the land descriptions
- a national system of code numbers to identify persons, corporations and organisations

- coordination of local, state and federal activities in the collection, storage, retrieval and use of land data.

Details of the CULDATA model are described in COOK (1969a, 1969b, 1974) and MOYER (1973, 1974).

A computerised land records system based on the CULDATA model has been implemented in Forsyth County in the United States (AYERS et al, 1974).

The institutional approach also involves the application of computer and surveying technology but combines these improvements with reforms in existing real property and survey legislation, fundamental changes in the procedures for land registration and conveyancing and significant changes in the roles of the legal and surveying professions. This reform uses as its model the European multipurpose cadastre and is based on the premise that "these institutional reforms will prove to be the most significant element in the long-term effort to modernize the cadastral arrangements" (McLAUGHLIN & CLAPP, 1977). This is in stark contrast to the CULDATA philosophy of a localised application of technology aimed at achieving significant benefits in the short term. The cadastral reform programme of the Canadian Maritime Provinces was to be implemented in four phases:

1. the extension and densification of the second-order control network as soon as possible
2. the production of large scale planimetric and topographic maps at scales ranging from 1:1000 to 1:20000 and the introduction of a large scale cadastral mapping series
3. the systematic replacement of the existing rudimentary deed registration system with a computer based land titles system, based on a modified Torrens System and guaranteeing the position of the property as well as ownership rights
4. the gradual development of a computerized land data bank based on phase 3 and containing information on title, assessment, structures, utilities, land use and intended to assist in decision making in community and regional planning.

The original economic feasibility analysis of the programme can be found in LARSEN (1971) and its progress is described in ROBERTS (1969, 1970, 1971, 1975, 1979a, 1979b, 1980).

Australia

The introduction of Torrens title registration relatively early in the settlement of the Australian continent has meant an up to date and almost complete registration of land has been in existence since the turn of the century. Significantly, from the point of view of the classical approach to cadastral reform outlined previously, this registration had been achieved without recourse to accurate large scale mapping based on a uniform control network. Land registration continued to function smoothly for almost a century. However, the efficiency of the system was soon to be put to the test. GRIFFITH (1974) relates the experience of the New South Wales Registrar General's Department:

> "The Department administered the Torrens title system quite comfortably and efficiently from its beginnings last century until after the 1939-1945 War. The systems in use had evolved over a century and were simple, tried and proven. However, we were about to be taught an important lesson by the post-war land boom. The lesson was that a system that was efficient when handling a volume of business of, say, 500 lodgements per day (1939) was not necessarily capable of handling business in the order of 1,200 per day (1960). How it would have fared with current lodgements of 2,200 per day, we could not afford to find out."

In 1959-60 the whole system was critical and a comprehensive plan was formulated involving "radical changes in long-established practice," culminating in the design on automated title system. Automation of the register began to be seriously considered in the early 1960's (WHALAN, 1967). In 1971 a Torrens Register Automation Project (TRAP) was commenced to assess the feasibility of developing an efficient system that would cope with the rapid growth of business and provide ready access to public records. The Project produced a model for an automated register, the main features of which were:

- a high quality map index clearly depicting each land parcel and its parcel identifier
- a parcels file containing an individual record for each land parcel containing the parcel identifier and current title information

- the parcels file held on-line to enable direct access by staff and public
- the parcel identifier, as the prime key in the system.

Details and progress of TRAP are found in GRIFFITH (1974, 1975) and MILLBURN (1981).

TRAP was specifically designed to improve title records management and was developed independently of automation in other records systems. Consequently these reforms could not be sufficient, in themselves, to produce a LIS, although an automated title register would form an integral part of such a system. Prompted by an awareness of the large number of departments developing computer systems relating to land, the South Australian government in 1974, investigated the possibility of coordinating these developing systems, together with those already established, into an integrated land data base, to serve the functions of State government. The investigations concluded that there existed a need for a centralised and integrated land information system but that it should be developed in stages. The Land Ownership and Tenure System (LOTS) was developed as the first stage of such a system. Conceptually, LOTS is designed as a multipurpose data base, gathering information from a variety of sources, centralizing it in one comprehensive recording system and making it available to numerous remote enquiry locations. In practice, LOTS comprises two main files:

- the LOTS File, holding proprietorship and sales details and incumberances and conditions for every land title parcel and updated daily by transactions input as part of the daily work flow of the Land Titles Office.
- the Valuation File, holding such data items as land value, improvements, land use, zoning, availability of services for every tax assessment and rating parcel, and updated weekly as a result of transactions input as part of the day-to-day operations of the Valuer General.

All information in LOTS can be readily accessed by any member of the public or any government department.

To complement LOTS, a geographic data base has been proposed as a central and accessible data base of coordinates for the boundaries of every land parcel in the State. The system is seen as providing for the spatial analysis and display of data in the LIS (see HILL, 1977). Future stages of the total LIS subsequent to LOTS include:

- a computerised title system
- a planning information system
- an underground services system
- a data bank of survey data
- a data bank of soil tests (SOUTH AUSTRALIA, 1977).

Significantly, these and other existing data files are seen as peripheral to the central property-based LOTS files. The development of LOTS is fully described in SEDUNARY (1977, 1980, 1981).

Developments in property-based planning information systems have been confined to a few independent and uncoordinated developments at the local level, without any assistance from national government. The comparatively low level of activity in this area can be explained by the character of local government in Australia. Recent surveys of computer usage in Australian local government (DAVIS & WALKER, 1978, MOORE, 1977) confirm the overseas experience that the main usage of computers is for the routine processing of basic administrative functions and accounting. However, the relatively small populations served by individual local governments in Australia, and the comparatively fewer services which these agencies provide has meant that only the larger city councils have been able to economically justify the processing of this basic administrative data for strategic planning purposes. The highly urbanised character of Australian society, however, implies that these few systems will form an important component of any future LIS both as a contributor to, and user of the system. The Council of the City of Sydney currently operates the most advanced system which is based on the design principles of the British LAMIS system. The system is described in detail in NASH et al (1973b), NASH & MOLL (1976), BRADY (1978).

1.4 Purpose and Format of the Thesis

A precursory definition of a LIS is a computer system designed to aid in the collection, storage, maintenance, processing and dissemination of data and information relating to land. Land-related data is defined as any data items to which a location can be assigned and which can be directly or indirectly spatially referenced by points, lines or areas. Land-related data can be categorised as relating to attributes of the earth's surface; man-made features; persons; activities associated with the land; or events occurring at specific locations (McCALDEN, 1974). The LIS itself is a property-based information system, that is its data base comprises a single record for every parcel of land within its jurisdiction. Property-based data is therefore defined as that subset of land-related data which can be attached to a single land parcel or grouping of land parcels. It is the fundamental integrating role of the land parcel and the general utility of cadastral maps which enable this property-based LIS to service a wider variety of land-related functions.

LIS development can be viewed in its present context as an attempt to improve the availability, quality and utility of property-based data through the use of computer technology. This development has been initiated primarily in response to operational problems with existing manually oriented land record systems and to the inability of these systems to provide timely, accurate and useful information for administration and planning. When viewed within the context of the evolution of cadastral systems, LIS development can be seen as the eventual outcome of current cadastral reform measures.

The main aims of this thesis are:

1. *To assess the strengths and weaknesses of the Australian cadastral system from the point of view of LIS development.*

It adopts the view that the Australian cadastral system is not presently of the form or quality necessary for LIS implementation. Reform of the system is therefore a necessary prerequisite for LIS development. However, the Australian cadastral system is unique, with its own existing cadastral data sources and procedures on which an LIS can be built. A unique approach to cadastral reform is therefore required. For example, the classical phased approach to reform is inappropriate to this task as adequate registration of title and significant progress in LIS development have already been achieved prior to the introduction of large scale mapping.

2. *To formulate a conceptual model for a LIS designed to operate within the existing Australian cadastral framework.*

The model is offered in response to the urgent need expressed by the 1981 resolution of the FIG Commission 3 to "try to elaborate a conceptual framework for LIS and make efforts to elaborate a common terminology" (INTERNATIONAL FEDERATION OF SURVEYORS, 1981).

3. *To establish principles for the design of an efficient LIS and to establish principles for its successful implementation and operation.*

These principles and the conceptual model to which they apply are considered transferable to all State governments. They are also considered essential to the successful development of a LIS which is to efficiently perform its role as an aid to the administration and planning functions of government.

4. *To detail the conceptual model by describing each of the main subsystems and by devising procedures for their creation and implementation.*

The approach which the thesis has taken to fulfill these aims is to examine overseas and Australian LIS programmes and to selectively apply many of their successful features to the specific task of designing an Australian LIS. Only a few aspects of system design have been derived from experimentation. The overseas programmes which have contributed most to this research are the Land Data Bank Project of the Swedish Central Board for Real Estate Data, the cadastral reform programme of the Canadian Maritime Provinces Land Registration and Information Service, and the British National Gazetteer Pilot Study. A considerable amount of material has also been drawn from reports of the South Australian Land Ownership and Tenure System and to a lesser extent, the feasibility studies associated with the Western Australian (P.A. CONSULTING SERVICES PTY. LTD., 1979) and Northern Territory (P.G. PAK-POY AND ASSOCIATES PTY. LTD., 1976) Systems.

It is important to establish that the thesis concentrates on the technical issues associated with LIS development. Institutional problems are not discussed in detail, even though it is recognised that these problems may determine the ultimate success of the system. As well, it is not the intention of the thesis to remove the "within context" considerations of system design by analysing information systems in terms of their elements (data management, data acquisition, data input and storage, data retrieval and analysis, information output and information use subsystems). Its aim is not to establish criteria for the comparison and evaluation of alternative system designs but to establish principles for the design of an efficient system for Australian conditions. Similarly no attempt has been made to quantify the costs and benefits of system implementation or to quantify the costs of alternative approaches and designs. Procedures for ongoing evaluation of system performance are also not considered.

The following two chapters deal with the reform of the Australian cadastral system in preparation for LIS development. Chapter 2 discusses the strengths and weaknesses of the Australian cadastral system and attempts to show that its present form has evolved more from historical institutional factors than from a desire to satisfy contemporary requirements. An integrated surveying and mapping system for urban areas is formulated in chapter 3 in response to the deficiencies of the present concept of integrated surveys.

Chapter 4 is the key chapter of the thesis. It identifies the main operational problems of the existing manually oriented land data system, formulates a conceptual model for the LIS, and establishes principles for the design, implementation and operation of the LIS.

The remaining chapters discuss in detail the major subsystems comprising the conceptual model. In chapter 5 a primary land parcel identifier is selected for use as the key for the LIS Base File and Central Index. The design and creation of the Central and Peripheral Indexes are also described. A theory of spatial referencing is presented in chapter 6 and methods for the spatial referencing of land parcels are compared. Chapter 7 formulates a file design for the Digital Cadastral Data Base (DCDB) as the base file of the Spatial Referencing System, and devises an efficient digitization procedure for the creation of the basic DCDB files. Design principles for land-related subsystems are briefly described in chapter 8.

Final conclusions are given in chapter 9.

2. THE AUSTRALIAN CADASTRAL SYSTEM: STRENGTHS & WEAKNESSES

2.1 Introduction

The purpose of this chapter is to examine to what degree the Australian cadastral system exhibits the characteristics of an efficient cadastral system as presented in 1.3.1. The following assessment is based on the principle that the nature and extent of reforms required to implement the LIS will depend to a large degree on the nature and scope of existing cadastral arrangements.

As a preliminary step in this process, the place of cadastral operations in the existing administrative structure is established. This will also serve as a framework for the examination of present land data organisation in chapter 4. As a first approximation the governmental system of Australia may be regarded as hierarchical, with three principal strata: Federal, State and local government (see figure 2.1).

> "Each of the strata can be further subdivided, though the principal divisions within a stratum are vertical rather than transverse.
>
> [The] divisions between the strata represent abrupt and significant changes in the scale and data homogeneity. Data gathered by Federal agencies.... will generally be available in the same format and degree of detail for all parts of the nation. Data bases serving the functions of State Governments will be confined to that state, and will not in general be compatible with data gathered by the corresponding agency in other states. Indeed, it may well be that there will be no strictly corresponding agency, or data series.
>
> At the lowest stratum there is a large number of authorities with administrative or service responsibilities at a local or regional scale. Among these are Shire and City Councils, electricity, water and gas supply authorities, and bodies concerned with regional planning and development" (McCALDEN, 1973).

Traditional cadastral functions of valuation, land registration and cadastral survey are exclusively State responsibilities. There is, however, some overlap between these responsibilities within the State stratum and, in the case of cadastral mapping, between State and local government. Local government also maintains valuable property-based data which comprise

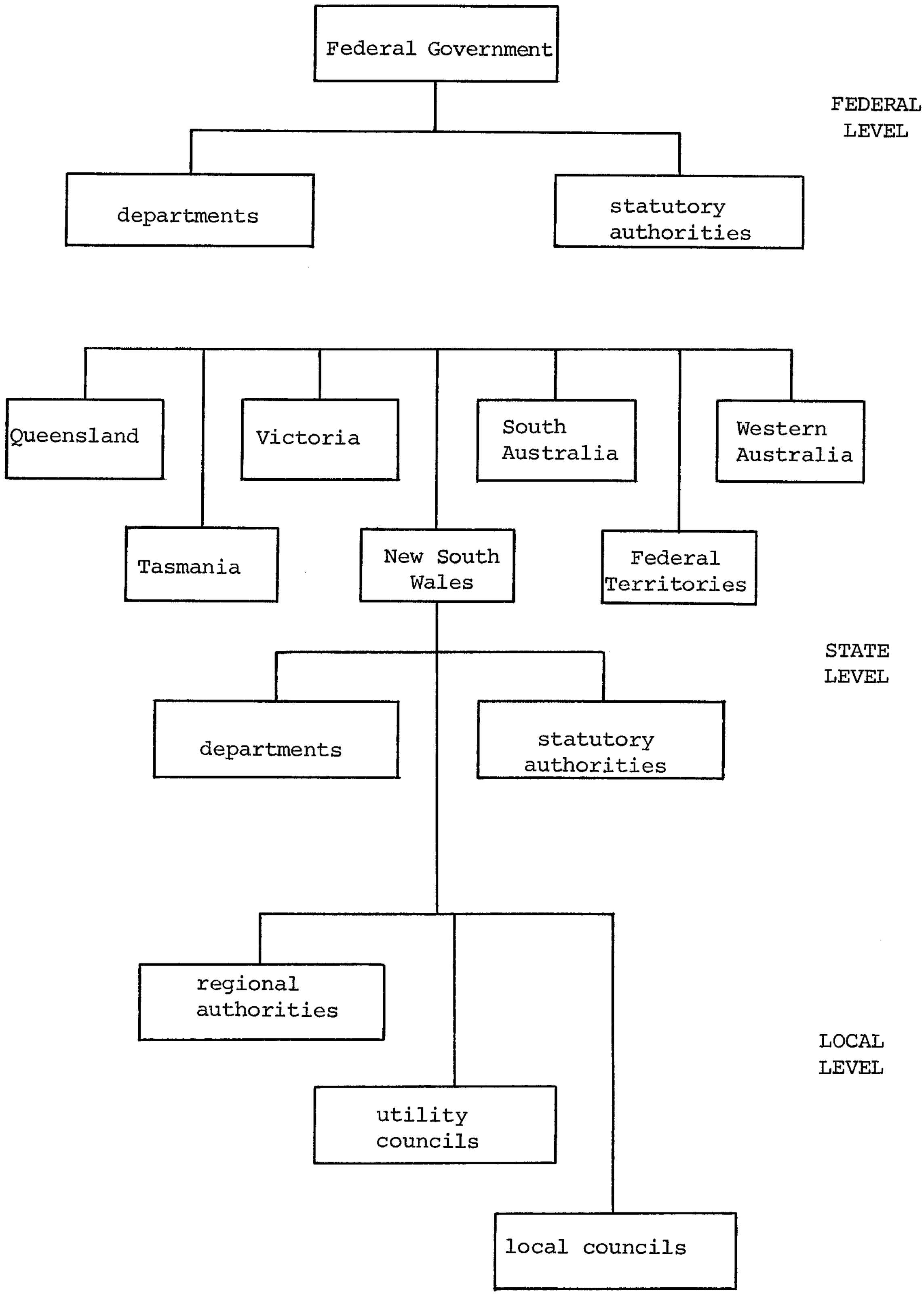


Figure 2.1 The structure of Australian government (after McCALDEN, 1973).

a large proportion of the land records residing outside the cadastral framework.

Within State government, present day cadastral organisation reflects the original pattern of land settlement and the machinery established to meet the immediate needs of the colony. When the Australian Continent was first settled in the early 19th century, the major land policies of the early colonial government were:

- to make land available for development;
- to create and maintain a system of conveyancing which permitted ease of transfer of interests in land; and
- to give owners of land security of tenure.

The Department of Lands or Crown Lands Office (CLO) in each state under the Surveyor-General was given the responsibility of implementing the first of these policies while the Department of the Registrar General or Land Titles Office (LTO) administered the second and third policies. In practical terms the former agency is responsible for the administration and some management of Crown tenures and the alienation or granting of Crown Land to settlers to be held in freehold estate. Once land has been alienated, subsequent transfer and subdivision becomes the responsibility of the LTO.

The early introduction of the Torrens Title System in Australia around the mid 19th century has meant that today, the vast majority of land titles in all states are registered under this system. The Torrens system not only had a major effect on the cadastral records system, but also on the standard and practice of cadastral survey. The LTO provides a well regulated administrative mechanism for the recording of all changes in ownership and all parcel mutations and consequently forms the central component of cadastral arrangements in each State. As there is little variation in title registration procedures between the different states, the Australian cadastral systems can be adequately reviewed (with some generalisation) by describing the New South Wales (N.S.W.) system. The evolution of the cadastral record and survey systems are now reviewed up until the modern era of cadastral reform in the early 1960's.

2.2 The Cadastral Record System

The origins and principles of the Torrens system were described briefly in 1.2.3. The same Torrens statutes, with minor amendments, continue to regulate the subdivision, conveyancing and registration of all freehold land. The exception is freehold land alienated prior to the Act, which remains under the provisions of the various Deed Registration Acts and is commonly referred to as Old System title. Each certificate of title comprising the Register contains the following information:

- legal description
- name of land holder
- exceptions, reservations and conditions contained in the grant
- exceptions of minerals etc
- restrictions as to user
- rights of way
- easements
- mortgages
- leases
- caveats.

SIMPSON (1976) explains that, basically the Torrens idea was derived from the relatively simple principle that records of the sort normally kept by any competent land office for Crown leaseholds could also be kept in respect of freehold grants, and could be readily implemented as with the present any title good at the time of grant could easily be kept good by efficient record backed by law. The machinery measures of the Torrens Act were designed to achieve two goals:

- the promotion of a simple, efficient, public record of title to land
- the guarantee of the contents of the record (TOFT, 1968).

The basic management concepts which the Torrens system employs to achieve these goals have been described by RUOFF (1957) as:

- *the mirror principle,* whereby the present state of ownership is reflected accurately and completely by the Register alone

- *the curtain principle,* whereby the Register is the sole source of data and no further historical search is necessary beyond the Register
- *the insurance principle,* whereby a bona fide owner who is contradicted by the Register is reimbursed from an insurance fund if, through human frailty, a flaw appears in the mirror.

In the early days of settlement in Australia, there was little need for the valuation assessment of land for taxation purposes, because the primary goal of land policy was to encourage the settlement and development of land. Today, a major portion of local government revenue is raised from taxation on unimproved values. The statutory function of the Valuer General is to determine the values of land properties and to provide that statutory rates, taxes, duties and contributions are based on these values. In support of this function, the Valuer General is required by statute to establish and maintain a Valuation Roll of all ratable lands other than Crown Lands. The N.S.W. Valuation of Land Act, 1916 requires that a Valuation Roll be compiled for each local government district which is to be a valuation district for the purposes of the Act. The Roll may be in a form to be decided by the Valuer General, and is to include (so far as is practicable);

- valuation number
- postal address
- name and address of owner
- name and address of lessee
- situation, legal description and dimensions or area of the land
- nature of improvements and/or property classification
- unimproved, improved and assessed annual values.

There is also a statutory requirement to supply copies of the Valuation Roll (Valuation Lists) to all local government councils.

Because of their rating power, councils are concerned with individual parcels of land and are therefore important both as users of data relating to land use and occupancy, and as sources of update information (McCALDEN, 1973). HANNA (1979) lists some of the property-based data held by local government as:

- ownership and certificate of title
- property improvements
- development applications
- building applications
- land area
- floor area
- land use
- substandard buildings
- places of heritage significance.

While the content of these files will vary, particularly between States, it is clear that they constitute a valuable source of up to date property-based data.

The principal deficiencies of the present cadastral record system are apparent when compared to the model of an efficient cadastral system presented in 1.3.1. These deficiencies stem primarily from the outmoded organisational structure in which the system operates, and the failure to preserve the principles of the original Torrens management concepts and administrative procedures.

1. *In its present form, the Torrens Register does not lend itself to automation; and the integration of title, valuation, local government and other land parcel record systems is restricted because of the lack of common identification keys.*

Original Torrens management concepts and administrative methods remained unaltered in N.S.W. for approximately 100 years until the reforms of the early 1960's (see 1.3.2.). At this time, reforms were initiated to remedy some of the deficiencies of the system which had begun to complicate the process of conveyancing. The principal administrative deficiencies of the system at this time were seen as:

- the lack of an adequate charting map series as a key to the register from which a current certificate of title could be obtained directly
- the retention of a partially cancelled certificate after subdivision as the current reference for the residue

- the binding of certificates within a book preventing the purging of dead matter and restricting access to the register.

The changes included the introduction of loose leaf titles in 1961 which discontinued the practice of folios being bound into volumes thereby permitting the purging of those certificates which had been cancelled. In 1972 approximately half of the 2.5 million titles were dead but unculled (GRIFFITH, 1972). As early as 1961 a general policy was adopted to limit one certificate of title to one parcel. In 1966, the eleven different categories of survey plans were refiled into one comprehensive numbering series in preparation for their anticipated metrication and microfilming. This action had the effect of providing a unique parcel identifier (plan/lot number) for over 95% of parcels on the register. The creation of the Land Index in 1968 linked this parcel identifier to its volume/folio number. In most cases the necessary reforms are of a minor nature and their application to LIS development is discussed in chapters 4 and 5.

2. *The Torrens Register does not provide complete coverage for all land parcels.*

From its inception, the Torrens system was designed to deal only with alienated land. The continued separation of the administration of Crown and Freehold tenures has meant that the registration and conveyance of rights under Crown licenses, leases, conditional purchases and other Crown tenures continue to be carried out in various departments. For example, in New South Wales, records are kept in the Lands Department, Water Conservation and Irrigation Commission and Western Lands Commission. Mining leases and authorities to mine are also administered in the Mines Department. Each agency also maintains its own survey records and operates its own systems of registration (see DARBY, 1979). The continuation of these arrangements is clearly not in the best interests of efficient land administration. Also, a significant number of parcels remain recorded in the Deeds Register (approximately 150,000 of the 2,000,000 parcels in the case of N.S.W.) (GRIFFITH, 1972). The Torrens Acts have always provided for any owner of Old System land to voluntarily bring his land under the provisions of the Act. The original legislation, however, offered little incentive to the land holder to convert, while the purchaser of title under the Old System derived no immediate benefit from paying for his title to be investigated and an accurate plan of survey prepared. In this regard, the costs of investigation have been cited as a major inhibiting factor to conversion:

> "In many cases the expenditure involved in investigation has not been warranted, when considered on the basis of probable risk. Less rigorous initial examination would have been possible if the Assurance Fund had been made more flexible to cover cases of error in the Mirror due to incomplete investigation..... It is considered that Australian practice has tended to be too conservative" (TOFT, 1968).

While the amount of Old System land gradually decreased under voluntary conversion, continued subdivision and conveyance of Old System land saw a steady increase in the number of Old System parcels and consequently, the continued growth of the Deeds Registers. Compulsory conversion upon subdivision is therefore necessary to restrict the growth of the number of Old System parcels. Finally, if the Torrens Register is to be completed at a certain time in the future, a systematic conversion programme under the initiation of the Registrar General will be needed.

3. *The Torrens Register is not final on the existence of other interests in land.*

In any conveyance, a prospective purchaser must also conduct a search of land records maintained outside the Titles Office. SEDUNARY (1977) explains the gradual erosion of the mirror and curtain principles of the original Real Property Act in the following terms:

> "This Act provided, not only a simple and efficient record from which a comparative layman could obtain the complete details of rights, charges and conditions affecting land - together with a proprietor whom he could regard as the absolute owner. This situation successfully existed until the economic upheavals of the depression and the second world war. Since then the rights of this "absolute" owner have become progressively eroded by a series of economic, planning and environmental legislation - each Act contributing to an increasing confusion that once again requires interpretation by a trained professional."

A South Australian study identified no less than 50 different Acts that can restrict the use of a land parcel in that State (SOUTH AUSTRALIA, 1977). Constraints included:

- zoning and use restrictions
- density and floor space ratio controls
- parking provisions
- setbacks
- landscaping and preservation
- scenic foreshore protection
- proclaimed water catchments
- nature conservancy areas.

A similar situation would be expected to exist in all other States.

2.3 The Cadastral Survey System

Within the confines of the early settlements, the marking and measurement of land could satisfy the immediate requirements of the time. However, as settlement spread into the vast expanses of territory to the West and South of New South Wales (especially in the random alienations which resulted from the rapid migration of settlers) problems of parcel definition began to occur. The limited surveying resources of the colony were severely stretched to keep pace with this rapid expansion of settlement. The measures introduced to meet the needs of early settlement have had a profound effect on present cadastral survey practice. BARRIE (1976) describes the early situation thus:

> "The guiding principle behind most early surveys - in fact, most title surveys until well past the middle of the 19th century - was to measure and demarcate land holdings by the cheapest and most rapid means possible. In the short term this was really the only rational and possible method which could be justified, having regard to the pressing logistic difficulties and the value of the land. For so sparse a population spread over such a large territory, the introduction of a sophisticated and expensive system could not have been justified - nor would it have been tolerated."

The demands of settlement gave rise to an "isolated" survey system in which each parcel was surveyed as a single entity, and marks placed at the corners and turning points of the boundary. These monuments were then related numerically to one another by measurement. Demarcation of boundaries by artificial corner marking rather than by natural boundary features was necessary because of:

- the lack of any substantial natural features to serve as stable monuments for the original grant boundaries
- the sporadic nature of settlement which resulted in odd-shaped blocks often unrelated to topography (TOFT, 1967).

The quality of these early measurements was generally poor with distances often paced and understated, and directions related to a local magnetic bearing. Marking was not durable, and was usually restricted to stakes at corners or blazed trees near the boundaries. Once the parcel was originally demarcated the position established on the ground at that point in time was forever the fixed position. In the event of dispute, the original marks are paramount to plans. That is, in the event of a boundary dispute, monuments prevail over measurements.

The introduction of the Torrens system saw a dramatic change in the philosophy of making surveys. As the act of registration made the Government the guarantor of title, land parcels comprised in the various titles needed to be unambiguously identified. Thus the quality of surveys and record had to be upgraded (BARRIE, 1976). To achieve this goal the Torrens Acts provided for the licensing of surveyors and had the effect of increasing the standard of accuracy and uniformity of surveys. The introduction of the theodolite and steel band around the same time also contributed to a general improvement in the quality of survey measurement.

The system of isolated surveys remains today as the established method of cadastral survey. The only major changes have been the introduction of stringent regulations controlling survey practice and the preparation of plans, and a further increase in the precision of survey. Present regulations require a relative accuracy of 1:8000 or better for most surveys in urban areas. Corner marking is now almost exclusively confined to the use of reference marks - a permanent mark selectively placed to provide for an azimuth and datum in retracement. The most commonly used reference mark is the buried iron pipe in addition to the concrete block and rock or drill mark.

The demands of the early alienation surveys on the limited financial and labour resources of the colonies (together with the extensive and sporadic nature of land settlement) also inhibited the establishment of control networks to provide a framework for the interconnection of scattered land grants, and as the basis for a uniform cadastral charting map. Connections between surveys were also not an economic means of consolidating the cadastral pattern. With the intensification of settlement, the connection of isolated surveys to previously surveyed portions became practical, and the compilation of Parish maps (to serve as a parcel index to title records) was commenced. Parish maps were compiled from individual portion (grant parcel) plans. However, even though the dimensions of each parcel were plotted to a reasonable accuracy, the accumulated errors derived from plotting, lack of adequate azimuth control, and the fact that no account was taken for earth curvature etc. made it very difficult to join adjacent maps (ELFICK, 1974). Attempts to establish State trigonometrical networks specifically to permit the production of a uniform cadastral mapping series were commenced in the mid to late 19th century. However, most were abandoned during the First World War and were not taken up again seriously until after the Second World War (see FLETCHER, 1968).

The deficiencies of the present cadastral survey system are now reviewed in terms of the characteristics of an efficient cadastral system presented in 1.3.1.

1. *The system lacks a uniform, accurate control network and coordinate system on which an integrated system can be based.*

Although the Australian Map Grid (AMG) has been officially adopted as the national coordinate system for all standard mapping, the Australian Geodetic Network upon which it is based has not been sufficiently densified and monumented in urban areas to permit the economic connection of all surveys. The progress of current control survey programmes is discussed in chapter 3.

2. *The system lacks a complete, comprehensive, standard, large scale (1:1000) urban mapping series based on the AMG which depicts all buildings and other structures and important natural features in addition to cadastral boundaries.*

Older style urban cadastral mapping usually took the form of "litho" maps, published in monochrome and compiled from individual plans of survey deposited by surveyors. These plans generally depicted cadastral (boundary) information only and were usually not based on a local control network (TOMS, 1978b). While these plans were adequate for indexing title records in the Titles Office, their geometric instability and lack of topographic detail made them unsuitable for planning, administration and other purposes. Following the completion of the Australian Geodetic Survey in 1966, mapping programmes have been commenced in each State to produce large scale topographic and cadastral maps based on the AMG. These maps have generally been compiled by the delineation of the cadastral pattern as evidenced by occupation depicted on the line or orthophoto base map. Techniques used in the production of these maps are described in Chapter 3. Map scales and content vary considerably between the States. However, not all maps meet the criteria proposed in 1.3.1. For example, the 1:4000 orthophotomap series for urban areas in New South Wales (see URBAN, 1973) was originally devised as a compromise to the high costs of conventional 1:2500 mapping (FLETCHER, 1970, 1973) and consequently fall well short of the 1:1000 line mapping envisaged in 1.3.1 which is based on the specifications of most European cadastral maps and the British Ordnance Survey series.

3. *There is no finality in the cadastral survey system in that boundary evidence must be continually reexamined in order to reestablish each boundary.*

Unlike the Continental title registration system, Torrens legislation does not extend the guarantee of title to cover survey deficiencies. As KONECNY (1969a) explains:

> "Presumably, regulations covering the survey, the monumentation of boundary monuments and their upkeep were easier to establish under Code law than under Common English law. But it may also be true that the Torrens system could not give legal significance to land boundaries because these were not as well established as in Europe."

Uncertainty of boundary location stems primarily from the use of impermanent and invisible artificial marking. The unsatisfactory nature of original marking is directly responsible for continual reassessment of boundary evidence becoming an accepted part of the boundary reestablishment process. As WEST (1974) explains:

> "it is clear that boundaries of land are where they were created originally and to define them many years later is a matter of arriving at a conclusion based on the evidence available from survey in the field and investigation of the relevant plans and documents."

For the purposes of boundary retracement, it is recommended that the surveyor be armed with all relevant survey information including the basic plan and nearby surveys and may also require information from title searches and specialised information from departments outside the Titles Office and/or Lands Department (HAMER, 1967). Boundary retracement is therefore often a complex process which usually necessitates some form of survey based on the assessment of this evidence. A rough guide to the priorities to be given to evidence in deciding on the location of fixed boundaries have been recommended by HAMER (1967) as:

- natural features,
- original Crown markings of grant boundaries,
- monuments,
- original undisturbed markings of private surveys,
- occupations, and
- measurements (including coordinates).

This ranking is based on the principle that most weight should be given to those matters about which the parties at the time were least likely to be mistaken. This plan searching and continual reexamination of boundary evidence (needed to ensure a satisfactory relocation of a boundary) becomes more complicated and costly over time. The mirror and curtain principles, the fundamental features of the Torrens title system, do not apply in the survey system.

Continual resurvey of boundaries has also become a major feature of retracement procedures primarily because of the dependence on "reference" as opposed to "witness" marking. Witness marks are a permanent mark placed near a corner mark to relocate a corner without the need for resurvey to adjacent corners. These are seldom used and are not required by legislation. The absence of witness marks necessitates an extensive resurvey when boundary relocation is required, so much so that relocation of boundaries has become synonomyous with "resurvey" *(TOFT, 1968)*.

One measure implemented to offer some protection in this regard (in addition to licensing of surveyors) is the examination of all plans submitted to Titles Office. Plan checking involves the comparison of submitted plans with previously registered surveys and is usually confined to a comparison of measurements on plans. Field examinations are infrequent. A second security measure designed to counteract the uncertainty of boundary location is the identification survey. An identification survey is a surveyor's report normally required by the legal profession and lending authorities in connection with most conveyances and practically every mortgage of urban land. The survey is in effect a reexamination of the physical facts on the ground and involves the precise definition of the parcel boundaries and the determination of the relationship of any structures within the property to those boundaries. Marks are not usually placed. The purpose of the survey is to identify the land, to determine whether there has been any encroachment and to certify compliance with local government ordinances, e.g. distances of walls from the side boundaries (WEST, 1974). The identification survey is a matter between the surveyor and his client and is not required to be recorded in any public register.

4. *No provision is made for the continuous updating of the cadastral and topographic information depicted on the maps.*

Each State mapping agency generally updates its cadastral master sheet as changes to the pattern occur. However, prompt dissemination of this information is necessarily restricted to copies of the master. Agencies are therefore forced to accept periodic updates or implement their own updating mechanisms. The Land Titles Office (as the agency which processes parcel mutations and subdivisions) is the agency best placed to provide continuous updating. However, it does not regard itself as a mapping agency and is reluctant to provide copies of its up to date cadastral index mapping to external agencies. These arrangements have therefore lead to considerable duplication, delay and incompatibility in the updating of cadastral map data. For example, a New South Wales study (INSTITUTION OF SURVEYORS, N.S.W. 1977a) revealed three main sources of large scale cadastral mapping for the largest city in that State - the State's own mapping agency, the Land Titles Office and the Metropolitan Water, Sewerage and Drainage Board. The study subsequently found that considerable duplication existed between these agencies and the five other utility agencies servicing the same area. Mechanisms for the updating of topographic detail are even less satisfactory and are generally restricted to periodic, wholesale resurvey. For example, FLETCHER (1973) states that the adopted revision programme for the 1:4000 urban topographic maps in New South Wales is every 3 to 5 years and simply involves the acquisition of new orthophotography. Possible existing mechanisms for continuous updating of cadastral and topographic data are examined in chapter 3.

2.4 Summary and Conclusions

The comprehensive coverage provided by the Torrens title system and the sound administrative procedures under which it operates, provide a solid basis upon which to build a LIS. Only minor reforms will be required to incorporate all land parcels in the Register and to ensure unique identification of all land parcels. These reforms will also make the Register and registration procedures more amenable to automation. Additional measures may also be required to register interests not currently endorsed on the certificate of title. Details of these reforms and their place in the framework of LIS development are discussed in 4.4.

The present cadastral survey system provides a relatively secure definition of boundaries for the purposes of guaranteeing title. This security, however, is not sufficient for the State to guarantee the related survey records, and can only be maintained by supplementary measures such as plan checking and identification surveys which add to the overall cost of the system. In order to meet the requirements of an efficient cadastral system, the following reforms will be necessary:

- the densification of the control network in urban areas
- the integration of cadastral and other surveys into a homogeneous system based on this network
- the provision of mechanisms for the automatic and continuous updating of cadastral and topographic maps.

It is argued that these reforms cannot be successfully implemented without a major reassessment and reform of current boundary definition practice. This conclusion is based on the realisation that these practices (and the principles upon which they are based) have evolved over the last 150 years under the influence of a number of factors which are no longer in operation in the contemporary urban environment. The main argument in support of this conclusion is that the precise measurement of boundaries is no longer necessary in an integrated survey system based on a densified control network. The improvements to survey practice which occurred soon after the introduction of the Torrens System, have tended to create the idea in the minds of surveyors and lawyers in Australia that precise measurement is a necessary feature of the Torrens System. While improvements were necessary in order to guarantee title, it is the degree of precision of measurement which is under question. The association of Torrens title with precise measurement has been reinforced by the introduction of theodolite and band technology around the same time as Torrens legislation. However, it must be recognised that precise measurement was originally introduced so that (in the absence of a control network) a uniform cadastral charting series could be built up "from the part to the whole." As the survey fabric consolidated, precise measurement continued to be used to substitute for the inadequacy of original monumentation. Such measurements were essential to control the propagation of errors in individual surveys which will occur in any system which needs to adopt the reference marking of adjacent surveys as a datum for new survey work. As BARRIE (1977) concludes:

> "the motivation to impose increasingly stringent standards on surveys for land description has been based upon the need to inhibit the growth of errors in surveys *and not upon the inherent demands of parcel description.*"

Demands for increasing survey precision have continued up to the present, partly in response to improvements in measurement technology and partly in response to the uncertainty which the crude measurements of earlier surveys had created in boundary definition. DALE (1976) also identifies the plan checking process as being partly responsible for the entrenchment of precise measurement in the system:

> "There has, throughout, been undue emphasis on measurements as evidence as to the position of the original boundaries, in part because of an insistence by most Registrars General that they must examine surveys. Since, in general, they have had no survey background, they have had to rely on the most basic and obvious form of evidence, namely, that of measurement."

That precise survey is not an inherent feature of a State guaranteed title registration system is evidenced by the successful application in Britain of the "general boundary" rule which defines boundaries by physical features, supported by graphical description in the form of large scale maps. The success of this approach can be attributed in part to the highly stable nature of the physical urban environment (see 1.2.3). Contemporary Australian society is now highly urbanised in character. The vast majority of the population now lives in urban areas where a wide variety of substantial and well defined physical details exist which could serve as permanent, visible monuments for the definition of boundaries. As well, most boundaries are now delineated by linear features in the form of fences, walls etc. It therefore follows that, once the control network becomes sufficiently dense to permit the connection of all cadastral surveys in urban areas the precision with which boundaries are presently measured can be relaxed. It would also seem appropriate to make greater use of existing "natural" monumentation in these areas.

Current survey integration proposals, however, fail to appreciate that the present cadastral survey system is more a product of its past than a system designed to operate within the contemporary urban environment and designed to satisfy contemporary requirements. The Australian integration concept attempts to immerse traditional "isolated" practices into the framework of an "integrated" system. Consequently, attempts to reform the cadastral surveying and mapping system have been stifled by the desire to retain traditional practices. This has had the effect of inhibiting the three necessary reform measures in the following ways:

- the accuracy specifications of the control network (which are designed to meet current cadastral accuracy requirements) make densification a costly and protracted process.
- the continued dependence on artificial and invisible monumentation (when existing physical detail could serve this purpose) perpetuates the insecurity and costs associated with the present system.
- the failure to utilise this existing detail for boundary definition means that cadastral and topographic survey operations continue to be mutually exclusive.

Chapter 3 examines the present approach to reform of the cadastral survey system (as expressed in the concept of survey integration) and based on the preceding arguments, proposes a new approach to the implementation of an integrated surveying and mapping system in Australia.

3. AN INTEGRATED SURVEYING AND MAPPING SYSTEM

3.1 Introduction

Reform of the Australian cadastral survey system is currently taking place within the framework of survey integration proposals formulated during the late 1960's. The principles of survey integration currently being practiced in Australia, have their origins in North America in the late 1950's. McLAUGHLIN has defined the classical North American concept of an integrated survey system as:

> "a system of survey in which there is a common spatial referencing framework upon which are integrated the various types of public and private surveys (photogrammetric base mapping, cadastral surveys, engineering surveys, utility surveys, etc.). These surveys are further integrated in the sense that there is a common examination process and a common process for recording the spatial information generated "
>
> (CHRZANOWSKI & DORRER, 1977).

McLAUGHLIN also acknowledged the strong influence of European surveyors in the initiation, formulation and promotion of these reforms. It is therefore understandable that the proposed system exhibits the characteristics of the European survey operations described in 1.2.3. This is a significant factor in the following analysis of the appropriateness of these reforms to contemporary Australian needs.

Principles of survey integration in their classical form - are described in more detail in 3.2. Essentially, survey integration involves several technical and administrative reforms which are designed to establish a homogeneous system of survey data which will overcome the inherent shortcomings of existing survey practice. At the heart of these reforms is the breakdown of the national control network to a sufficient density to permit the economic connection of surveys to the control marks. Legislative measures are also required for the proclamation of such areas and for the centralisation of the results of survey to enable survey data originally acquired for one purpose to be used for a variety of other purposes.

The concept of survey integration, introduced into Australia in the late 1960's, was partly inspired by reports of the reforms taking place in the Maritime Provinces on Canada (see ANGUS-LEPPAN, 1967). The principles formulated at this time certainly exhibit the same characteristics of the Canadian proposals (see FLETCHER, 1969a).

Reforms have generally been implemented through the amendment of the existing Survey Coordination Acts which had been introduced in the late 1940's in the Eastern states but which had proven ineffective in their intended purpose to rationalise survey activity. The failure of these Acts and the proposed reforms are also reviewed in 3.2.

Although introduced primarily as a means of rationalising survey activity, survey integration provides the necessary technical and administrative basis for the introduction of an efficient cadastral survey system described in 1.2.4. More than a decade ago, BLACHUT (1969, 1971b), KONECNY (1969a, 1969b, 1971) and other North American surveyors further refined the integration concept and shifted its emphasis away from meeting the immediate and specific needs of surveyors towards providing the basis for a large scale topographic and cadastral surveying and mapping system of far greater scope and significance than its original purpose. The ability of the proposed reforms to keep the large scale mapping system up to date was of particular importance in this regard.

The broader scope of survey integration was also recognised in Australia. For example, MORGAN (1973) defined survey integration as:

> "an all embracing system which should provide for the capture, storage, analysis and disposal of all survey data related to all Earth Sciences. The disposal can be achieved through graphical, pictorial or digital media which includes maps, orthophotomaps, aerial photographs, survey plans, computerized data banks and microfilm."

As well, the draft survey integration legislation in New South Wales prefaced its proposals with the following:

> "Surveys are a means to an end; not an end in themselves. The government is aware that management of resources has reached that critical stage where decisions can only be based on complete and accurate information and the retrieval of the information from records must be rapid. An Integrated Surveys System provides the indexing base for a land information system data bank, from which the information for decision making can be obtained in the terms of completeness, accuracy and speed which are deemed necessary for the future" (INSTITUTION OF SURVEYORS, N.S.W., 1974).

However despite these sentiments, survey integration in Australia has remained primarily a system designed by surveyors to meet the needs of surveyors. The needs of users outside the survey profession do not appear to dominate the present concept.

After almost ten years of protracted and turbulent discussion on the subject of integration KENNEDY (1975b) was prompted to state:

> "In my view, integration in Australia is almost always discussed emotionally rather than rationally. Unfortunately it generally ends up in an argument about zone widths and therefore it takes a very narrow view of survey integration....It is seen as an end in itself and not as a means to an end. I believe that the problem was not thought through completely and that very little thought has been given to the part played by survey integration in national information systems. Rather, it seems to have adopted the short term view of merely linking all surveys to a national framework."

The narrowness of the concept in Australia is evidenced by the inflexibility and inappropriateness of several of its major technical features. These deficiencies, and the reasons for their existence, are the subject of 3.3. Chapter 2 has already identified the desire to retain "isolated" survey practices in an integrated survey system as a major contributing factor to the stifling of reform measures. A reassessment of cadastral boundary definition practice in urban areas is therefore a necessary prerequisite for reform.

That the integration concept is deficient and needs reform is evidenced by the fact that relatively little progress has been made in the decade since integration programmes began to be implemented in the early 1970's. Proclaimed survey areas have proven costly to establish, and support from government to densify the control has been difficult to secure. For example, by the mid 1970's, areas of densified control in Victoria comprised only a "very insignificant" part of the state (INSTITUTION OF SURVEYORS, VICTORIA, 1976d). The benefits of connection to control to surveyors are necessarily long term and governments are naturally reluctant to fund such projects.

Finally, the following review of survey integration and the recommendations made in 3.4 for an efficient integrated surveying and mapping system, are confined to urban areas where the majority of survey activity takes place. Discussion is also restricted to horizontal control.

3.2 Principles of Survey Integration

BLACHUT (1969) has stated that acceptance of the need for integrated surveys involves a decision on how best to meet the different requirements for survey work and products, in the nature of the products (graphical and numerical) their accuracy and extension:

> "The principal question that must be answered is whether it is more economical and efficient to provide cities with a uniform integrated surveying system that will take care of all these diverging requirements, or whether it is more advantageous to satisfy each demand as it arises, relinquishing in advance the functional integration and systematic updating of information."

Once the former option has been adopted, an appropriate system must be designed. The concept of survey integration is generally seen as providing the framework for a comprehensive and homogeneous survey system in each State. All surveys would be correlated by connection to the national control network and expressed in the form of plane coordinates. This information would then be lodged in a central plan register. Survey information would therefore be in a compatible form, and readily available to all potential users, thus avoiding expensive and wasteful duplication of survey activity. BROCKLEBANK (1966) listed the components of the integrated survey system as:

- monumented basic control network of density compatible with intensity of development, estalished to standard and appropriate accuracy specifications and with plan coordinates in a standard coordinate system;
- legal or cadastral surveys, tied to the basic control network and with all corners computed, or computable, on the standard plane coordinate system;
- engineering, location, topographic and other surveys tied and related to the coordinate system via coordinated property corners or the basic control network;
- plans or maps, at appropriate scales and to standard specifications, graphically protraying the inter-relationship of the above data to physical, cultural and topographical details, and
- systematic up-dating of surveys and plans in keeping with property subdivision, development and other physical and cultural changes.

An integrated survey system also denotes standardization and systemization of accuracy standards, specifications, monumentation, coordinate systems, map scales, map format etc.

KONECNY (1971) was one fo the first surveyors to redefine the survey integration concept in terms of the production of and maintenance of the large scale (1:1000) urban map which he claimed was a satisfactory scale for the compilation of a basic city map from which all other needed city maps may be derived (see figure 3.1). The information to be collected and depicted on the maps can be divided into three groups: ownership distribution, topography, and the utilities record. Ownership information consists of title boundaries including easements over land. Topography includes man-made features such as buildings, streets, footpaths, walls, fences, tunnels as well as natural features such as vegetation, spot elevations and contours. The utility record consists of water, sewerage, drainage, power, gas and telephone lines, most of which will be underground, together with all the pertinent installations and components such as poles, manholes, hydrants, etc. In addition, the physical urban environment is continually changing. Land is subdivided into smaller parcels, buildings demolished and new ones constructed, new services installed in streets, roads widened and expressways built. If these changes are not monitored in some way, then any large scale map will quickly become out of date and therefore be of questionable reliability.

The base map would initially be compiled by photogrammetric means. However, photogrammetry has its limitations. As ZIEMANN (1970) points out, it can only yield information which is recognizable on photographs. Therefore, while it can provide information on elevation, vegetation and man-made features all fixed in relation to each other; underground services, detail covered by the "lean-over" effect of buildings on aerial photos, easements and proposed developments can only be surveyed by field methods. If this information is to be correlated with, and of the same accuracy as the photogrammetrically derived data, then field surveys will need to be connected to ground control as well. Photogrammetry, being an interpolative method, will automatically base its data collection on the control network through necessity. The same situation does not necessarily apply to field survey methods. Legislation will therefore be necessary to ensure the connection to control, mathematical coordination and error analysis of field and survey results.

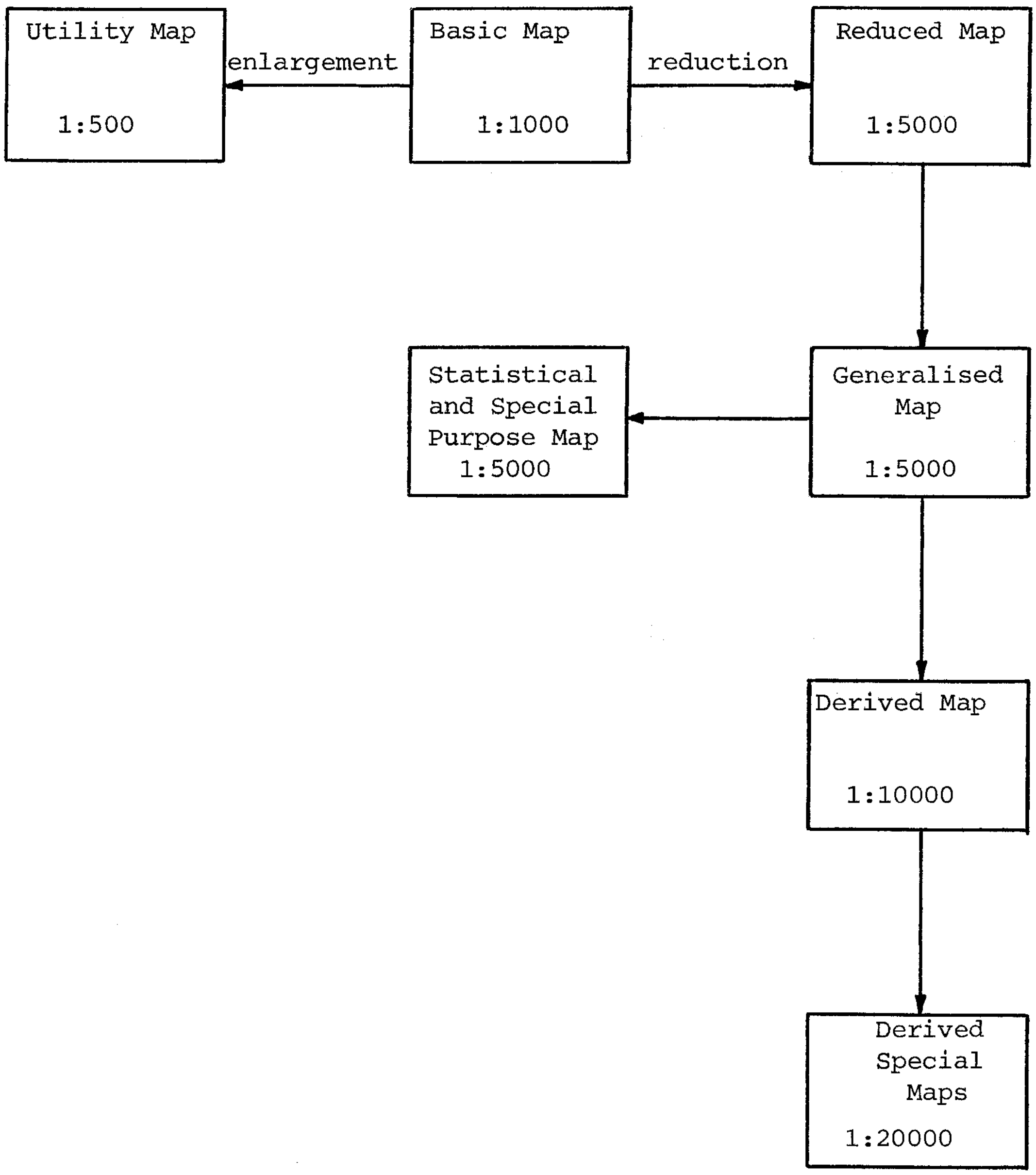


Figure 3.1 The basic city map as the central element component of the urban mapping system (after KONECNY, 1971).

By establishing a dense coordinated control network and by requiring all field surveys to be connected to this control, survey integration provides the capability to collect all the urban information described previously, in a compatible, homogeneous form. ZIEMANN also adds that photogrammetry is a mass-production method and so the smaller the project the less economical the method becomes. Therefore, it can only be used for the periodic updating of large scale maps (by taking new photography), and not for the continuous updating required by an urban mapping system. Changes in the urban environment will generally be recorded by some form of field survey, for example, plans of subdivision, engineering surveys. It is vital that these surveys, as well as being connected to the control network, be centrally collected so that they may provide a continuously up to date record of change in the urban environment. By enacting legislation to require the lodgement of all cadastral, engineering and other detail surveys in a central register, survey integration provides the means for continuous updating of the large scale base map series.

In summary, field and aerial survey complement each other in providing a complete record of the urban environment. Survey integration provides the means by which this information can be correlated and maintained in an accurate continually up to date, and homogeneous form. The constituents of such an integrated survey system are depicted in figure 3.2

Much of the legal and administrative machinery for survey integration in Australia has already been established under the Survey Coordination Acts and it is at this point which discussion will commence. FLETCHER (1969b)described the Survey Coordination Acts as a "belated and partial attempt to preserve surveys". The main purposes of the Survey Coordination Acts were:

- the development and proclamation of survey areas by the placement and maintenance of permanent marks.
- the connection of marks by precise surveys to the state triangulation system
- the compilation of registers of permanent marks
- the collection, recording and maintenance of details of surveys in all categories carried out by government, semi-government, and local government authorities and some Commonwealth Authorities.
- the supply of data, information and advice to authorities and the general public as required

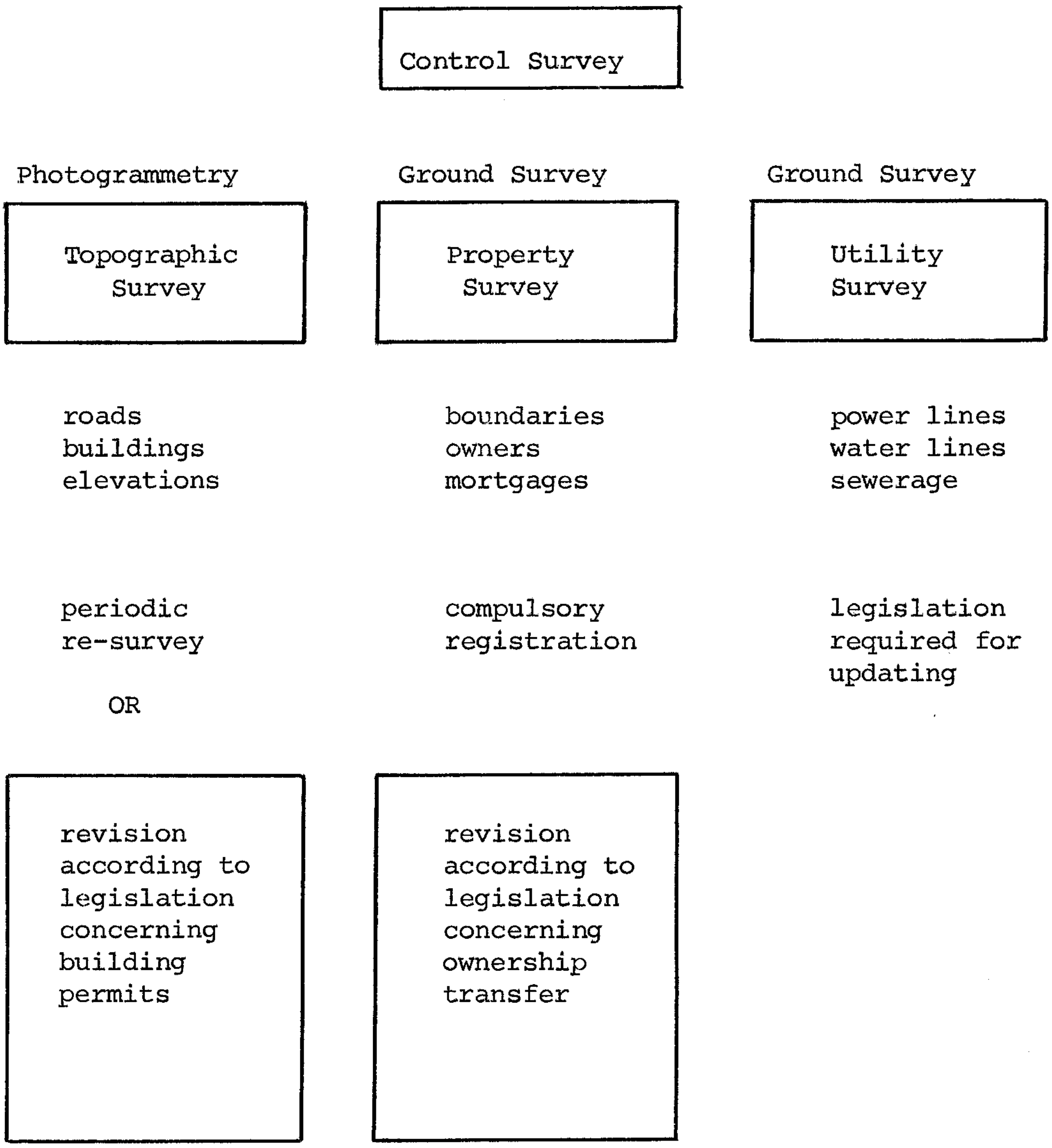


FIGURE 3.2 Constituents of an integrated survey system (KONECNY, 1978).

- the maintenance of records of "intention to survey" required for lodgement under the Act.
- the regulation of standards of measurements and accuracy and classification of surveys

(FLETCHER, 1970; INSTITUTION OF SURVEYORS, VICTORIA, 1976d).

The Acts required all surveyors (public and private) to connect their surveys to at least two permanent marks established in areas proclaimed under the Act. Submission of plans to the central register however, did not apply to private surveyors.

For several reasons, the Acts did not achieve their aims. As FLETCHER (1971) wrote:

> "It was envisaged that a system of monumentation would be extended rapidly over the state and that each survey would be connected to the Trigonometrical Survey.
>
> However, this aspect of survey coordination has failed for two reasons. Firstly, progress with the surveys has been far too slow and, secondly, no system of plan coordinates....was introduced to allow proper integration of all surveys. Furthermore, the Act provided only for connection to the control survey and not for the extension by coordinates from the control survey."

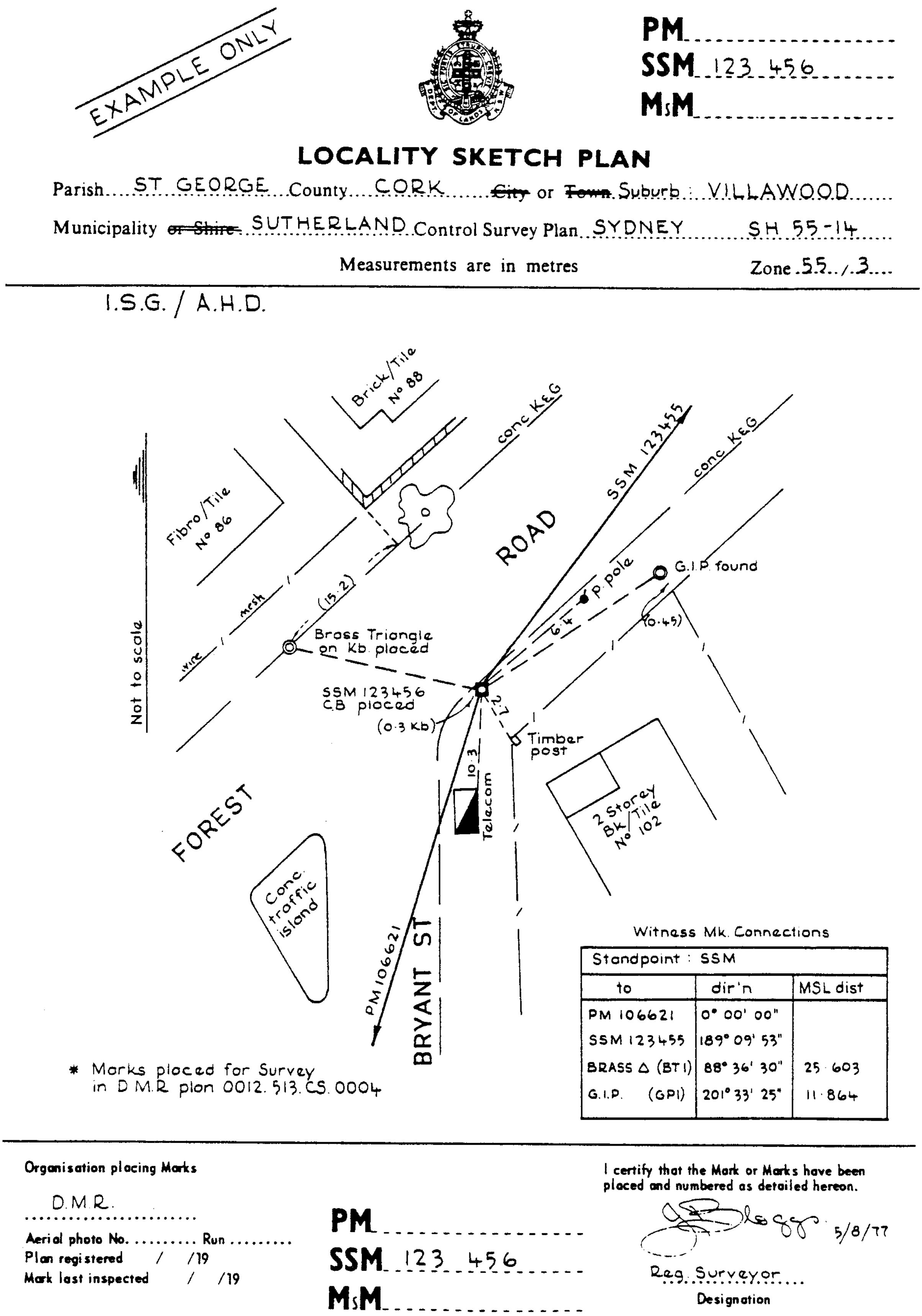
TOFT(1968) explained the fundamental weaknesses of the Acts in the following manner:

> "The Acts do not destroy the basic principle of an isolated system: that of working from part to whole. They do attempt to modify this principle by introducing a system of correlated surveys. That is, the parts of the whole may be connected to an unconformed whole.
>
> The Acts do not facilitate the diversification of survey methods because a plan coordinate system for general use has not been introduced with them.
>
> The Acts do not perceive the various fields of survey operations as comprising an integrated and systematised whole. Rather they maintain these fields as mutually exclusive and provide for connection between them.
>
> The full exploitation of a horizontal network of control is not possible if it is used only as an aid to connecting surveys rather than as an essential for survey."

With the publication of the Australian Geodetic Datum and the Australian Map Grid (AMG) in 1966, amendments to the Survey Coordination Acts were proposed for the densification and precise mathematical coordination of the national control network and the expansion of the Central Plan Register to include plans submitted by private surveyors.

The major technical features of the proposed integrated survey system were, and remain, the following:

- The adoption by almost every state of the AMG as the coordinate system for the integration of surveys. Only New South Wales has opted to create a special narrow zone (2°) projection of the Australian National Spheroid through a desire to minimise and preferably eliminate the effect of projection scale factor in the computation of survey coordinates. The arguments for this choice are given in FLETCHER (1969a). The main criterion for choosing the parameters of the new system was that the difference between projection and ground distances be not greater than 1:8000 (cadastral survey accuracy). The narrow zone system is compatible with the AMG and both grids appear on all published maps.
- The densification of control is seen as being implemented in stages, beginning with developing areas and progressively extended to established urban areas (OVERALL, 1974).
- The spacing of control points in the proclaimed survey areas varies between 200m and 500m (TOMS, 1978b).
- Monumentation is almost exclusively in the form of concrete blocks set below the road or footpath surface and are referenced by witness marks (see Figure 3.3).
- Horizontal control survey tolerances are generally specified in terms of the relative accuracies of control traverses. For third order control over metropolitan areas, a permissable tolerance of 1:10000 is generally specified (TOMS, 1978b) in order to achieve a standard error approaching ±1cm for each point in the control network.



Standpoint : SSM		
to	dir'n	MSL dist
PM 106621	0° 00' 00"	
SSM 123455	189° 09' 53"	
BRASS △ (BT1)	88° 36' 30"	25.603
G.I.P. (GP1)	201° 33' 25"	11.864

Figure 3.3 Locality sketch plan for recovery of permanent survey marks (DEPARTMENT OF MAIN ROADS, 1981).

3.3 Deficiencies of the Survey Integration Concept

The weaknesses of the present cadastral survey system were identified in 2.3 as:

- lack of a uniform, accurate control network
- lack of a complete, comprehensive large scale urban mapping series
- lack of finality in the cadastral survey system
- lack of provisions for the continuous up-dating of maps

For several reasons, current survey integration proposals described in 3.2 fail to secure the necessary improvements needed to overcome these weaknesses.

Firstly, the existence of two official grid referencing systems in New South Wales (one for mapping and one for the integration of surveys) has caused considerable disruption for map production agencies and constitutes a potential source of confusion for most map users (URBAN,1978). Demanding that the grid system meet the needs of surveyors first and foremost, has eroded the basic integration principle of a system of homogeneous survey data, and has fallen short of the goal of a uniform large scale mapping system.

Despite considerable increases in funding in the last decade, and despite advances in survey technology, the densification of control has proven an expensive and protracted exercise. Early proposals suggested a desirable density of marks to be one per 100 head of population (FLETCHER, 1969) which has been estimated to be approximately one station every 50m (DALE, 1976). Cost considerations subsequently saw a relaxation of this density to the presently accepted 200m spacing. However, even at this density, it is costly to place artificial survey marks and fix them accurately on the AMG. Delays in densification meant that the practice of connecting surveys to a common reference framework of permanent marks has not been widespread since, under the present provision of the Act, connection is not mandatory until the area has been proclaimed. As the concept is presently formulated, any further lowering of control density specifications in order to accelerate densification will necessarily increase the costs involved in connection to control, to the detriment of the concept of integration:

> "The cost factor remains the greatest deterrent to the private sector's further involvement in survey integration. While the practice can absorb some of the costs involved, it is difficult to pass on the balance to clients who are not aware of or not concerned with the benefits of integration, unless it can provide assistance in the processing of their requirements" (INSTITUTION OF SURVEYORS VICTORIA, 1976d).

Survey operations become uneconomical unless marks can be tied into the survey within or on two set-ups at most (BLACHUT et al, 1979).

MCLAUGHLIN & LARSEN (1976) report that insufficient monument density was partly responsible for adding approximately 30% to the costs of cadastral surveying within the newly designated survey area of Saint John in the Maritime Provinces.

Artificial monumentation has also proven expensive to maintain in urban areas. It has been estimated that between 5% - 20% of placed marks are destroyed per annum in proclaimed survey areas through street excavation, road resealing, kerb reconstruction, building construction etc. (BLACHUT et al, 1979).

Finally, the expansion of the central plan register to include all private surveys is not sufficient to monitor all changes to topography, since identification surveys, building applications and other potential sources of update data are not subject to the provisions of the proposed amendments of the Survey Coordination Acts.

The majority of these deficiencies can be attributed to the fact that the survey integration concept in Australia has failed to appreciate that the integration of spatial information about topography, utilities and ownership can be achieved in a number of ways, depending upon available technology, manpower and local needs:

> "One end of the spectrum is represented by the classical manual integration approach based entirely on large scale maps correlated by the grid of a coordinate system. The maps are supplemented by files of geometrical descriptions containing the results of original surveys.... The eventual setting-out or relocation of some details in the field is satisfied either on the basis of measurements taken directly from the graphical maps or on the basis of original survey documents retrieved from files.
>
> At the other end of the spectrum is a computerised integrated system based entirely on numerical maps in which positions and geometry of all details are shown by their coordinates. In such a system the horizontal control is used both for positioning and for relocation purposes. Graphical displays may also be used, but they serve only for indexing of data or for providing an overview. Various combinations of these two extreme cases are of course possible " (LAND REGISTRATION AND INFORMATION SERVICE, 1977).

The Australian concept is unsure of its position in this spectrum and has, almost by default, adopted a numerial or "computational" system as its goal. In this system, the coordinates of all positions can be re-established from the central network irrespective of the original method of connection and coordinate computation. The network provides a means of controlling errors in the survey, and computing a measure of absolute accuracy, as well as a means of correlating all forms of survey data. The concept has failed to recognise that the majority of the users of the results of survey work are satisfied by a grpahical representation of the survey data and the positional accuracy associated therewith. In this regard, PAWSON (1974) recounts the experiences of compiling a new cadastral mapping series in Alberta:

> "...with an increasing demand from many disciplines not directly connected with legal surveying, for coordinate information, it became increasingly apparent that possibly 80-90% of map and plan users would be satisfied by an approximate and non rigid reference system which might fall far short of the rigorous standards demanded by surveyors and engineers....Although surveyors provide the reference monuments along with the mathematical and geometric framework of the control system, they are but one user of the system once it is operating .... It therefore seems somewhat illogical and uneconomical when planning a cadastral [map] series based on coordinates to place the needs of land surveyors ahead of all other users. ....Surveyors must not deny the advantages of modern control systems to the general user by being unnecessarily rigid demanding precise [maps] or none at all."

Provision of control for the production of large scale mapping should therefore be the immediate concern of the integration reforms. Procedures for the compilation of such maps are discussed in 3.4. Proclaimed survey areas are a secondary and separate consideration. They are not the "foundation" of an integrated data system as they were promoted during the last decade (see KONECNY, 1969b). The justification for proclaimed survey areas is a separate issue in the integration concept, and one in which there appears to be considerable scope to re-assess and redefine user needs.

To begin with, the detail survey requirements for most engineering design purposes are generally satisfied by plans at scales of between 1:500 - 1:2000 (DEPARTMENT OF MAIN ROADS, 1981). However, dense, accurate control networks generally established for most engineering projects in order to service the survey needs of the design, construction and post-construction phases of the project.

A similar justification for control survey can also be made for large subdivisions in new housing or industrial estates where cadastral boundaries need to be designed, computed, pegged and repeatedly re-pegged during the development process. The same control network is also used for the associated engineering work. In both circumstances the cost effectiveness of accurate, artificially monumented control networks is indisputable because of the intensity of survey activity associated with these projects, and because of their duration.

However, the need for the same types of networks in established urban areas has never been satisfactorily quantified. In such areas, survey activity is comparatively static. Land has been subdivided, roads and houses built, utilities and services provided without the aid of a control network. It is not surprising, therefore, that governments have been reluctant to accept the arguements for the provision of accurate control en masse, over the entire urban area. Engineering surveys in established urban areas are limited in their extent and conducted over a long period so as to justify the establishment of a local network to service each project. In contrast, cadastral surveys in established areas are conducted at random and are completed in relatively rapid time. If the network is to control errors in these surveys, then cadastral survey becomes the only remaining justification for the widespread provision of accurate control in established urban areas.

It has taken more than two decades since the principles of survey integration were first formally formulated, for the surveying profession to recognise that the accuracy criteria for urban networks "are mainly defined by the requirements of the cadastral surveying system" rather than by the spatial tolerances required by other users of the control network(CHRZANOWSKI & DORRER, 1977). An analysis of the requirements of cadastral survey in an integrated survey system therefore becomes a necessary prerequisite for determining the necessary specifications for the projection, density, accuracy and monumentation specifications for establishing urban control networks.

With regard to horizontal control tolerances for cadastral survey, ADLER has remarked:

> "... what is most important is a relative accuracy within a given area. It is almost immaterial in cadastral surveys... whether the detailed points, or the boundaries are very accurate with the relation to the first order geodetic framework "(CHRZANOWSKI & DORRER, 1977).

In order to satisfy the needs of traditional cadastral survey practice for high relative accuracies, draft integration legislation in New South Wales requires that all cadastral surveys in proclaimed survey areas be connected to two control stations which are used to check and adjust the boundary traverse and to compute accurate coordinates for parcel corners. As the proposed legislation adopts the current accuracy standard of 1:8000 closure of boundary surveys in urban areas, the relative accuracy of the control network must be of at least this order. However, the fact that the coordinates derived from this procedure are not allowed to play a significant role in future re-establishment boundaries can be viewed as a major contradiction in the present integration concept.

It has been clearly and repeatedly stated that "it is not envisaged that coordinates will dominate other evidence for the re-establishment of boundary marks" but will "simplify the accepted practices now adopted" (FLETCHER, 1969). The place of coordinates in the hierarchy of evidence (see 2.3) will be "about equal with any other measurement" and no where was it suggested that the coordinate will define the corner "at this stage" (KEARSLEY, 1972).

Any proposals to overturn the established common law principles in favour of coordinate definition of boundaries were seen as usurping the professional responsibility of the cadastral surveyor, and proponents of integrated surveys were quick to placate any unrest on this issue in order to gain support for their reforms. Instead, the need for dense control networks was argued on the grounds of the additional security and simplicity that they would impart the cadastral survey system within the framework of traditional practices. It was claimed that "the system will provide a more positive basis for land titles and allow easier and less costly redefinition of these boundaries in the future" (DEPARTMENT OF LANDS, 1976). The connection of cadastral surveys to the control network would provide:

- the establishment of adequate standards, expressed in absolute rather than relative terms, providing a more satisfactory indication of the consistency of survey
- the elimination of the possibility of overlapping titles

Cadastral field work and computation would be greatly simplified by:

- permitting independent checks from different stations, thereby eliminating the need for double measurement, closed circuit traverses and other checks to detect gross errors.

- reducing the need to establish an azimuth for the survey based on existing reference marks
- providing better reference marking for surveys in the form of easily located, uniquely identified, permanent and stable control stations
- providing a network which would become more dense as more surveys we connected to it.

A 25% reduction in survey costs in the future retracement of coordinated boundaries was projected, based on Canadian cost/benefit analyses (ANGUS-LEPPAN, 1967). This cost saving was to emerge from the fact the "coordinated boundary monuments and points of secondary evidence permit much more ready finding, verification and assessment of evidence" (INSTITUTION OF SURVEYORS, NSW 1974).

Despite the purported benefits, it can be shown that the continuation of traditional procedures within a dense control network only serves to perpetuate the deficiencies of the present system and fails to take full advantage of the benefits which the network offers.

For example, under the proposed system, the surveyor is still required to collect all available survey evidence as part of a retracement survey. The "curtain principle" does not operate in the survey records system and survey searching remains a costly and complex part of the redefinition process (see 2.3).

Also, according to VAN DER STERR (1975), one of the benefits of an integrated survey system is that, in theory, a parcel corner which is common to other properties need only be fixed once, while in an isolated survey system as at present, it is required to be fixed each time one of the properties is independently surveyed. Under the present integration proposals, existing corner coordinates cannot be adopted by the surveyor in an adjacent property survey as defining that corner, but a new and probably different set of coordinates describing a common point will be generated. This situation is further complicated by the apparent acceptance of different sets of coordinates for the same point (FLETCHER, 1969b) which would seem to complicate and lengthen the searching and assessment process. Rather than simplifying boundary retracement, coordinates merely add to the evidence which the surveyor must collect and assess.

The continuation of existing demarcation procedures is another failure of this approach. HALLMANN (1974) remarked that, under a control system the practices of emplacing reference marks near the parcel corners as presently practised, would disappear in the future because the control monuments would provide future datum lines for azimuth whenever a retracement is needed. The present proposals do not at this stage provide for the relaxation of existing demarcation regulations but insist on the continuation of extensive reference marking.

The continuation of traditional "isolated" cadastral survey practices in an "integrated" survey system is clearly not cost effective. There are few benefits to be gained, while initial survey costs are considerably increased. It is unreasonable to expect that any control network be cost effective if the coordinates which it generates, at the accuracy for which the system has been designed, are then relegated to an insignificant role in the boundary definition process. Accordingly, the only justification for the establishment of urban control networks at the current accuracy specifications is if the coordinates are permitted to define boundaries, and boundaries re-established by coordinates alone.

Such a reform has been proposed for North America and Europe in what has become to be called the "computational cadastre" (ZIEMANN, 1968; BRAASCH, 1975). The principal advantage of the system is that it enables all surveying tasks to be solved analytically prior to the execution of the survey, in a similar fashion to engineering survey. This considerably speeds up the process of subdivision and acquisition of real property. The dense control network also provides absolute legal security for boundaries. Based on European experience, BRAASCH (1975) claims that the benefits of the system far outweigh the costs of establishment and maintenance of the extremely dense control network needed to support the system, and that the computation cadastre, in the long run, is the most economical method for cadastral survey in a large city. McLAUGHLIN (1974) summarizes the arguments upon which the North American proposals are based:

> "Most cadastral systems of English Common Law origin have as a fundamental concept, the principle that, in defining property boundaries, original monuments override all other evidence.
> Historically, there is much justification for this concept. In an era of primitive surveying techniques and instrumentation security of title could be best served by emphasizing what could be seen and easily described - natural and artificial monumentation. Biblical quotations to the contrary, it is largely this concern for security that brought about the legislation which enhanced the principle; and it is tradition which has protected the importance of monumentation.

> The advances in equipment and survey techniques and the advent of the plane coordinate system have eliminated the need to give such stress to original monumentation. Indeed, an analysis of the costs involved in retracement surveys, stemming from much searching for evidence and the lack of security, caused by so much missing monumentation, emphasizes the need for a drastic change.
>
> Coordinates, not original monuments, should control the position of property boundaries. This would, however, be subject to the condition that the importance of existing monumentation would be respected. These monuments would be tied to the coordnate system. If destroyed, the coordinate values would define the property. Original monuments would not be re-established."

Legislation has been drafted in the Maritime Provinces to implement these principles in designated survey areas (ROBERTS, 1975). Under the provisions of the legislation, boundaries would only be monumented where requested by landholders who may have difficulty in visualising their boundaries without monuments (MCLAUGHLIN, 1975). Because original monuments would generally not be replaced, the legislation is aimed at achieving a gradual implementation of coordinate supremacy.

A study of the European and Canadian proposals as well as other literature on the subject (see HOWE, 1970; VOLOHATUKE, 1975 and YOUNGS, 1968), confirms the notion that the motivation for reversing Common Law principles stems from the problems experienced with the reliance on physical monumentation of boundaries. Supporters of the concept argue that, by establishing a few monuments at safe locations, accurately surveyed on a common datum and then relating the position of boundaries to them by precise measurement, the control marks serve as eccentric monuments for the boundaries and the position of the boundary is retained for all time. The compulsory direct monumentation of boundaries can therefore be abolished in favour of symbolic or token marks e.g. pegs, which would not need to be permanent and which would have no legal significance.

Despite the appealing simplicity of the concept, there are overwhelming reasons for rejecting the raising of the status of coordinates in the hierarchy of evidence for boundary definition. These reasons can be best understood by differentiating between boundary definition and boundary description. As DALE (1976) wrote:

> "The definition of a boundary is a matter of law: in a strictly legal sense, it is the infinitessimally thin line... that lies at the interface between one man's property rights and those of his neighbour. A boundary is something that exists upon the ground and, although in some senses it is an abstract concept, it is nevertheless real and absolute. A description on the other hand is a portrayal of some object in literal, numerical or graphical terms. A

> description is a means of identifying an object; what the object is, is a matter of definition."

The principal deficiency of the computational cadastre is that although coordinates are a technically superior form of boundary description, there are distinct disadvantages in basing the legal definition of boundaries entirely on measurement data. Much of the criticism of the computational system stems from its total reliance on precise measurement data and on the fact that the coordinate value intended to define a point on the ground may not always preserve the intended position.

MITCHELL (1971) poses the serious legal problems which occur due to shifts in the earth's crust if coordinates defined boundaries. Geodetic positions of the corners remain fixed with respect to the chosen reference spheroid, but the physical evidence of the boundary e.g. fences, would move. If coordinates describe boundaries, then this movement is of little legal consequence. If coordinates define boundaries, then, at law, the limits of each property owner's rights will shift in relation to what he occupies. This argument could be dismissed as having little or no relevance in such a geologically stable continent as Australia, but WATTLES (1975) suggests that similar problems may also occur due to localized land slip in urban areas, with the consequence that the resulting encroachment of buildings would have to be rectified by expensive physical or legal processes. A similar problem arises with any redefinition or readjustment of the control network.

Other critics of coordinate definition of boundaries are not convinced that the mechanics of surveying in a control network will ever be sophisticated enough to guarantee the error-free measurements which are essential to the system. HADFIELD (1966) has warned that:

> "in the enthusiasm for coordinate systems and control surveys, certain matters are apt to be assumed as facts without close examination. This is especially true in the relationship of legal surveys to coordinate systems. The tendency is to accept, without question, that, because the theory of the coordinate system is indisputably sound, the resulting product is technically reliable. In other words the feeling engendered by knowledge of the precision and care with which first, second and third-order coordinate points are established, is extended unthinkingly to the local network, the very meat of any coordinate system from the standpoint of boundary definition."

Intermediate standards of accuracy may appear in extending control to local coverage. This problem arises from errors in determining coordinates of a new point from the established control points, and in the accurate reproduction of any point by measurement from other known coordinate points.

Machinery for the thorough examination of all survey returns for adherance to the defined accuracy specifications is therefore a prerequisite for a computational cadastre.

Due to the dynamics of the control network and the inherent limitations of measurement, the use of coordinates to define boundaries only serves to create and perpetuate a disagreement between the legal (coordinate) and the defacto (monumented) boundary.

This problem can be overcome in a computational cadastre by only guaranteeing coordinates to prescribed accuracies. For example, in the Canadian approach, if any form of boundary monumentation falls within this boundary tolerance or "insurance lane", then the true coordinate position would be taken to lie within the monument (McLAUGHLIN, 1974). MURPHY (1980) goes as far as recommending that any proposed legislation for a legal cadastre in Australia, should include a tolerance in the variation of coordinate values of up to 10 times the current accuracy. However, if this practice is adopted, then the coordinates are, in reality, fulfilling a descriptive role. Monuments continue to define the boundary in practice.

Finally, the futility of placing greater emphasis on measurement in cadastral survey is readily apparent when viewed in the light of the enormous costs involved in establishing the control network necessary for the computational cadastre. If corner points are to be located independently by coordinates,then the standard error in the determination of relative positions of these points should be $\pm$ 1cm if current cadastral accuracy standards are to be satisfied. In his error analysis of a model urban control network CHRZANOWSKI (1972) determined that, in order to achieve a standard error of $\pm$ 1cm in the relative position between two points whose positions had been determined from separate traverses between 3rd order control points at 200m spacings, the required relative accuracy of the first order control network would need to be of the order of 1:200 000. Such accuracies are obtainable, but at considerable cost.

In conclusion, it can be argued that the real issue in improving cadastral survey in urban areas is one of improving the nature and timing of monumentation, not in better measurements. It is a question, not of precise measurement of boundaries, but of certainty of location of boundaries. Measurements (including coordinates) are an excellent means of describing boundaries, but good monumentation is the best means of defining them. Accurate measurements are needed in boundary definition only to support monumentation.

As SIMPSON (1976) has observed:

> "the accuracy of the survey required for title purposes varies with the permanence and effectiveness of the boundary demarcation. The more permanent the boundary demarcation, the less will re-establishment or confirmation be needed. Poor or movable marks, however, must be supported by good survey."

It has already been noted that the computational cadastre arises from dissatisfaction with monumentation. From the viewpoint of the land holder, boundary monumentation in the form of walls, fences and other substantial , visible features are the most desirable means of securing and identifying the limits of his ownership (see 2.4); not the present system of invisible and impermanent artificial monuments. The success of general boundaries in Britain (see 1.2.3) in which boundaries are defined by monuments and described by large scale maps, is testimony to this fact. A cadastral survey system in which boundaries are defined in terms of existing, "natural" monumentation and in which boundary measurements are purely descriptive, would constitute a workable system in urban areas.

Such a system would eliminate many of the deficiencies of the present system described in 2.3. In particular, the curtain principle would operate. Boundary retracement would no longer require a search for evidence to locate original markings. An inspection of the property would be sufficient. Finality would be achieved in that identification surveys would generally not be required since the relationship between the boundaries and other structures are depicted on the survey plan. Cadastral and topographic survey are integrated and can economically serve as the basis for compilation and updating of a large scale mapping system. Such a system is described in 3.4.

It is important to recognise that such an approach does not erode the traditional Australian concept of "fixed" boundaries. Boundaries can be fixed precisely by the use of witness marking (see 2.4). Measurement of the actual boundaries is only necessary for the computation of parcel area and frontage for valuation purposes, and to satisfy planning requirements for minimum area and boundary to side-wall information. Precise measurement is not an indispensible tool for precise boundary re-establishment in urban areas in which a control network (sufficiently accurate for large scale mapping) exists (See 2.4).

Arguments to the effect that precise boundary measurements are needed for valuation of urban land are also not tenable. As BLACHUT et al (1979) state:

> "Naturally, high land values in urban areas make owners particularly sensitive to questions concerning property boundaries and property rights. However, the actual value of a property is only very loosely connected with its precise size. The price of land is a negotiable quantity depending upon many factors, primarily upon the market situation at the moment."

VAN DER WEELE (1974) argues that the value of a parcel is not determined by multiplying its area by a fixed amount per square metre, but that the price per square metre is calculated only after the property has been valued or bought. A property is bought on the basis of its definition on the ground. The area of the property will always remain constant, as the purchaser viewed it. Any error or inaccuracy in the numerical description of its area does not deprive the purchaser of any land. The purchaser still retains the quantity for which he has paid.

3.4 An Integrated Surveying and Mapping System

Based on the preceding review of deficiencies of the present integration concept, and of the options available for cadastral survey in proclaimed survey areas, the following recommendations are made for the implementation and operation of an integrated surveying and mapping system.

The immediate task is to integrate topographic and cadastral information to graphical accuracy in order to satisfy the needs of the majority of users. Topographic base maps can be rapidly and efficiently produced at large scales in the form of orthophotomaps. Unlike the classical concept (see figure 3.2) cadastral information need not be acquired by field survey but by one of the following methods:

- numerical integration: computation of a framework of cadastral control by the adjustment of existing numerical survey plan data between selected control points

- graphical integration: manually fitting individual survey plans to the fence detail depicted on the topographic base.

The latter method has been used successfully for the production of large scale (1:4000) cadastral mapping in New South Wales. It was estimated that, using the numerical method, "the time necessary to plot the cadastral map would be more than twice as long, and the final result much less satisfactory from the point of view of overall accuracy and relationship to topography" (CENTRAL MAPPING AUTHORITY, 1980). The orthophoto provides an accurate base, true to scale, on which the majority of land parcels are clearly and visibly indicated by boundary fences or their shadows. Boundaries which are not visible on the orthophoto are plotted by measurement and scaling.

Digital methods, in which a digitized version of the original cadastral map or plan is automatically transformed and fitted to control, offer a potentially more flexible means of compiling the new cadastral pattern. Their main advantage is that anomalies can be removed and edge-matching achieved by inter-active editing of the digitized data. The use of digital methods incorporating numerical survey plan data can also be used for initial map compilation or for future upgrading of the digital map. Appendix A describes an experiment in the use of dimension data for the reconciliation of Parish mapping for a rural area in New South Wales. The advantages and limitations of this technique are described in Appendix A and in an earlier experiment using the same test area (BULLOCK, 1979a).

An important by-product of digital compilation techniques is the resulting digital data bank which can be used to service a digital cadastral mapping system with the following features:

- increased productivity, including a lesser demand for skilled personnel
- integrity and flexibility of the digital data which is important in map maintenance, compilation and drafting
- variety of output, by selecting the required map content, scale, orientation and format

- plotting is rapid, accurate and automatic, eliminating the duplication of effort currently expended within agencies in the continual redrawing of the same cadastral pattern in a variety of different forms
- modification (updating and upgrading) of the cadastral map can be achieved more easily and rapidly.

More importantly from the view of land information system development described in the following chapters, is that the digital data bank of cadastral coördinates can, through the application of data base technology, solve the problems of duplication in the present cadastral mapping system, and provide a system of continuous updating to replace the present inadequate system of periodic revision described in 2.4. Such a system is described in 4.5.5.

Ultimately, large scale (1:1000) line mappingwill need to be produced by photogrammetric means for all established urban areas. An example of this mapping for Australian cities is shown in figure 3.4. Control density for the production of these maps is significantly less than that required by proclaimed survey areas. The production of these maps can then be used to densify control through the implementation of the following measures.

The Survey Coordination Acts should be amended to provide for the immediate proclamation of all established urban areas, and to require all surveys to be connected to the nearest, well-defined, stable objects including:

- corners of the structure on the property
- corners of adjacent structures
- hydrants
- manholes
- gully pits
- electricity poles
- junction boxes
- stop valves
- path intersections
- kerb lines.

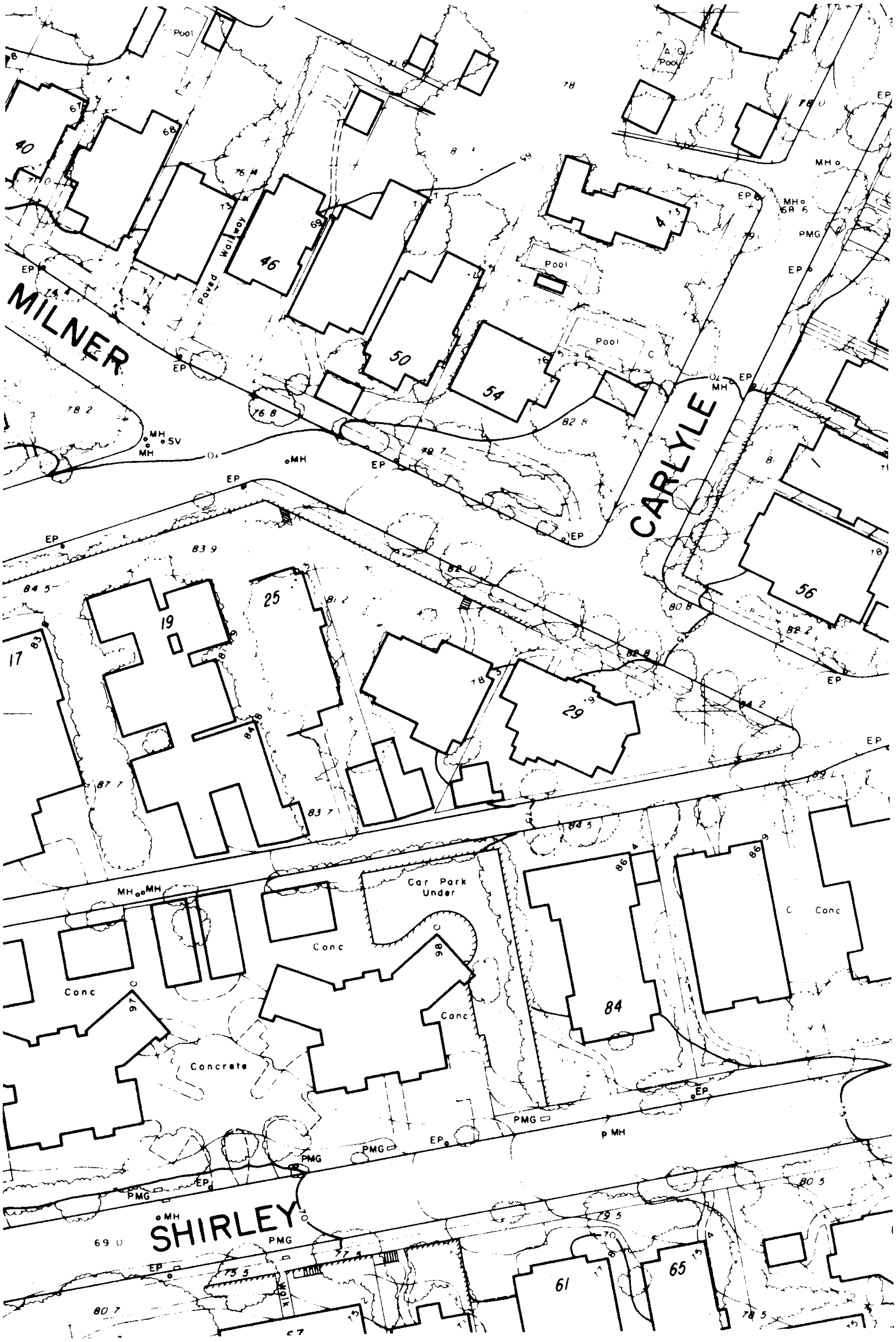


Figure 3.4 Example of large scale urban topographic mapping for Australian depicting the location of utilities and services and kerb lines.

The Survey Practice Regulations should be amended to require all identification surveys (see 2.3) in established urban areas to be carried out according to the following procedures:

- boundaries are reestablished according to traditional practices based on original monuments (see 2.3)
- these boundaries are then referenced by measurement to existing physical features, and these objects and measurements are noted on the plan and become the primary evidence for subsequent reestablishment
- original invisible monumentation such as drill holes, buried pipes etc, must not appear on the plan
- the original plan dimensions (bearings and distances) are recorded on the plan for descriptive purposes
- the plan is recorded under its parcel identifier in a special register in the Land Titles Office, but is not checked by the Office.

Figure 3.5 depicts an existing identification survey for a property appearing in figure 3.4. Figure 3.6 depicts the same property referenced according to the above procedures (without dimensions shown). The proposed method clearly satisfies the requirements of traditional identification survey, especially in providing wall-to-boundary distances. Connection to utilities does not significantly add to the cost of the survey since these objects are generally within 15m-20m from the front boundary (see figure 3.4). The major problems to be overcome in the introduction of these reforms are:

- obtaining Land Titles Office acceptance of identification surveys as a legitimate source of boundary evidence
- ensuring that these plans are submitted by private surveyors, since there is no administrative machinery currently in place which can monitor these surveys.

In developing urban areas, control networks will generally be established as a matter of course, because the intensity of survey activity makes them economically jusifiable in this case. The Survey Practice Regulations should be amended to require the definition of newly created boundaries in terms of visible monumentation, along the following lines which are similar to procedures suggested by HADFIELD (1966) and INSTITUTION OF SURVEYORS, VICTORIA (1976b):

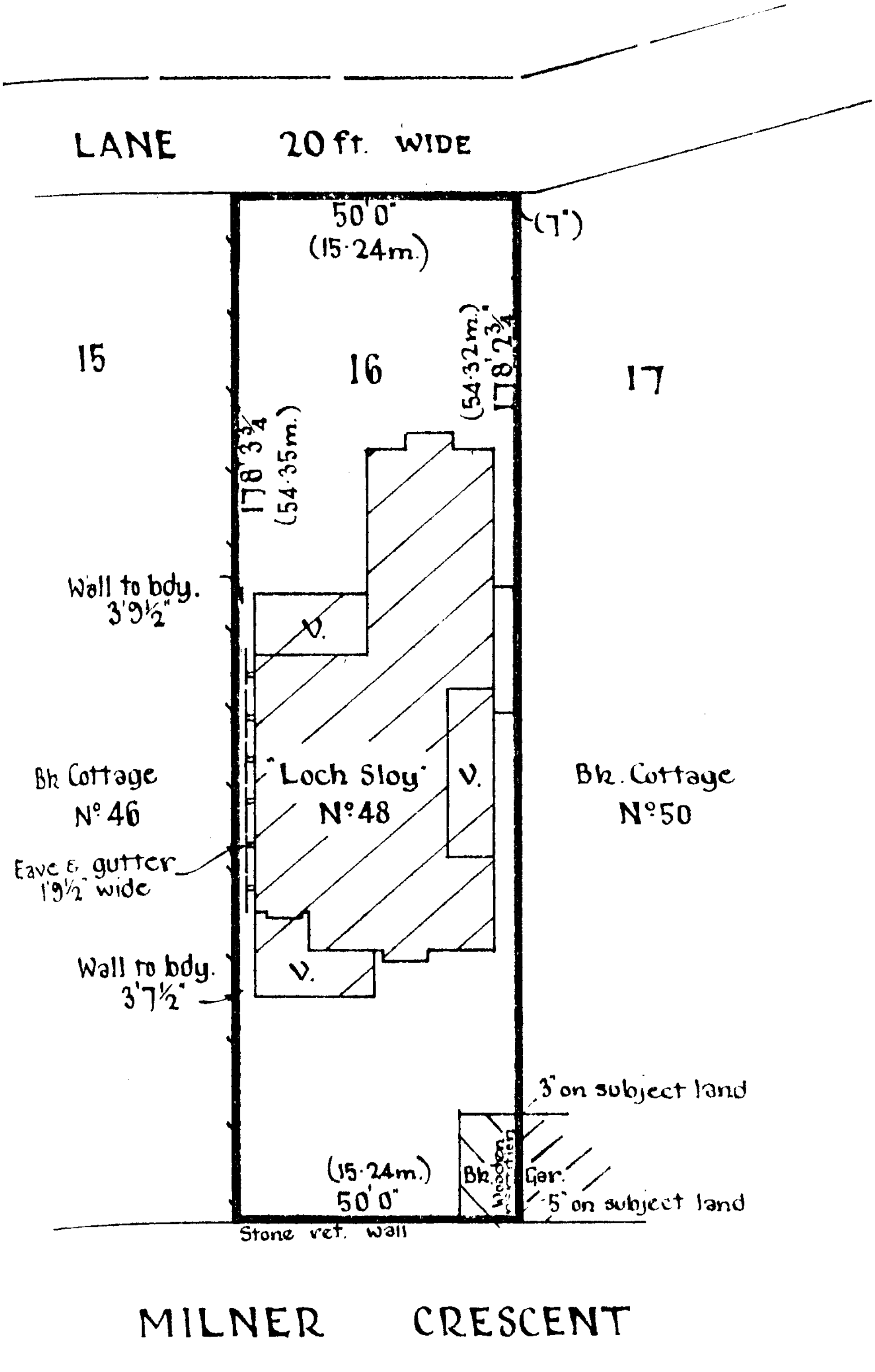


Figure 3.5 Identification survey for number 48 Milner Street depicted in Figure 3.4

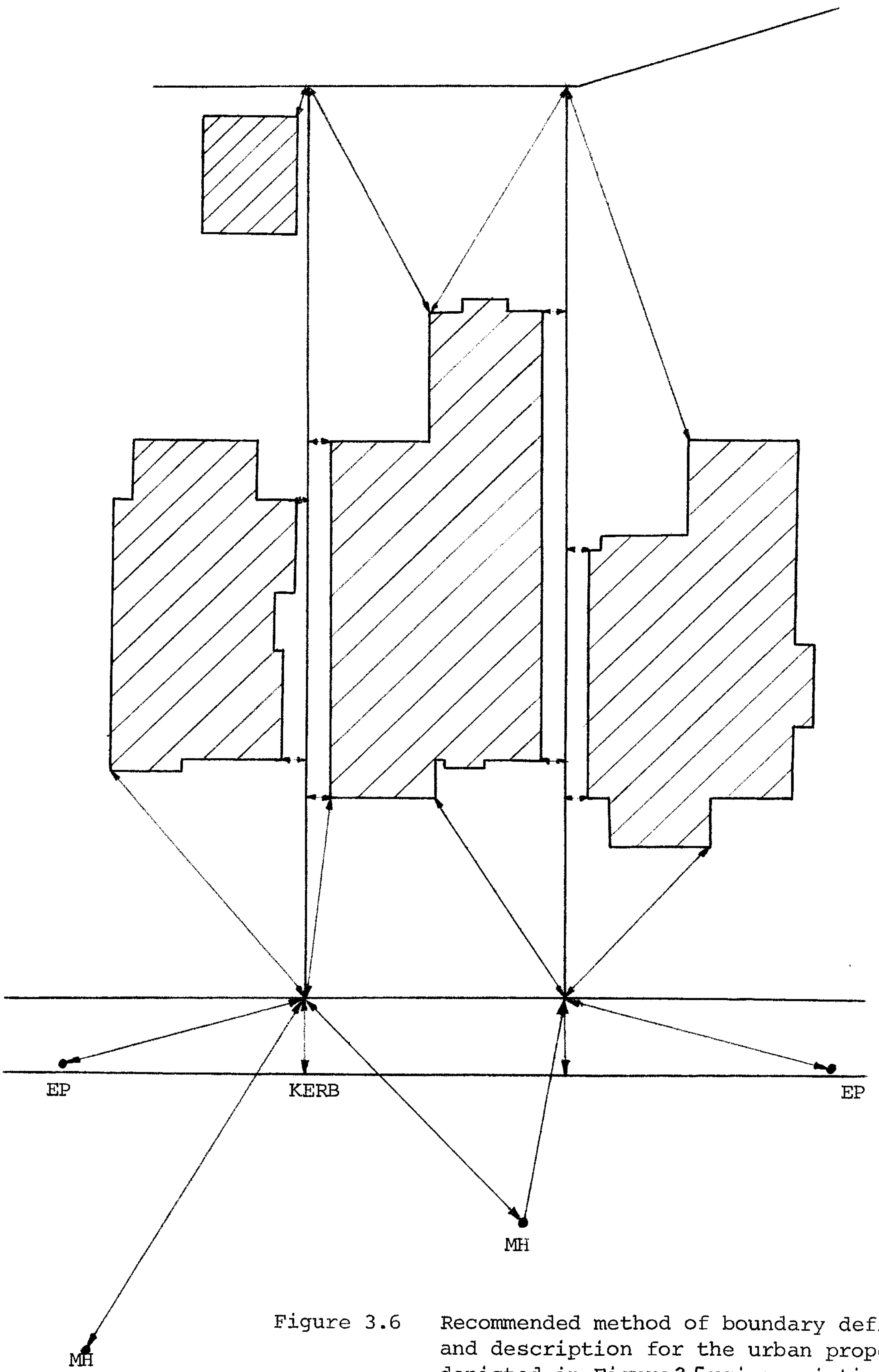


Figure 3.6 Recommended method of boundary definition and description for the urban property depicted in Figure 3.5 using existing urban detail such as house corners, adjacent house corners, kerb lines, electricity poles and manholes.

- sufficient control is provided for the construction of streets and provision of services
- interior parcel boundaries would remain in draft form with their exact positions undetermined
- titles are issued "subject to survey" with the understanding that when houses, fences, footpaths and services have been constructed, the boundaries will be certified by the surveyor
- certification would involve checking that the position of the fences have been erected in accordance with the subdivision plan; and defining the boundary in the manner described for established urban areas
- the new plan would be recorded in the identification survey register in the Land Titles Office
- once the plan has been registered, the qualification of title can be removed.

These procedures not only ensure that the boundaries are defined in terms of visible monuments at an early stage, but also reduce the instances of artificial boundary monuments being destroyed during construction.

The final phase of system implementation is the coordination on AMG of the objects to which all surveys have been, and will be, connected. These marks, which the classical integration concept used only as witness marks for control monumentation (see figure 3.3), now constitute the basic control network at far greater densities than are possible under current mark placement procedures. This reduces the costs of connection and provides redundant points for verification of marks. They are also already in place and maintenance free. Destruction rates for marks such as hydrants, manholes and house corners are also likely to be less than for artificial survey marks which rely on special legislation for their protection.

Since the control network is not required to reestablish cadastral boundaries, these marks need only be coordinated to ±10cm to ±20cm to permit the integration of surveys to large scale (1:1000) map accuracy. Coordinates for these marks can therefore be acquired at far less expense than current field survey methods, as a by-product of a large scale digital mapping programme (ZWART,1981a). As figure 3.4 shows, utility marks are readily identifiable from the large scale photography used to produce the line mapping.

The proposed reforms also remove the requirement for a narrow zone grid system for cadastral survey, since boundary measurements are descriptive only. Engineering requirements can be met by local plane grids which can be connected to the national network to provide AMG coordinates for submission to the Central Plan Register (INSTITUTION OF SURVEYORS, VICTORIA, 1977).

Finally, the connection of cadastral boundaries to house corners and other visible topographic detail, and the registration of identification survey plans, provide the means for updating the large scale maps, since few changes to property structures are carried out without such a survey.

3.5 Summary and Conclusions

The reforms to the cadastral survey system proposed in this chapter have been formulated on the premise that the classical survey principle of working from the whole to the part is fundamentally sound, but that the present means of implementing a system based on this principle is deficient. The system described in 3.4 preserves this principle, while providing greater scope for the implementation of a truly integrated system than the classical model depicted in figure 3.2.

The reforms recognise that the present integration concept has been designed primarily to meet the needs of surveyors, and consequently the present system has not received widespread support or funding. It has neglected its major users. As ELFICK (1974) concluded:

> "Surveying is a service industry to provide basic information for a multitude of different types of projects. Unfortunately surveyors often become so embroiled in the technical problems associated with their work that they tend to lose sight of the potential uses of the end product of their labours."

The proposed reforms shift the emphasis of the classical concept away from the connection of surveys to an independently surveyed and maintained "artificial" control network, to a system which ties cadastral surveys to topographic and utility detail. A greater reliance on existing "natural" monumentation permits the rapid introduction of the system and eliminates many of the weaknesses of the present cadastral survey system discussed in 2.4. Similarly, a relaxation of cadastral accuracy standards enables control marks to be more rapidly and economically coordinated.

The remainder of this thesis addresses itself to the main task of formulating principles for the design of an efficient land information system. This system can, in its initial stages, be based on large scale orthophotomapping as described in 3.4. Ultimately, efficient land information management demands that a cadastral surveying and mapping system based on the preceding model be implemented in order to satisfy all user requirements.

4. DESIGN PRINCIPLES FOR LAND INFORMATION SYSTEMS

4.1 Introduction

The philosophy of land information systems (LIS) development can be broadly defined as an attempt to improve the availability, quality and utility of property-based data through the use of computer technology. Chapter 1 introduced the LIS concept as the latest stage in the evolution of cadastral systems and as part of the cadastral reform measures currently taking place in most Western countries. Section 4.2 presents a more formal framework in which to explain LIS development by formulating several basic principles of land information management from which a general definition of the LIS is derived. These principles have been drawn from overseas and Australian experience in overcoming operational problems in existing manually oriented land record systems.

Although these basic principles are generally applicable to all cadastral systems, the means of implementing the LIS and the form that the LIS will eventually take, will depend to a large degree on the nature and scope of existing cadastral arrangements. In the Australian context, the LIS will be developed within State government administration as outlined in chapters 1 and 2. Based on overseas and Australian experience in LIS development, and on the previously established theory of land information management, this chapter establishes principles for the implementation and operation of the LIS, and for system design within this administrative framework. To assist in this task, a conceptual model of a LIS in the Australian context has been formulated, and is depicted in figure 4.1. The model identifies the main data files comprising the LIS and those existing data systems from which the LIS derives its data.

As regards system implementation, SEDUNARY (1980) has commented that

> "while there is no one correct way to develop a land information system, there are a considerable number of wrong ways."

The proposed method of staged implementation through coordinated development is presented in 4.3 as one of several possible approaches. The conceptual model provides a framework for the development of the separate LIS sub-systems, and for their integration into the total system.

Although useful for systems implementation, the conceptual model is limited in its application to systems design. As WILLIS (1972) has stated:

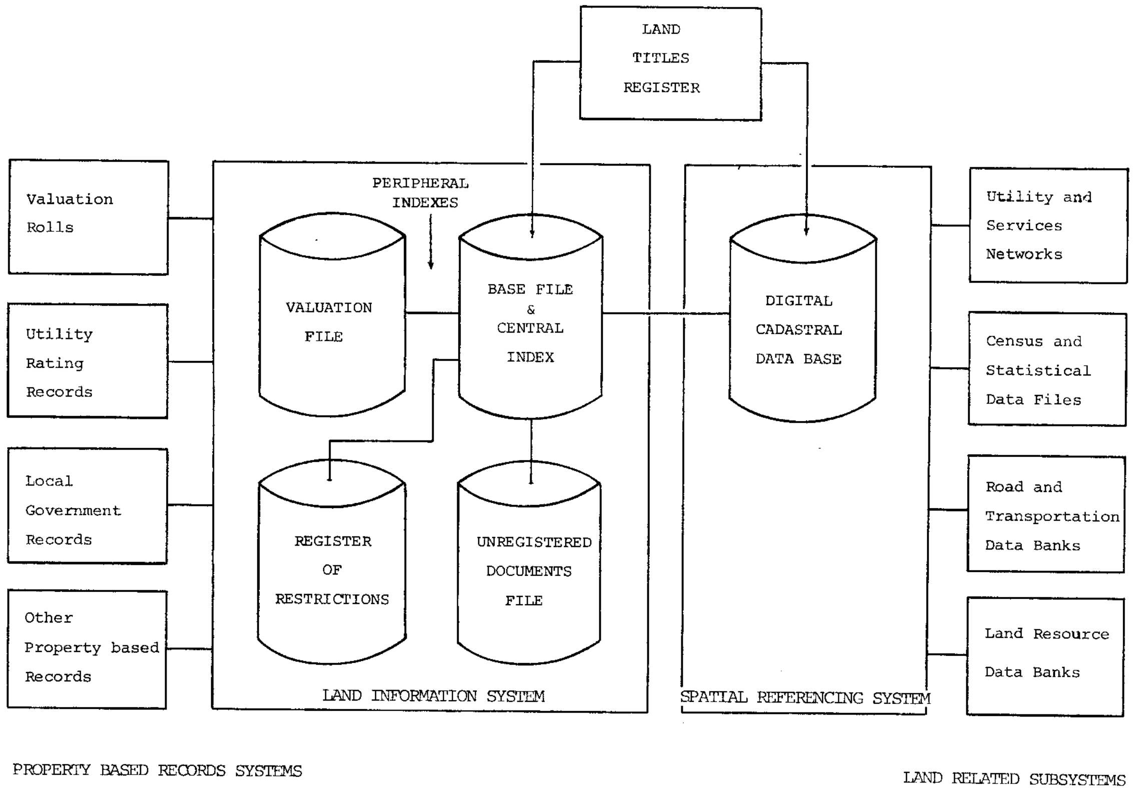


FIGURE 4.1 Conceptual model of a property based land information system in the Australian context.

> "Designers must distinguish between a conceptual model.... and an actual operational system. There is much to be gained by having an overall conceptual framework in mind but in practice, it is unlikely to provide a blueprint for what can actually be achieved."

Design principles for the LIS are presented in sections 4.4 and 4.5, and are viewed in terms of the primary function of the LIS as a tool in land administration and of its secondary function as an aid for planning. Subsequent chapters discuss in detail several of the major system components introduced in these sections.

Finally, no attempt has been made in this chapter to quantify the costs and benefits of system implementation or to monitor system performance. It is assumed that the proposed LIS model will satisfy DALE's (1976) criteria for LIS development, namely, that it will be

> "useful, technically possible, economically justifiable and politically acceptable."

It is recognised that system evaluation is required as a continuous process throughout system design (JOHNSON, 1981). Also, continuous review of system performance is required subsequent to system implementation, to determine the need for new legislative and administrative initiatives (MCLAUGHLIN, 1975b). It is assumed that the staged approach to system implementation within the framework of coordinated development is sufficient to ensure the success of consecutive stages of system development.

4.2 Land Information Management

4.2.1 Existing Land Data Organisation

Traditionally, government administration is structured along functional lines with separate agencies established to carry out some specific objective defined by statute. In support of their operations, agencies need to collect and maintain certain data items concerning their particular administrative tasks. An important distinction can be made between data which an agency has a statutory responsibility to collect and maintain (for example, ownership data within the Land Titles Office) and data which an agency requires to support its operational activities (such as traffic flow data or health statistics). In many instances, the former agencies often provide a primary data source for the latter, the statutory requirements under which the former operate ensuring the accuracy of this basic data. HUMPHRIES and KENNEDY (1974) have expressed this administrative environment in terms of intra and inter-departmental data exchange:

> "Essentially the environment of Land Administration is seen as one of Data Exchange. On one hand there are the "owners" - the authorities who are responsible for the collection and maintenance of data, and on the other, there are the "users" - those who need this data to discharge their responsibilities."

Problems in the operation of existing land data systems in recent years have stemmed from the inability of traditional manually oriented procedures of data recording and retrieval to keep pace with the increasing number of requests from outside and from within the agency. Understandably, reforms within these primary data sources have generally been confined to remedying the internal problems of records management. The particular problems in this regard include:

- increased storage space requirements;
- difficulty in the location and culling of dead matter from files;
- increasing difficulty in the rapid retrieval of records;
- growth in the number of routine enquiries on the records;
- increasing labour costs.

The 1960's and 70's saw an increasing trend towards the automation of records and routine administrative tasks within individual data systems in order to overcome these deficiencies. WHALAN (1967) states that the basic characteristics of the computer which lend itself to this task are its ability to:

- automatically carry out a specified sequence of simple operations at extremely high speed, and
- store vast quantities of data which can be dealt with, added to, subtracted from, varied, searched or analysed in any manner specified.

Although automation has largely overcome many of these internal deficiencies, its application has generally been restricted to the improvement of routine manual tasks associated with record keeping, and almost always carried out within the confines of the particular agency with little or no coordination by State or Central government. Reforms of this nature have therefore had little impact on the problem of interagency data exchange. The major impediment to interagency data exchange is the isolated nature of traditional land data recording. Whether agencies are "owners" or "users", the data systems which they create are designed primarily for the internal management or recording purpose of that agency. Although the data they administer may be of interest to other agencies, the data systems are not specifically designed to provide this data to other government departments. The consequence of this environment is that data are organised according to their function, reflecting the responsibility or interest of the various government agencies, rather than according to the nature of the data itself. The resulting parallel operation of data systems and the traditional "housekeeping" approach to land recording which has evolved as a consequence of their independent development, have given rise to considerable duplication and incompatability between data systems. This situation not only adds unnecessarily to the public and private costs of maintaining and accessing land data systems, but also restricts the use of these basic data sources for decision making purposes.

The problems associated with this functionally oriented land data organisation have been studied in North America (TESSARI, 1974b; ZIEMANN, 1976a) and Australia (CRISP, 1974; HUMPHRIES & KENNEDY, 1974; SEDUNARY, 1977) and can be categorized as:

Data duplication: the extensive duplication and storage of the same data items occuring between individual recording systems.

Data availability: data required is not available either because it has not been recorded or because of the way it is recorded it is not recoverable as required, or only after an inordinate delay; data useful to other departments is often not collected at all even though another department could easily collect this data in the course of its regular operations; a lack of awareness of potential data sources by other agencies, unwarranted confidentiality of data when obtained at its source and the cost of acquisition have also been cited as restricting availability.

Data accessibility: the difficulties of coping with a multitude of indexing methods and output media, together with the delays caused by internal administrative constraints mentioned earlier. Different indexing methods designed to serve the agency's particular requirements lengthen search time and impede effective intercommunication between data systems; considerable distance between individual data sources also restricts accessibility.

Data accuracy: the need to go to the particular authority responsible to ensure that the data is accurate, despite the fact that it may be available in other more convenient locations; and inadequate arrangements for keeping data up to date, usually by those agencies not statutorily responsible for the particular data, resulting in inaccurate and/or incomplete data records.

Data compatibility: a lack of compatibility between different data types in terms of classifications, definitions, coverage etc., which seriously limit their usefulness for decision making purposes. Aggregation and integration of different data types is subsequently restricted.

4.2.2 Application of Data Base Technology

The evolution of land data management in the last two decades under the influence of advances in computer technology has been described by DANGERMOND et al (1981) in the following terms:

> "The management of [land-related] data began simply enough with storage of data on punched cards or tape. Next the storage medium became magnetic tape; then computer disk and now large, bulk memory devices with increasingly rapid access times. With new developments in storage devices we can expect ever larger amounts of information to be stored in even smaller physical spaces with lower cost and faster access times. The sheer amount of [land-related] data being stored has forced the creation of data base management systems (DBMS's) to handle these large data bases. With success of these DBMS's the assembling of even larger composite data bases and the networking of data bases for data sharing has become a reality."

Traditional internal record automation, combined with these early storage devices, resulted in a "data bank" structure. A data bank can be defined as a collection of computer processable data that is structured in a defined format and which is designed to serve individual applications. There is little or no correlation between individual data items. The data structure can be described as "static" and severely inhibits data sharing.

The introduction of "data base" technology in the last decade, and the development of DBMS's designed specifically for the creation, maintenance and interrogation of the data base contents, have provided the technical basis for inter and intra-agency data exchange in addition to improved data management. A data base can be defined as "a non-redundant collection of interrelated information processable by one or more different computer application programs" (HUMPHRIES, 1972). Data is structured in a logical fashion and can be described as "dynamic". The application of data base technology to independent data systems and the networking of these systems, provides the following advantages to the land data management problem:

- the *elimination of all redundant data* through the appearance of data across a multiplicity of authorities;
- *accessibility and availability* of data through the on line sharing of data via remote terminals;
- *consistency and compatibility* of data through the use of the same data by all users of that data;
- the *modification* of existing data quickly and easily without disrupting data structure or system operation;
- the *addition* of new types of data without the need to redesign the system, thereby obviating the identification of the need for particular data items sufficiently far in advance;
- the *independence* of computer application programs from the physical storage of data, thereby facilitating the operation of information for purposes not forseen at the time of system design; and
- *significant reductions* in application program development costs, physical storage costs and processing costs.

4.2.3 Land Information System Defined

The elimination of data duplication and the increase in data accessibility implies the transformation of existing data systems into a centralised information system. The difference between a data system and an information system lies in an appreciation of the difference between data and information.

> "Data are observed or measured facts or values which become information when meaning can be derived from the data which is not explicitly contained in the data " (COWIE, 1972 a).

A data system by itself stores facts and recalls these facts for later use. An information system transforms these data into meaningful information for decision making purposes. The essential differences between a series of networked data systems and an information are therefore:

- the extent to which all flows of information are an integral part of the system and
- the extent to which the system is a tool for analysis, planning, operation and control (MOYER & FISHER, 1973).

An information system therefore implies all functions contained in a data system but in addition includes:

- the manipulation and analysis of data;
- the use of data or its analysis in decision making; and
- feed back from the results of decisions to influence subsequent enquiries (BACKER, 1967).

An information system can therefore be satisfactorily defined as:

> "a [data base] linked to a set of procedures for collecting data and coupled to a set of techniques that can transform the data into information for decision making and transmit them to decision points where they can be used." (WILLIS, 1972).

In Chapter 1, land-related data was defined as any data item recorded within existing data systems which has a spatial element, that is, which can be depicted on a map. Based on this definition, a *land information system* has been broadly defined as:

> "a tool for legal, administrative and economic decision-making and an aid for planning and development which consists, on the one hand of a data base containing spatially referenced land-related data for a defined area, and on the other hand, of procedures and techniques for the systematic collection, updating, processing and distribution of the data " (INTERNATIONAL FEDERATION OF SURVEYORS, 1981).

For the purposes of this thesis, the land-related data which the LIS contains is restricted to that *property-based* data which describe the attributes of the individual parcel. The data which a fully operational LIS would therefore be expected to contain include:

- land parcel identifier
- land ownership and tenure (details of leases, mortgages etc.)
- names and addresses of owners
- names and number of residents
- restrictions on user
- area and frontage
- current values
- land use zoning (statutory land use)
- actual land use
- nature of improvements
- building (year of construction, materials, number of rooms etc.)
- services available
- topography and soil quality (rural properties only)
- productive capacity (rural properties only)

The LIS depicted in figure 4.1 is a property-based information system in which the data base is comprised of a series of interlinked master files. Each file contains an individual record for every parcel of land in the jurisdiction of the LIS. The contents of the files are made available to users via remote access terminals. The dual functions of the LIS, namely, its primary function as a tool for administration and its secondary function as an aid for planning, reflect the two distinctive characteristics of an information system, those of data management and data processing. The ability of the LIS to fulfill these functions will depend to a large degree on the means of implementation and operation and on the flexibility of system design. Principles of system implementation, operation and design are now discussed in terms of these dual functions.

4.3 System Implementation and Operation

In developing a land information system as a centralized source of property data, the question of control of the system and responsibility for its operation and ongoing development must be addressed. SEDUNARY (1981) has observed that:

> "When considering the most effective administrative and political organization of a comprehensive land information system , arguments invariably polarise into either of the two alternatives - centralized systems management or an autonomous network with dispersed authority."

The concept of the LIS formulated in this thesis is not a large centralized agency which gathers and disseminates land information to user agencies. It is developed and operated as a public enquiry system for property data drawing its data from existing land data systems. The LIS is an integrated network of separate subsystems which continue to function independently of one another and remain responsible for the correctness and maintenance of the data which they generate and contribute to the LIS. The choice of an integrated LIS is based on the principle that data are recorded more quickly, accurately and in the most useful manner when it is gathered by the agency most concerned with its use (AUSTRALIAN GOVERNMENT, 1978). The inherent disadvantage of centralized systems management is that a centralized agency has no control over the data, a deficiency which would result in unnecessary inaccuracies within the system. An integrated system also ensures that new data is collected only once and collected only by the authority best placed to record it and has the added advantage that the contents of the LIS are kept continuously up to date through existing, on-going processes resulting from day-to-day operations of the source agency. The conceptual model in figure 4.1 reflects this integrated systems concept by depicting the LIS as central facility drawing data from and supplying data to the peripheral sybsystems.

The concept of a LIS created through the integration of separate land data systems demands the acceptance of certain principles for successful systems implementation and operation. These principles have been influenced to some degree by the present allocation of departmental responsibilities within State administration and will in turn demand reforms of the organisational environment in which the LIS is to operate. These principles can be broadly categorized under the headings of:

- coordinated development
- staged implementation
- data compatibility
- data security and confidentiality

4.3.1 Coordinated Development

The encouragement of individual agencies to computerise their land data with a view to their ultimate linkage in the future was promoted as "the most achievable goal both technically and economically" in the early stages of LIS development in Australia (FLETCHER, 1972).

> "The virtue of this approach is that it should ensure short term returns from investment and that the system designed will meet the needs of the authority concerned and its customers in the first place. This should eliminate any chance of creating a great white elephant." (GRIFFITH, 1974)

However, based on the South Australian experience, SEDUNARY (1981) suggests that such an approach does not ensure the successful future integration of subsystems.

> "Whilst stringent system design can ensure compatibility between systems, procedural decisions can be made at a local level without an appreciation (or concern) for the detrimental effects on the total integrated system."

The answer which SEDUNARY offers is a combination of the two approaches of centralized and autonomous/dispersed control.

> "Firstly, the total system must be allowed to consist (in the system-organizational sense) of separate, discrete systems designed to meet local applications, but totally compatible and capable of complete integration. What is imperative, however, is the establishment of an agency with the major objective of ensuring that the maintenance and on-going development of the LIS data base continues in a formal and coordinated manner and in accordance with an agreed and pre-determined policy. Whilst the ultimate responsibility for the operations of the discrete systems must remain with the authority statutorily responsible for the product emanating from their data, the central agency must be in a position to bring pressure

for conformity with the general framework on which the efficient operation of the total system is dependent."

TESSARI (1974b) has summarised the function and responsibilities of such a coordinating agency within State administration as:

1. *Coordination* - active promotion of coordination among systems;
   - provision of information to agencies necessary for achieving and maintaining coordination;
   - strengthen liaison between systems and their users;
   - design and maintenance of a master plan for coordination of systems; and
   - establishment and maintenance of standards to ensure data compatibility among systems.
2. *Research* - monitoring of developments locally, nationally and internationally;
   - dissemination of information on these developments;
   - on-going research; and
   - monitoring of agency requirements.
3. *Dissemination* - supply of information on the location, form and general specification and documentation of available data.
4. *Assistance* - assistance in system development in an advisory capacity as required; and
   - financial assistance to agencies.
5. *Advice* - advice to state government on matters relating to existing, developing and proposed systems.

Overseas experience confirms the notion that the agency best placed to coordinate LIS development is that agency which already exerts some degree of statutory control over the existing cadastral system. That is, a data "owner" has more chance of success than a data "user" in coordinating this development, even though the latter agency may benefit more from this cadastral reform and may be more willing to assist LIS development in its initial stages.

For example, the Swedish land data bank project was made the responsibility of the Central Board for Real Estate Data (CFD) which was created in 1968 to carry out the recommendations of the 1964 Cadastral Reform Committee (WALLNER, 1969). Direct Federal responsibility for cadastral administration enabled a pilot project to be implemented, a national system design to be formulated, and the gradual extension of the system (county by county), to the whole country. Similarly, each of the states comprising the German Federal Republic has its own government which administers the cadastral system within the limits of "framework" statutes passed by the Federal Parliament (SIMPSON, 1976). The Federal involvement in cadastral administration has enabled the successful development of a national system design for an automated real estate register, land (title) register and real estate map. Responsibility for this development is to be distributed to different states and funded by a national program for the promotion of data processing (BASTIAN, 1980).

In contrast to European experience, the highly fragmented and diffuse nature of cadastral arrangements in the United States has seen the coordinating role in LIS development being undertaken by Federal "user" agencies, and usually restricted to the coordination and funding of research programs at the local level. According to MOYER, (1971) Federal interest in the coordination of efforts to develop urban data banks stemmed from two reasons. Firstly, concern for the apparently large number of urban planning agencies who were creating or intending to create their own data banks. It was thought that development costs could be substantially reduced if the Federal Government could disseminate information from one city to another. Secondly, the Government appreciated the potential of unifying these local data banks in the future to provide information for planning at the regional, state and national level. In the late 1960's the Federal Department of Housing and Urban Development (HUD) funded several research projects into the design of transportable property based information systems for planning. One project was the Urban Information Systems Inter-agency Committee (USAC) six cities project in 1969. The objective of the USAC project was to develop, test and document prototype systems so that the proven systems could be transferred to other cities. However, by the mid 1970's, and despite very comprehensive documentation, the systems devised under the USAC project did not appear to have attracted much interest from potential adopters for reasons which are discussed in 4.5.2. MOYER (1971) also describes the involvement of the Federal Department of Agriculture in the funding of research into the development of a Comprehensive and Unified Land Data System (CULDATA) partly through its concern for the need for urban-rural coordination. It was planned to first implement the CULDATA system in a small number of counties and then after these county systems were performing smoothly, the technology and knowledge could be transferred to the remaining counties (MOYER, 1974). However, Federal financial assistance and research alone were not sufficient to ensure transferability of system design. A computerised land records system based on the CULDATA concept was implemented in Forsyth County in the United States (AYERS, 1975). Although county officials expected that the system would set the example for other counties in the state, it soon became apparent that the Forsyth county system was uniquely suited to the one county, and could not readily be transferred to other counties (SCOTT, 1981).

In the Australian context, the Department of Lands (which ideally should include the functions of the Land Titles Office and preferably the Valuer-General's Department) is best placed to coordinate LIS activity. This is partly because of the highly centralised operation of these agencies at the State level but mainly because these agencies administer the core of the "basic" land data items (see 4.3.2) and therefore can exert greatest influence on cadastral reforms generally. For example, a Western Australian study found that 50% of the 600 information flows between State government departments originated from the Lands Department and Land Titles Office (P.A. CONSULTING SERVICES, 1979). MOORE (1976) had earlier recommended the Lands Department as the LIS coordinating agency in Western Australia because of its acceptability to other departments which stemmed from this long established and widely recognised role as a service organisation.

4.3.2 Staged Implementation

Two important aspects of LIS development:

- the diversity of the data which a fully operational LIS would contain
- the considerable financial investment required to transform a series of independent data banks into a centralised data base linked to remote terminals

suggest that the LIS cannot be efficiently built up as a whole but should be undertaken in stages by progressively developing partial data files based on an existing base file.

According to SEDUNARY (1980), WILLIS (1972) and JERIE (1979), staged implementation:

- significantly reduces the financial outlay at any one point of time;
- shortens the lead time on the individual components of the system resulting in quicker return on financial investment;
- permits immediate pay offs to be demonstrated at each stage of the systems development, necessary to ensure further funding;
- enables expertise to be progressively developed in the form of experienced personnel and extensive system documentation as a result of research, experimentation or investigation associated with system development;
- reduces the danger of making commitments on the basis of existing technologies when developments in hardware and software open up new design options;
- enables the complete coverage of whole area in the shortest possible time based on the principle that limited information is better than no information; and
- permits successive phases of improvement to be implemented according to priorities as they arise.

The early experience of the Swedish Land Data Bank exemplifies the inherent dangers of developing, testing and implementing a total system design at an early stage of LIS development. The original program of the Swedish Central Board for Real Estate Data envisaged the creation of one register including the urban and rural cadastres of real estate files and the land register (WALLNER, 1969). In 1970 a pilot project of 100,000 parcels was established in which both registers were combined to form a land data bank and, based on this experience, a design concept for a national land data bank was formulated (ANDERSSON, 1974). It was planned to progressively extend the pilot project to achieve national coverage (3.5 million parcels) by the early 1980's. However, by

1971 the original cost estimates of the system in 1966 had increased tenfold (BLACK, 1972a). A government review of the program concluded that the immediate integration of real estate and land registration systems had resulted in too complex a system which would be difficult to maintain over a long period and that short term investment would be too great if the data bank continued to be developed in this fashion (RYSTEDT, 1977b). Consequently, in 1977 it was decided to divide the data bank into two systems and to continue these in parallel, with land registration being delayed until 1985.

The staged approach to LIS development dictates that the first stage of LIS development must be chosen so as to ensure greatest benefits in the shortest time. The creation of a central reference file containing the most frequently collected and requested property data items would logically comprise the most suitable first stage of the LIS by eliminating the expense involved in the duplication of these data items.

A South Australian study set up in 1974 to investigate the possibility of creating an integrated LIS revealed that land ownership was the most frequently recorded data item in all government land records (SOUTH AUSTRALIA, 1977). The expense of this duplication was compounded by the different sources which each data system uses to maintain this ownership data, resulting in data of doubtful integrity. Accordingly, the study proposed the creation of a single, simple, common record of land ownership and tenure as the first stage of its LIS. This first stage, known as Land Ownership and Tenure System (LOTS) became operational in 1979 (SEDUNARY, 1980) and incorporates details of land use, value and improvements obtained from the valuation rolls.

Similar findings were made in a survey of provincial agencies in Alberta, Canada. (TESSARI, 1974b) which revealed that the three types of land related data most frequently required by the majority of agencies were:

- land entitlement (ownership and tenure) 62%
- land use 57%
- land assessment 53%.

This study recommended the creation of a "basic" land information system containing these data items, as the first stage of LIS development.

The LIS Base File depicted in figure 4.1 represents this first stage in LIS development. Peripheral files such as the Register of Restrictions and an automated Land Title Register are longer term developments and are discussed in more detail in section 4.4.

4.3.3 Common Standards for the Definition and Classification of Data

The lack of data compatibility was cited in 4.2 as a major problem associated with functionally oriented and fragmented data organisation. Because of the lack of common standards for the definition and classification of data, it will be very difficult in the future to match and aggregate data and to exchange information between different data systems within the concept of an integrated LIS (BOGAERTS, 1977). Information flow in particular, requires a high degree of comparability of records between any two systems (TESSARI, 1974b). Although administrative mechanisms can be established by the coordinating agency to enforce the adoption of common standards, there are technical considerations which will restrict the degree of integration possible.

The mechanics of data compatibility are concerned with the definition of entities and attributes. An entity is a uniquely identified observational unit. An attribute is a characteristic that is chosen to describe an entity and naturally reflects the nature of that entity (BAXTER, 1976). Data integration can be viewed in terms of the identification of entities and the classification of their attributes. Within the context of LIS development, the entities under consideration are land parcels. The principles associated with land parcel identification are introduced in 4.4 and discussed in detail in chapter 5. While the major problems of matching property records (entities) in different data systems can be largely overcome by the use of standardised land parcel identifiers, the comparison, analysis and exchange of data on the basis of their attributes are more complicated processes.

> "It is very important to maintain the 'purity' of the data series in information systems. Cost is increased and usefulness is restricted by mixing of attributes that are both basic and separate with respect to the collection and use of data " (BOGAERTS, 1977).

The classification of attributes involves the grouping of similar data into unique classes and assigning to each class a machine readable code.

The latter process is simply a systematic labelling and recording of groups of data for processing purposes, primarily to minimise storage and to convert the attributes into a computer compatible format. In practice, both the classification and coding of attributes can be carried out as the one operation.

> "Classifications may vary enormously in complexity, depending partly on the nature and availability of data, but ultimately upon the requirements of the analysis. A classification system should help to elucidate, not hide, important differences amongst the entities. The system should be comprehensive - all entities should find a place. It should be designed so that additions and changes can be made in the future without having to scrap the whole system and to start again (this is easier said than done). The various structures which can be used to store attribute information determine the storage and retrieval parameters of the system. They tend to be a subject in their own right " (BAXTER, 1976 citing PERRATON, 1970).

In the context of LIS development, the lack of a uniform classification system for land use has often been cited as a major contributor to the non-comparability of different land data systems. In addition to the differences in classification which arise purely from the lack of consultation between different agencies, problems of non-uniformity in land use coding will occur because of:

- mixing of land use and other attributes
- aggregation of land use attributes under the one code.

Problems of mixing occur because the land use classification and coding system reflects the functional orientation of the agency designing the system. In this regard, EDDINGTON (1981) has identified two coding activities:

- land improvement
- land resource coding

in addition to land use coding, which attempt to classify land use for a particular purpose. These three activities comprise the subject of land inventory.

Land improvement coding is a detailed inventory of the physical improvements to the land, primarily for land valuation (and hence rating/ taxation) and for land resumption/development purposes (INSTITUTION OF SURVEYORS, N.S.W., 1977b). Land resource coding can be described as an inventory of existing environmental parameters (including slope, terrain, soils, geology, land use, vegetation, erosion) generally of non-urban land and undertaken for a variety of purposes including agricultural and urban capability studies and forest management. In both of these coding activities, there exists a tendency to combine land use attributes with other dimensions of the land. For example, occupancy or assessment characteristics in the former and tenure or productive capacity characteristics in the latter.

According to FOGARTY and RASKALL (1976), aggregation occurs because different land use coding systems attempt to combine in a 4 digit code, all necessary descriptive characteristics such as the industry with which the parcel is associated, the function that the particular establishment performs on that parcel, and possibly the sector (public, private etc.) in which the enterprise operates. That is, they classify attributes according to only one scale or variable.

> "Unfortunately, what typically happens in practice is that aggregation of the single code occurs, with a consequent reduction in the detail of data available and a resultant limited use for purposes which require the individual attributes..... It is a fundamental truism, that there is no single general classification system" (FOGARTY & RASKALL, 1976).

Problems associated with mixing and aggregation of attributes have made difficult the formulation of a widely acceptable land use coding system in most countries. For example, BARNES (1980) has recently reported the failure of local authorities in Britain to accept the 1975 National Land Use Classification, developed specifically for land use planning purposes. Problems of mixing and aggregation have already become evident in LIS development in Australia. For example, the advantages of adopting property improvement codes for recording land use in the LIS are that they are already available in a computer compatible form in the State valuation rolls and are usually the most accurate codes available and cover the greatest area. However, recent experience suggests that they are too broad for general statistical use for planning purposes (WILKINSON, 1980). Nevertheless, while it may not be possible to design and enforce the use of a uniform land use classification and coding system to meet all user requirements, there does exist some scope to reduce the possible proliferation of incompatible systems in the future. To this end, TESSARI

(1974b) lists the desirable characteristics of a uniform land use coding system as:

1. it maintains a clear separation of land use from other important dimensions of land, such as ownership, occupancy, economic activity, tax and assessment;
2. it does not combine more than one land use under the one code number;
3. it provides various levels of detail to suit the numerous user requirements; and
4. it is structured in such a manner that the principal categories can be expanded to accommodate future requirements without disrupting the system.

A major problem in any Australian attempt to devise such a coding system is the lack of Federal/State coordination in land inventory. The fact that no State or Federal authority in Australia has a statutory responsibility to record and maintain land use data has been identified as a major factor contributing to the apparent lack of awareness for the need to standardise the recording of land use data (INSTITUTION OF SURVEYORS, 1977b). The different data requirements of the Australian Bureau of Statistics (ABS) and the State valuation and planning agencies also restrict the degree of data compatibility possible in this area. A recent Federal study (AUSTRALIAN GOVERNMENT, 1978) approached the problem of Federal/State compatibility in terms of expandability in the coding format and recommended that:

> "......each State should be free to classify land in detail in accordance with its own aims and objectives. There is, however, an area of common ground which would allow a significant degree of aggregated data comparison between the States. A land use classification code could be given a series of prime and secondary digits.... The States could be free to adopt their own tertiary digits which could reflect their own individual requirements."

Therefore, in devising a standard land use coding system, the State LIS coordinating agency must concentrate on compatibility at the higher level of classification. In this regard, there is a need for the principal categories of any future coding system to reflect compatibility with the Australian Standard Industrial Code (ASIC) of the ABS, through a desire to maintain Federal/State departmental exchange and in recognition of the wealth of data that the ABS collects and disseminates (INSTITUTION

OF SURVEYORS, N.S.W., 1977b). However, there is no need to take into consideration the primary classification structure of the Australian Standard for Interchange of Feature Coded Digital Mapping Data (STANDARDS ASSOCIATION OF AUSTRALIA, 1981). Although a significant amount of digital map data may have already been encoded under this system, feature coding of "cultural features" and "vegetation" will in future be derived from the LIS files and land resource data banks, rather than from the subjective classifications currently used by cartographic agencies within the framework provided by this Standard (see 7.6).

4.3.4 Data Security and Confidentiality

The concept of an integrated LIS, in which information is treated as a corporate resource, must necessarily give rise to problems of data security and confidentiality. These problems stem primarily from the ability of data base technology to introduce an element of transparency to all data sources by providing rapid access to data which normally remain under the control of the responsible authority.

> "As access to information is extended outward to operating levels, security measures must correspondingly extend outward to control this access....... In reviewing each data processing application, management's traditional concern has been to establish policies to protect against loss of any vital data stored and processed by the system. This loss can stem from not only nature's calamities, but also equipment failures and both the accidental and malicious acts of people.
>
> Policies and procedures have evolved which minimise the problems posed by the computerisation of vital data. Today's critical concern arises from storing and processing that additional proprietary or personnel data considered sensitive" (HUMPHRIES et al, 1971).

Data security from a management perspective remains an essential requirement of an integrated LIS whose data is updated by the responsible authority. Adequate security measures are a prerequisite to ensure the continued contribution of the owner agency, and will ultimately lead to the users acceptance of the LIS as a reliable data source. The key issues of data security measures are now primarily concerned with the protection of confidential information by preventing its indiscriminate release or its disclosure to, or modification by unauthorised persons.

Data itemswhich can be regarded as sensitive generally fall into three categories. The ability of the LIS to integrate person and business data in addition to property data is discussed in 4.5. Proposals for the integration of population and taxation records in the Swedish land data bank project is a feature of LIS development which those Western countries brought up in English traditions would be inclined to regard as "an unwarrantable, politically quite unacceptable, intrusion into individual privacy " (SIMPSON, 1976).

The unlikely event of similar developments occuring in Australia, however, does not negate the issue of data security, because of the potential of the LIS to integrate less restricted, but equally sensitive data such as health statistics, social security payment records and the local household surveys. As with personal files and taxation records in the Swedish data bank, data of this nature will only be contributed by the source agency to the LIS on the condition that confidentiality is preserved.

Community sensitivity, however, is not confined to only data derived from records of a personal nature. The potential of the LIS to increase access to all property based data can create community sensitivity to disclosing data which has traditionally been considered relatively neutral, for example:

- ownership
- occupancy details
- a persons current address
- land tax liabilities
- records of payment of government raised charges
- health and improvement orders and other encumberances
- mortgages.

The South Australian LIS study (SOUTH AUSTRALIA, 1977) found that, although this data is already recorded in individual systems, access is not always easy and interchange of data does not generally include items of a confidential nature. However, current restrictions result from reasons of difficulty rather than enforcement. Increased ease of access therefore demands that:

> "future investigations should include a detailed examination of the constraints which may reasonably be applied to the transference of data from subsystem to subsystem, and to making such data more easily and generally accessible " (SOUTH AUSTRALIA, 1977).

From a technical systems point of view, data security will involve assigning security authorizations to the independent users of the system and to data elements in the system. It is clear, however, that a solution to the problem of data security lies outside the technical sphere.

> "Privacy and confidentiality are sensitive issues especially with respect to data relating to individuals........ [T]he emerging view is that the problems are administrative and political rather than problems of systems per se. The technology is neutral. It can be protective or revealing according to how it is used. Privacy and confidentiality are issues of the use of information, not of the collection and storage of data" (COWIE, 1972a).

Attempts have already been made in Britain to solve this problem through legislative and administrative means. In 1978, a Parliamentary Committee recommended the introduction of a Data Protection Act, the establishment of a Data Protection Authority and the control of personal data handling systems by means of Codes of Practice.

> "The recommendation that Codes should be prepared for all systems which process personal information would appear to be in conflict with the concept of data bases. The latter can be defined as any common pool of computer-held data shared and accessed by more than one user. In order to avoid the breakdown of database systems, no Code of Practice should inhibit the use of data for legitimate purposes or cause the duplication of data holdings" (BARNES, 1980).

To date, legislative and administrative measures to protect information privacy in Australia have been confined to use of data collected in the national census. The Australian Law Reform Commission has put forward procedures and requirements designed on one hand to uphold the guarantee of confidentiality and on the other hand to make the best national use of the data collected (AUSTRALIAN LAW REFORM COMMISSION, 1979). Privacy issues concerned with the development of computerised data bases concerning private property, however, have not been addressed.

Given the lack of direction from Federal government in this area at this point in time, it is imperative that the State LIS coordinating agency, at the earliest stage in LIS development, prepare clearly defined codes of practice which should provide for:

- a clear definition of owners and users of data and the links that exist between different data systems
- a determination of which agencies and which individuals are permitted access to which data
- an indication of the legitimate uses of data
- inclusion of a facility to allow for the approval of new purposes.

4.4 Design Principles for Administrative Applications

The primary function of the LIS is to support existing land administration procedures. The LIS is implemented in order to overcome the deficiencies of existing data organisation by providing a central, non-redundant source of accurate, up-to-date property data in a compatible, readily accessible form. Its ability to fulfill other functions is secondary to this main role. The ability of the LIS to perform this function efficiently will depend on at least three choices which need to be made as part of the system design process:

1. the most suitable land unit to be the basic recording unit of the LIS Base File and the adoption of this unit by other property records wherever possible;
2. the most suitable existing file on which to build the LIS Base File
3. the most suitable land parcel identifier to serve as the primary key for the LIS Base File and to facilitate the integration of the various property records.

4.4.1 Basic Recording Unit

The land parcel was defined in chapter 1 as a single, self-contained and continuous piece of land bounded throughout by other similar contiguous land parcels (see DOWSON & SHEPPARD, 1956). It will be readily recognized that different agencies will use different criteria to define the boundaries of a parcel, depending on the purpose for which the property record is kept. There are at least three types of land parcels which are of interest to administrators and planners and which are currently used as the recording units in various files:

1. the ownership parcel
2. the assessment parcel
3. the land use parcel

(MOYER & FISHER, 1973, see also SIMPSON, 1976).

The *ownership parcel* can be defined as:

"a contiguous area of land described in a single description in a deed or as one of a number of lots on a [plan]; separately owned, either publicly or privately, and capable of being separately conveyed" (MOYER & FISHER, 1973).

Other definitions used in jurisdictions with Torrens Title registration systems place similar emphasis on the concept of the ownership parcel being the smallest, self-contained area of land whose boundaries are both continuous and defined by reference to a plan of survey registered in the Land Titles Office (TESSARI, 1974a, GARDNER, 1981) and capable of sale without prior subdivision (EDDINGTON, 1980). Although one ownership parcel has one and only one certificate of title, the reverse case does not always hold. For example, GRIFFITH (1974) has estimated that in New South Wales about 4% of all titles contain more than one ownership parcel.

The *valuation or assessment rating parcel* can be broadly defined as a contiguous land area under single fee ownership and (as far as may be practicable) used or intended for use as a single piece and not bisected by any significant administrative boundary (ZIEMANN, 1976b). For valuation purposes, groups of adjoining ownership parcels held under the one ownership are often handled as a single unit or holding. The British gazetteers, designed for use principally by Local government, were to be based on the rating hereditament in urban areas and where necessary, the subdivision of such hereditaments. The hereditament was simply defined by the General Rate Act of 1967 as property which is or may become liable to a rate (DEPARTMENT OF THE ENVIRONMENT, 1972). In

Australia, the various State Valuation Acts define the ratable parcel for valuation purposes. The New South Wales Valuation of Land Act, 1916 defines the valuation parcel as a grouping of adjoining ownership parcels which are owned by the same person. Separate valuations are issued for those groups of ownership parcels within the valuation parcel which:

- are separated by a road
- are separately leased
- have buildings erected thereon "which are obviously adapted to separate occupation"
- are in separate valuation districts.

The *land use parcel* (unlike the former parcels) is not statutorily defined, but may vary between the different agencies concerned with different aspects of land management and land use planning. Land is delineated into homogeneous land use units for the purposes of natural resources inventory and environmental assessment, with little or no concern with the ownership of these resources. Different crop types within the one agricultural holding are grouped into units which may not conform to the boundaries of the ownership parcels comprising the holding. In urban areas, individual ownership parcels may comprise one or more land use units which the community planner needs to identify and handle as separate entities e.g. the car parks, recreation spaces and commercial buildings comprising a shopping centre complex.

It has been suggested (ZIEMANN, 1975, SEDUNARY, 1977) that from the point of view of compatibility with other data systems, the parcel used as the basic recording unit of the LIS should be the smallest registered, contiguous area of land in one ownership and in one general use which has been approved for separate occupation and that, where possible, this parcel should be used as the basic unit of all land data recording to ensure that one ownership parcel is identical with one assessment parcel and one land use parcel.

In urban areas, this desire for compatibility has manifested itself in the adoption of the "establishment" or "tenancy" as the basic recording unit in property based information systems within Local government in Australia. The establishment is identified as the smallest unit for which data would be collected and stored, and is more precisely defined as "a discrete unit performing a special function and occupying identifiable space at a fixed addressable location" (NASH & MOLL, 1976). The unique qualities of the establishment are that it has one ownership (or covered by only one certificate of title if one exists), one land use, one assessment and one address (a pseudo address being supplied if presently unaddressed or not generally applicable). Because of the lack of uniformity in the classification of land use (see 4.3.3), there is some degree of flexibility in the definition of the establishment. The definition is therefore not restricted by real property constraints and so is usually, but not always, equivalent to one or more ownership parcels (HANNA, 1979).

This element of flexibility in the definition of the establishment is in conflict with the requirement of the LIS for compatibility in entity definition (see 4.3.3). For this and other reasons, the ownership parcel is recommended in this thesis as the most suitable choice of recording unit for the LIS Base File in Australia, and the term "parcel" will now be used to exclusively denote this entity. This choice is supported by the following characteristics of ownership parcels.

The title register is the *most complete* public land register, identifying and recording all public and privately owned parcels (whether or not subject to a rate) and depicting these parcels and their identifiers on the standard cadastral map series. In contrast, the valuation rolls list only those parcels subject to a rate. NASH (1978) claims that non-ratable land, including roads, may comprise up to 30% of all land in urban areas in Australia. This figure is also supported by Canadian experience (SYMONS, 1972).

The legal requirements of the Torrens Registration System and the administrative machinery established to administer the registration process ensure that changes to parcels in the Base File can be *monitored through existing procedures*, and that the LIS can be notified of these changes almost instantaneously upon registration. In order to facilitate this procedure, an Unregistered Documents File (see figure 4.1) may be necessary to provide an on-line display of all documents lodged in the LTO, but not registered (SEDUNARY, 1977).

Finally, the choice of ownership parcel is supported by the fact that land ownership is the *most frequently recorded and requested* land data item, even by those agencies whose statutory function is non-title in nature. In explaining their choice of the ownership parcel, MOYER & FISHER (1973) claimed:

> "the major reason for linking non title land data with ownership parcels is that even though the parcel may not be the basic unit of inquiry, many uses of non title information require that it be correlated with ownership data, which in turn requires the sub-division of the sample area into ownership parcels anyway."

An accurate knowledge of ownership rights is particularly important in land use planning, and this importance is expressed in the procedures for the delineation of proprietary land units (DENMAN & PRODANO, 1972).

> "The rights and the land to which they pertain are the elements of a unit of decision-making which has been designated the proprietary land unit.
>
> The land use pattern of an area is, at any one moment, the outcome of decisions taken within the competence of particular property rights and within the confines of proprietary land units."
>
> (DENMAN, 1974)

Land ownership is therefore an indispensible common denominator for all administrative and planning functions and, unlike land use, can be unambiguously defined to satisfy all potential users.

Adoption of the ownership parcel is dependent on establishing compatibility between valuation and land use units. In assessing the potential for parcel record integration in New South Wales, GRIFFITH (1975) has referred to the considerable difficulty experienced in attempting to ensure that ownership parcels match valuation parcels "when dealing with title and valuation systems that have developed separately over 100 years or more." However, this same statement also implies that this incompatibility does not stem from any exclusive requirement in the definition of valuation units, but can be overcome by interdepartmental cooperation so that any valuation parcel can be made to always comprise one or more undivided parcels. The need to assess groups of contiguous parcels as single entities, particularly in rural areas, demands that a separate Valuation File be created and maintained within the LIS framework (see figure 4.1) and linked to the Base File via the valuation number under which it is indexed. The existing valuation roll would form the basis of this file.

The flexibility in the definition of land use units means that, if two or more portions of an ownership parcel are used for different purposes, these portions can be designated as "subparcels" and data stored against these entities in records separate from the main LIS files. Many of the establishments recorded in Local government files would fall into this category, and would be linked to the LIS Base File via the street address (see chapter 5).

4.4.2 The Base File

The choice of the ownership parcel as the basic recording unit for the LIS suggests that the maintenance of the Base File be closely linked to the administrative procedures of the LTO through the processing of applications for mutation (subdivision and consolidation) of land parcels. However, it does not necessary follow that the LIS Base File need be derived directly from the existing title register. Instead, it is recommended that the actual Base File be built from data derived from the ownership and descriptive property data contained in the existing valuation rolls. The valuation rolls in Australia are better suited for this purpose for several reasons:

- they are *already computerized;*
- they are *already publicly accessible;*
- they hold the *name and address of the owner* in addition to the other *basic real property data items;* (see 2.2);
- they hold the *valuation number, plan/lot number* and *address* within each property record;
- they are *more readily adaptable to reform* than the titles register, the form of which is governed by extensive and often inflexible legislation.

Valuation files have been readily adapted for this purpose in those jurisdictions where the land registration system was either not public or complete (as in Britain) or poorly administered and fragmented (as in the United States). For example, the British gazetteers were based on the valuation rolls because they were the most widely used and comprehensive property files in operation, were systematically updated at regular intervals, were in machine readable form, and contained useful information in addition to the addresses of properties (DEPARTMENT OF THE ENVIRONMENT, 1972). COOK (1969a) in his proposals for a comprehensive and unified land data system (CULDATA) in the United States suggested that the laws providing for the recording of title documents were fairly rigid and not readily adaptable to the use of EDP equipment. The logical solution appeared to be to develop the basic requirements of CULDATA in the Office of the Tax Assessor. ALMY (1977) has supported this view by pointing out that records in the Assessor's Office were already indexed by parcel identifier (in contrast to the grantor/grantee indexes in the Deeds Recorder's Office) and access was facilitated by address, owner name and other supplementary indexes. In addition, cadastral (tax) maps were maintained only in the Assessor's Office, the files were accessible to the public, and many were computerized.

Australian experience also supports this view. The Base File of the South Australian LIS - the Land Ownership and Tenure System (SEDUNARY, 1977) was created from an existing property file which was already computerized and updated from a variety of sources not directly linked to the LTO (DARLEY, 1976).

The use of the valuation roll for initial Base File creation, in preference to the title register, is possible for three reasons:

- the number of (non-ratable) ownership parcels not recorded in the valuation rolls does not represent a significant deficiency compared to the title register.

According to WILLIAMSON (1982), there are approximately 250,000 (approximately 10%) more ownership parcels than ratable parcels in New South Wales, this figure not taking into account vacant Crown land.

Although figures are not available for the percentage of ratable parcels which are comprised of more than one ownership parcel, it could be expected that a considerable number of the parcels in this shortfall could be extracted from the valuation rolls by processing of the legal descriptions contained in each valuation parcel record.

- the Base File contents, at least in the initial stages of LIS operation, need not be guaranteed under the same provisions provided by the Torrens Legislation and therefore need not be completely accurate.

LIS does not supplant the Torrens Register as the authoritative record for property conveyancing but can assist this process by supplying the necessary references to the certificate of title and associated documents.

- the majority of users do not require detailed information on ownership, but only basic data such as the name and address of the owner.

The acceptance of these three principles, together with the dependence of the LIS on the LTO for the maintenance of the Base File, call for the reform of the land registration system as a necessary component of LIS development. The nature and extent of these reforms will be influenced to a large degree by the acceptance of the following three principles:

1. *The existence of a land title registration system, is not a prerequisite to the development of an effective and efficient LIS.*

In discussing the reform of the Torrens System in New South Wales, GRIFFITH (1975) concluded that:

> "a comprehensive computerized land-data bank must be based on parcels of land, the descriptions of which are legally acceptable and the ownership of which is certain. Certainty of ownership in a concise and manageable record, in my view, requires a land-titles register backed by a government guarantee and good quality survey definition of parcels."

There is no doubt that title registration is a superior system of land registration, and will provide an excellent basis for LIS development in those jurisdictions in which it operates. However, the adoption of the above conclusion as an axiom for LIS development, particularly in those jurisdictions with rudimentary cadastral arrangements, must be approached with caution. Experience in Britain and other jurisdictions which have attempted to introduce title registration, has shown that conversion of a private conveyancing or rudimentary deeds registration system to one of State guaranteed title cannot be achieved without:

- considerable simplification of existing land law
- certainty of boundary location
- some degree of compulsion in initiating conversion. (SIMPSON, 1976).

Insistance on the introduction of these reforms on a large scale as a necessary prerequisite to LIS development may inhibit, and possibly stifle, the main objective of improved data exchange.

The experience of the 10 year cadastral reform programme of the Canadian Maritime Provinces' Land Registration and Information Service (LRIS) confirms this principle. Based on a sound geodetic survey network and large scale topographic and cadastral mapping series, the existing rudimentary deed registration systems in each Province were to be systematically replaced with a computer-based land titles system. This system was to be based on a modified Torrens System which would also guarantee the position of the property as well as ownership rights. This sound cadastral base was to be used as the basis of a computerized land data bank containing data on title, assessment, structures, utilities, land use to assist in decision making in community and regional planning. A detailed account of the philosophy and early progress of the Maritime Provinces cadastral reform programme can be found in ROBERTS (1969, 1970, 1971, 1972, 1975). Despite substantial Federal funding of the programme from 1973 to 1979 as part of a regional economic expansion programme and after nearly a decade of developments, classical lines had proven costly and had progressed more slowly than anticipated. Recently reports (ROBERTS, 1979a, 1979b, 1980) indicate that while the geodetic control and large scale cadastral mapping phases of the programme have progressed well, the conversion to state guaranteed title is progressing slowly and legislation for the introduction of title registration has yet to be proclaimed. Other North American approaches to cadastral reform have been prompted partly by the slow progress of the LRIS programme, partly by a genuine concern over the suitability of Torrens legislation in the American context, (DUNHAM, 1974) and partly by a vested interest in the existing system (see HORAK, 1977). These question the need for title registration and other major institutional reforms as a prerequisite for LIS development.

It has been suggested that certainty of ownership in a manageable record can be achieved incrementally through minor technical and legislative reforms, such as improved land parcel indexing systems and marketable title acts as proposed by DUNHAM (1974). In proposing reforms of the Ontario cadastral system in preparation for future LIS development, LAMBDEN (1976) has suggested that:

> "The present registry of deeds system needs little change to make it economically into a modern system by shifting the emphasis from title to parcel in the first instance through the simple expedient of attaching all documentation to the specific parcel at the time of conveyancing........and by doing this on the basis of the current work of surveyors and lawyers without massive examination by titles office staff. Thereafter the lapse of time without dispute will provide the maturity to confidence in the result."

It is not the intention of this thesis to argue the relative merits of the various approaches to cadastral reform in jurisdictions outside Australia. However, it is suggested that similar incremental and non-exacting reforms can be used to great effect to consolidate and streamline the Torrens system in Australia.

2. *Reforms of a minor nature are required in the existing Torrens system in Australia in order to ensure the completeness of the register for Base File creation and maintenance*.

> ".....if improvement to the registration system is to be made, such improvement should be directed towards the processes involved in effecting registration rather than to the principles behind registration which, as time has proved, are still basically sound. In simpler words we want to improve the mechanics of the system rather than its design " (INSTITUTION OF SURVEYORS, VICTORIA, 1971).

Chapter 2 described the weaknesses of the present cadastral records system as the incompleteness of the register with respect to:

- land not recorded in the Torrens Register,
- interests in land not recorded in the Torrens Register.

Accordingly, reform of the present system will need to concentrate on two areas:

(i) *Consolidation of Freehold and Crown Title records and procedures, to bring all land under the provisions of the Torrens Title Registration System.*

This reform involves two parallel processes:

Conversion of Old System Title

Provision has always existed in the various Torrens Acts for the voluntary conversion of existing freehold held under the Old System Deeds Register. Although the amount of Old System land gradually decreased under this procedure during the last century, voluntary application for conversion did not prove effective in completing the registration of outstanding titles. Continued subdivision and conveyance of Old System land has seen a steady increase in the number of Old System parcels and, consequently, the continued growth of the Deeds Register (see 2.2). If the LIS Base File is to be complete, then some degree of compulsion must be introduced to the conversion process, together with the adoption of a "business-risk" approach to conversion. Such an approach will necessarily include a relaxation of the acceptance criteria for *survey* as well as *legal* incidents of title, similar to that embodied in the recent amendments to Part IV of the N.S.W. Real Property Act, 1900.

Part IVA of the Act makes provision for "qualified certificates of title" to be issued when the land is adequately defined without need for further survey definition and to empower the Registrar-General, *of his own motion*, to convert Old System land to Torrens title by issue of such a certificate. Provision is made for the lapsing of the caution and automatic conversion to an ordinary certificate of title after a period of 6 years and a transfer for value, with an absolute limit of 12 years on the life of a qualified certificate of title. This provision speeds conversion by eliminating the need to fully examine all legal incidences of title and by imparting another degree of compulsion to the conversion process.

MULCAHY (1980) succinctly stated the attitude which needs to be adopted towards survey definition for title conversion when he wrote:

> "The objective of getting all properties on to the Torrens register, where they can be dealt with and identified so much more efficiently, and where they will be guaranteed, is far too important to be slowed up or not attempted for want of accurate definition of

boundaries by survey. That must be quite subservient to the main objective."

Part IVB of the N.S.W. Real Property Act was introduced to provide for a certificate of title "limited as to survey" in order to extend the provisions of Part IVA to those properties which do not have adequate survey definition. Part IVB permits the adoption of the existing factual situation as to the position of "occupational boundaries" (such as dividing walls and fences), these boundaries becoming the legal boundary of ownership when the ordinary certificate of title issues in the future.

Rationalisation of Crown Title Administration

Separation of Crown and Freehold tenures in which title and survey records are maintained in different locations, under different filing systems and often in duplicate form, were described in 2.2 It was shown that these existing arrangements have arisen from administrative structures established at the time of settlement to meet the immediate requirement facilitating the alienation of Crown land. These arrangements are now proving an unnecessary burden to a land administration process which now deals almost exclusively with alienated land. The consolidation of all title registration functions under the control of the Land Titles Office will require administrative reforms backed by amendments to the existing Real Property Acts and Crown Land Acts, designed to bring the administration of Crown Land under the provisions of the former legislation. These reforms will necessitate:

- transfer of registration functions and supporting plans and records from the Crown Lands administration to the Land Titles Office.
- issue of Certificates of title in lieu of Crown grants for purchases of Crown land.
- issue of Certificates of title for various leases, licences, occupancies and vacant Crown land in which cases the state would be recorded as the registered proprietor.

(ii) *Registration of all interests in land which are not currently endorsed on the Torrens Certificate of Title.*

In addition to the completion of the LIS Base File, measures are required to supplement the content of the Torrens Register so that it can assist in the conveyancing process. The erosion of the original Torrens concept of the certificate of title as a single, centralized record of all rights has been described in 2.2. The proliferation of economic, environmental and planning legislation in the latter half of this century has meant that, in any conveyance, a prospective purchaser of land is required to apply to several organizations outside the LTO for a certificate as to their charges and restrictions concerning the land parcel. As EDDINGTON (1980) has reported, many of these requests concern land in which the agency has no interest, but still require considerable time and cost to process.

Fortunately, this deficiency of the present land registration system can be largely overcome by technical and administrative measures in the form of a Register of Restrictions which can be incorporated into the design of the LIS. In its most primitive form, the Register of Restrictions, depicted in the LIS conceptual model in figure 4.1, serves as an inquiry system identifying those properties which are subject to some interest currently recorded in various departments. To this end, the Register should substantially reduce the number of fruitless enquiries to agencies which have no interest in the subject parcel. In the long term, if the Register of Restrictions is to be recognised as an authoritative record in the conveyancing process, supporting legislation will be required:

- to establish that no notice, order, declaration would have any validity unless registered with a nominated authority.
- to establish the areas of responsibility for negligent omission and mis-statements in registering these notices, etc.
- to provide some form of indemnity fund to compensate for these errors (SOUTH AUSTRALIA, 1977).

In the longer term, the Register would become an integral part of an automated title register.

3. *Automation of the land title register and its incorporation into the LIS operations should be regarded as a long term development and should not be permitted to inhibit the implementation of the basic LIS*.

The prospect of automation of any existing manual records system will often act as a catalyst for administrative reforms of that system. For example, the cost of automation of the Deeds register in N.S.W. was considered far too high for the volume of business to support, and this finding was a major factor in the introduction of legislative amendments to accelerate the conversion process in that State. As well, the recataloguing of the many plans series in the N.S.W. Land Titles Office, which provided the basis for the unique identification of land parcels (see 5.2), was undertaken in preparation for the microfilming of these records and to create a unique key for the computerized title records (GRIFFITH, 1973). The main advantages of automating the title register in N.S.W. were seen as:

- efficient records management
- automatic registration of dealings
- automatic searching of records
- automatic production of certificates of title
- decreasing document storage space requirements
- minimising future increases in staff levels (MILLBURN, 1981).

While such improvements alone are sufficient to justify the automation of records, automation itself should not be confused with the overall goals of LIS development. The immediate and overriding concern of LIS development is the creation of a centralised Base File of "basic" land data items (see 4.3.2) not the facilitation of property transactions which is a specialised function within the more general activity of land information management. In recognition of this principle, a reassessment of the Swedish land data bank project in 1974 concluded that:

> "Firstly, the integration of two complicated procedures such as property and land title registration in an on-line system will result in too complex a system which will be difficult to maintain over a long period. Secondly, the short term investment will be too heavy if an integrated system is chosen as the solution of the urgent needs for rationalizing property registration " (RYSTEDT, 1977b).

The Swedish investigations subsequently recommended the postponement of the automation of the title register in favour of developing the real estate register as the Base File of the system. In addition to the complex *technical* problems involved in title automation, the *legal* implications associated with the automation of a government guaranteed title register which is controlled by legislation as rigid and inflexible as the Real Property Acts, are considerable. For example, substantial amendments covering terminological and technical aspects of the law have been needed simply to enable the N.S.W. Register to be kept on magnetic and paper mediums (INSTITUTION OF SURVEYORS N.S.W., 1980). Development of the Valuation Roll as the Base File of the LIS permits Title Register automation to proceed at its own pace and under the control of the LIS Coordinating agency.

4.4.3 The Primary Identifier

Once compatibility has been established between different land parcels and the most appropriate means of Base File creation chosen, the integration of data within the framework of the LIS is achieved by matching the codes used to identify and/or index the parcels within their respective data systems. The distinction between *identification* and *indexing* is a crucial issue in system design, if the LIS is to satisfy the administrative requirement for an efficient environment for the free exchange of data between different sub-systems. Land parcel records are generally indexed within an agency in a manner which is most convenient for the daily operation of the agency, e.g. the certificate of title by its volume and folio: electricity records by the route of the meter reader; local government records by the ward and street order; the survey plan by the next plan number in the sequence; and valuation records by walking order along one side of the street. These indexes therefore become an indispensible means of accessing the records, and therefore become the means of identifying the parcel within that agency.

The criteria for an efficient index element (or key to a data file) include:

- the capability of being ordered into a logical and generally understood sequence
- the ability to discriminate among different items of information so that the user can retrieve selectively only the information he wants

- a high probability that the user of the file will possess the data that is required as the key and that it is associated in his mind with the information he wishes to obtain. (MOYER & FISHER, 1973).

It is the second of these criteria, that of discrimination, which enables the index to serve as an identifier for the parcel. If a code is to identify a parcel, then it must distinguish it from all other parcels within the file. The identifier must establish a one-to-one relationship with the parcel (entity set). That is, the identifier must be *unique*. Once uniqueness is established, it is possible to exchange data between different data systems using the identifier as a data linkage.

Ideally from the point of data integration, it would be desirable if a *standard land parcel identifier* could be designed which could satisfy the indexing requirements of all users and collectors of parcel related data. If all data files are organised on this common label, then reordering of files is unnecessary and the integration of data is extremely efficient (ZIEMANN, 1977a). However, given the diversity of user requirements for land parcel indexing, it is doubtful whether any single identifier can satisfy the indexing requirements of all land records. The promotion, and possible enforcement of the use of such an index key would be a futile exercise. An Alberta Study (TESSARI, 1974a) recognized that the heterogeneity of user requirements would preclude the selection of any single land unit identifier which would satisfy all indexing needs, and suggested that every agency will find it necessary to carry particular identifiers for their specialized use in addition to the common standard land parcel identifier.

In Europe, the unifying influence of the cadastral system together with the long history of centralised data recording, makes the choice of standard identifier self evident. For example, in Sweden the cadastral parcel number has traditionally been used to identify parcels of land in population, taxation and business records as well as for indexing purposes in the real estate, land title registers and other property based records (WALLNER, 1969). However, the same situation does not exist in other Western nations. For example, deed recording in the United States is usually carried out on a county basis. There are approximately 2,400 such recording districts across the nation, with little uniformity of recording practices (SCHMIDT, 1971). As well, local government officials keeping land records perform their duties under separate state statutes, with usually no central supervision of their activities at any level of government (COOK, 1969b). The fragmented nature of these cadastral arrangements and the lack of cooperation between agencies, has lead to a multitude of different land parcel identifiers. Similarly in Britain, the incomplete and secretive nature of cadastral arrangements has seen the proliferation of different parcel identifiers at the national and local level.

In these countries, several studies have attempted to establish the desirable characteristics of a standard parcel identifier to be included in the data files of all agencies and, preferably, one which would be acceptable to as many authorities as possible for use as a prime key so as to facilitiate data exchange (MOYER & FISHER, 1973, TESSARI, 1974b, ZIEMANN, 1976a, DEPARTMENT OF THE ENVIRONMENT, 1974, SPICER, 1977a, 1977b). The different opinions expressed and conclusions drawn in these studies indicate that agreement on a standard land parcel identifier has been all but impossible to achieve. The reasons for this failure can be attributed, in part, to the apparent desire that the standard identifier be acceptable as an index to as many agencies as possible, particularly for land registration purposes. LONGLY (1976) sees this desire as a confusion of the problems *data transfer* with the problems of *parcel identification*.

> ".....not only is it undesirable to standardize on a national property number, it is positively unnecessary...... To match two files relating to similar objects in two different systems, it is necessary to have at least one field in each record system which can be used for matching. This field does not, however, have to be the standard reference number within either of the two systems. It can be, of course, and the fact that it is, may subjectively give more confidence, but the requirement is not essential."

LONGLY sees the standard identifier as a link or transfer number whose only function in a system is to aid the transfer of information across into other systems. "This link does not have to be meaningful in any system in which it is used."

Acceptance of the principle of neutrality of the standard identifier for data integration purposes permits greater flexibility in the choice of identifier so as to include arbitrary numbering or coordinate identifiers (see 5.3). However, the requirement that the identifier be included in all existing data files whether by mutual agreement or enforced by statute, would still involve considerable disruption of existing administrative practices across a number of agencies. Recent developments in the implementation of property based information systems indicate that, in order to satisfy the requirement of efficient data integration, it is not essential for all records in all agencies to carry the same code in order to match records. Instead, the correspondence between different land parcel identifiers can be achieved externally to these agencies by the creation of a single, Central Index which holds, for each parcel record, a list of the identifiers commonly used for that parcel in other data files. The Central Index is ordered on an existing identifier which is chosen as the *primary land parcel identifier* and is supported by peripheral indexes which relate each of these secondary keys directly or indirectly to the primary identifier. Access to the system is supported by a graphic index which depicts the limits of each parcel, and the primary identifier.

The central index approach has been successfully employed in the Local Authority Management Information System (LAMIS) developed in Britain (HARRISON, 1979). Although designed to create an integrated property data base within local government organizations, the LAMIS central index principles are equally applicable to the integration of property records within State Government in Australia. The creation of a Central Index in the initial stages of LIS development is consistent with the principle of staged development because it permits external data files to be progressively incorporated into the LIS framework by the gradual expansion of the Central Index. This expansion can take place without interfering with the internal indexing requirements of the contributing agencies for example, by requiring them to incorporate a secondary identifier or to embark on a major restructuring of their existing records at least in the initial stages of system development (NASH & MOLL, 1976, WILLIS, 1978).

The Peripheral Indexes are, in effect, inverted files of the Central Index which permit access to the system in response to enquiries based on the principal access keys currently in use, namely title reference, plan/lot no., valuation number, street address and possibly owner's name. These files establish a two-way link between the Central Index and each of the contributing data files. This two-way linking of data through the Central Index permits a transparency of data through the LIS in that all data pertaining to a parcel can be accessed via any of the identifiers stored on the Central Index. The two-way linkage also caters for multiple links necessary for the integration of different parcel types, e.g. by linking the parcel to the establishments which comprise it, or to the valuation parcel of which it is a component (NASH & MOLL, 1976). The use of peripheral indexes for this purpose is also a fundamental principle of the GISP philosophy (JOINT LOCAL AUTHORITY STUDY TEAM, 1972) and the LOTS System (SEDUNARY, 1977, 1980) and is also supported by PAYNE (1974). The place of the Central Index and Peripheral Indexes in the LIS conceptual model is shown in figure 4.1. From the viewpoint of LIS design, the Central Index can be viewed as a component of the LIS Base File, as both files are indexed on the primary identifier.

The choice of the ownership parcel as the basic recording unit for the LIS, and the practice of displaying the legal description (plan/lot number) on current cadastral map series in Australia, would suggest the use of this key as the primary identifier. However, problems with uniqueness, uniformity, familiarity and other desirable characteristics of the primary identifier demand an objective assessment of other existing identifiers as to their suitability for the prime key to the system. The choice of this primary identifier is the topic of chapter 5.

4.5 Design Principles for Planning Applications

The secondary function of the LIS is as a tool for planning. This aspect of LIS development has been predicated on the belief that the ability of the LIS to coordinate data collection at all levels of government and make this data more readily accessible, would inevitably lead to "more accurate and complete analyses and predictions, which should lead, in turn, to more precise, more complete planning " (MOYER & FISHER, 1973). In order to assess to what degree an information system, designed primarily for administrative purposes, can fulfill this planning role, it is necessary to consider two aspects of planning information system development:

1. the data requirements for planning
2. design principles for planning information systems.

In the Australian context, the majority of planning functions may be taken to occur at the Local Government level. System design therefore concentrates on the possibility of integrating property based information systems at the local level as sub-systems within the LIS conceptual framework (see figure 4.1).

4.5.1 The Nature of Planning Data

According to HUMPHRIES (1973), BRADY (1978) and WELLS (1978), planners basically require two forms of data which reflect their role in the planning process: administrative planning data and strategic planning data-

Data for Administrative Planning

Administrative planning is primarily concerned with servicing the community on a day-to-day basis and with the *implementation* of an already approved planning proposal. There are three main spheres of administrative planning:

- *property matters:* Processing of development, subdivision and building applications involving the production of certificates, answering public queries and checking on property details.
- *community services:* provision of services such as public health facilities, fire precautions, cleansing, lighting, local transport.

- *community management:* maintenance of the local environment including pollution control, advertisement control, accident recording, street repairs, parking controls.

The distinguishing characteristics of administrative planning are that:

- it deals almost exclusively with "micro" data: highly detailed data on individual parcels, activities performed on these parcels and individuals associated with the parcel.
- it involves direct contact with the community, and many of its procedures are determined by legislation. Therefore, " [e] very single item of information must be correct, errors cannot be tolerated and indeed can lead to both personal and legal embarrassment." (WELLS, 1978)
- there is a need for frequent (often duplicate) enquiry.

In summary, the data requirement is for *discrete*, *accurate* and *constantly changing* data relating to individual properties.

Data for Strategic Planning

Strategic or long-term planning is concerned with the formulation of policies on long term financial, social, economic and environmental planning and involves the *creation* of a planning proposal.

There are three main spheres of strategic planning:

- *zoning policies*
- *development policies* on road widening, housing, shopping centres, schools and other major public works.
- *financial strategies*.

The distinguishing characteristics of strategic planning are that

- it is satisfied by "macro" data: geographical aggregations of "micro" data.
- it is not too concerned about the currency or positional accuracy of data.
- access to data is only spasmodic but subsequent analysis can be extensive, involving complex simulation,

modelling and statistical analysis.

In summary, the data requirement is for *aggregate*, *accurate* data, *fixed* at a point in time, and relating to spatial areas on particular topics.

The potential for the aggregation of administrative data to produce data for strategic planning purposes is a fundamental principle in the design of planning information systems.

4.5.2 Planning Information System Models

Urban Data Banks

In the early 1960's, urban planning agencies throughout North America began to assemble computerized data banks for strategic planning purposes, particularly in the area of urban renewal. These data banks were created from existing sources (e.g. zoning regulations, land use, building condition, tax value, ownership, area) and were made possible by the fact that many city agencies had already acquired automatic data processing equipment for accounting purposes (MOYER, 1971). MOYER (1969) describes two examples of these early data banks in Washington and Alexandria in 1965. Each contained a large number of data items including value and owner's name derived from local assessor's records, but lacked data on ownership rights and interests.

In order to coordinate these large number of data bank projects being undertaken at this time, the Federal government began to fund several research projects into the design of transferable property based information systems for urban planning. The first of these studies, The Urban and Regional Information Systems Study in 1968, found that, despite substantial investment in these data banks, many

- were out of date prior to their completion
- had no provision for updating
- in no way met the responsibilities of Local governments for keeping land records (DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, 1968).

The reasons for their failure have been explained by COWIE (1972a) who describes the data bank approach to planning information system development as:

> "the creation of a general purpose data bank catering for as many present and potential uses of data as possible. Creation of a data bank would involve the gathering together of whatever data was thought to be relevant from whatever source and in whatever form it could be obtained.... Such a collection of data would tend to be unsystematic in its coverage and ad hoc in nature. There would be no certainty that the data stored would be required in the future. It would tend to be static in that once collected and stored, a data file would be regarded as a self-contained entity with no arrangements made to keep it regularly up-to-date."

Corporate Data Base Model

By the late 1960's the deficiencies of the data bank approach were already apparent. COOK (1969a) states that in 1968, there was general agreement among planners in the United States that:

> "it had been a mistake to spend large sums of money on data banks sometimes of questionable accuracy, seated solely for strategic planning purposes. It was agreed that EDP equipment should be used by government agencies to perform their basic functions. Planning information should be a by-product."

Consequently, the early 1970's saw a change in direction in planning information system development towards the adoption of a "corporate data base" model. Within this model, strategic planning data is *derived* as required, from existing administrative sources, rather than *collected* from these and additional external sources, and maintained independently, as in the data bank approach. The adoption of the data base model is primarily a response to the cost and accuracy of assembling strategic planning data.

> "The reality of the situation is that government agencies have great difficulty in investing large sums of money in the collection of strategic planning data irrespective of how important this function may be. Indeed, experience suggests that investment in strategic planning data bases is not effective due to the difficulty of maintaining the data, and that only data constantly being collected and used by the administrative function has any guarantee of accuracy and veracity in an on-going situation " (BRADY, 1979).

The fact that not all strategic planning functions can be satisfied by these administrative data sources does not appear to have retarded the development of data base model.

> "Inevitably, much of the data sought by planners will simply not exist in administrative files. Nevertheless, to the extent that imaginative approaches can yield basic and useful information, more effective use will be made of available data resources.
>
> This is particularly critical in view of the increasing difficulty of eliciting information from the public, complaints over duplicated collections, resistance to surveys, curtailment or modification of national census taking due to spiralling costs, etc.
>
> .....The development of local computerized planning information systems may, overtime, provide better access to such data and can facilitate the generation of tailor-made statistics." (WELLS, 1978)

The development of the corporate data base model represents an evolution of planning data organization, paralleling developments in computer hardware and software. As data processing systems has become faster and more efficient, functional integration of data has tended to occur, with various separate files of administrative and planning data within an agency becoming more integrated over time. According to WILLIS (1978) the principal advantage of the corporate data base approach to the acquisition and storage of planning data is that it enables data from diverse sources and collected for one simple and routine purpose to be used for other complicated and ad hoc purposes.

> "Collection of data in this way would be systematic in coverage. It would be certain that what was collected was required for at least one purpose. The data base would be dynamic in that as changes occur they would come to the attention of the (planning) authority through the administration of services and the act of administration would cause the relevant data records to be amended " (COWIE, 1972a).

The data base model was first adopted for the United States Urban Information Systems Inter-Agency Committee (USAC) project in 1969 (see DUNN & HEARLE, 1972) and the General Information System for Planning (GISP) Report in Britain (JOINT LOCAL AUTHORITY STUDY TEAM, 1972).

Despite very comprehensive documentation, the computer systems devised under the USAC project did not attract much interest from potential adopters (McCALDEN & JARVIE, 1976). However, this failure has been attributed to the fact that coordination and funding of systems development was from above, rather than being implemented incrementally through cooperative developments at the local level (AANGEENBRUG, 1980).

Its failure did not represent any weakness in the data base philosophy. The British Local Authority Management Information System (LAMIS) package (HARRISON, 1979) has successfully incorporated the data base philosophy into its design.

4.5.3 The Land Information System as a Planning Tool

The increasing trend towards the development of information systems for planning in Local Government in Australia has paralleled LIS development at the State level in that the introduction of automation has lead to major changes in the approach to the problems of land information management at the local level.

> "The growing use of computers in local government administration, whilst predominantly employed for routine financial and accounting purposes, e.g. the processing of rate notices, payroll, creditor and debtor accounts etc., leads to an awareness of the duplication of record keeping in various branches of council activity. Recognition of the central integrating role of the land parcel and the possibilities flowing from computerization creates interest in a more systematic approach to the matter of land information." (WELLS, 1978).

The corporate data base model is symptomatic of these changes. In the same way that this model utilizes administrative data for strategic planning functions, so too can the LIS, as an instrument of State administration, contribute to the planning function. The use of the LIS in support of administrative and strategic planning stems from its ability:

- to provide a centralised source of up-to-date, basic (micro) data items concerning individual parcels of land.
- to integrate property based data external to the main LIS files, through the Central Index.
- to process these basic data items to produce more accurate, up-to-date and meaningful information in support of strategic planning.

The potential of the LIS for planning purposes was first formalized in the Swedish Land Data Bank project, under the direction of the Swedish Central Board for Real Estate Data (CFD). From its inception in 1968, the Swedish system, although primarily an instrument of cadastral reform, was designed to operate "within a framework of a uniform flexible net of information systems for community planning." (WALLNER, 1969). The Land Data Bank by itself provides basic facts about parcels of land which are of fundamental importance to all aspects of administrative and strategic planning. The fact that other data files outside the Data Bank also carry the cadastral identifier enables it to perform an integrating role for other property-based data. The place of the Land Data Bank within a conceptual model for a "*fully integrated*" information system for planning is shown in figure 4.1. The model envisages three linked registers of entities - properties, persons and businesses. While the CFD has the responsibility to maintain all files containing property details, it has no control over files dealing with persons and businesses.

The fully integrated system functions as follows. Each entity is assigned a unique identifier which is used for all record purposes and which is cross-referenced to one or both of the other registers as well as its own register. Through these master files it is possible to integrate a wide variety of topic files concerning these three entities. The philosophy of the Swedish system is to achieve maximum flexibility in the application of the LIS to a variety of needs, not all of which could be anticipated during the initial stages of system development. This flexibility is achieved by collecting data at the finest level of disaggregation as possible (the land parcel and person) and storing if in their respective data bases with linked identifiers so that the whole data base could be restructured to meet any unforseen requirement (WILLIS, 1972, McCALDEN, 1973).

Whether the LIS can adequately satisfy the needs of planners in this fashion has been questioned by several observers. McCALDEN (1974b) has stated that:

> "Proponents of systems of this type point out that once a detailed parcel file has been established, all other required information can be appended to the unit records. This may be so in theory, but it is questionable whether it represents the best approach in practice. The cost of establishing and maintaining a comprehensive parcel system would be substantial and might not be justified by the potential use."

McCALDEN (1974a) further supports this view by stating that the file organization within any system must reflect the operating requirements if the retrieval of data is to be economic. As the LIS is primarily designed for administrative purposes, this requirement can pose a serious problem to planning information system design, since a variety of search criteria may need to be used on these same files and that virtually all data items are potential descriptors.

WILLIS (1972) has also observed that the concept of one centralized fully integrated comprehensive system for planning purposes, epitomized by the Swedish System, although possible in theory, is subject to enormous *operational* difficulties. The practicalities and cost of assembling and outputting the data required by a wide range of users, of responding to users in time to meet their needs and of managing the data base should not be underestimated. Unlike administrative operations, user requirements for planning purposes are not readily identifiable at the initial design stages of the system. Consequently it seems improbable that operating procedures could be designed which would allow one system to satisfy all users efficiently and economically. This need for flexibility in the design of planning information systems has been recognized by WALLNER (1971) in relation to the Swedish system.

> "Another problem is that progressive development in society will cause a fast change of the need for data. The same result is given by the fact that planning methods and supply of data have a reciprocal influence on each other. Therefore the need for data can never be finally determined. This will set great demands on the flexibility of the technical system."

In summary, administrative data requirements and data flows at the State and Local level are usually well defined and simple to model in the system design at their respective levels of operation. Strategic planning functions are more diverse and dynamic. This implies that the role of the LIS is best restricted to one of a data source in support of administrative and strategic planning operations. Planning information systems must continue to be developed and operated at the local level but must also be subject to the control of the LIS coordinating agency.

4.5.4 The Spatial Referencing System

One of the main reasons that the LIS is restricted in its ability to integrate and process land-related data for planning purposes, is that much data of interest to planners is not always directly referenced to land parcels. For example, economic, demographic and social statistics although collected at the household or business level, have been traditionally aggregated and referenced to larger administrative or predefined areas such as census collector districts, planning zones, city blocks etc. In most cases these entities correspond to, or can be made to correspond to aggregations of individual parcels. The LIS can therefore be used to correlate parcel related data with data referenced to these units by carrying the relevant area code as an attribute of the parcel. For example, demographic data collected in the national census can be correlated with housing data obtained through the LIS by aggregating data from all parcels containing the appropriate collector district number.

However, the use of the LIS in this manner is still restrictive in that the smallest unit of data registration and the degree of data correlation is limited to the smallest statistical area. The continued dependence on these data collection units is proving increasingly unsatisfactory for planners for several reasons. WALLNER (1969) in discussing the use of the Swedish Land Data Bank for planning purposes pointed out the inflexibility of data integration using administrative areas and other large units to record data of interest to planners. These units are usually too large and heterogeneous and restrict the processing of data to one or a group of units. Where data has already been aggregated to areal units, the size, shape or boundaries of these may not meet the needs of a particular user. As well, administrative boundaries are changed from time to time making temporal comparison between successive data collection periods difficult. Finally, it is widely recognized that social research and physical planning require data for areas which are smaller than, or which do not coincide with these larger areas (CRISP, 1974).

As HART (1974) points out, many of these problems can be overcome by using smaller statistical areas and the related problems of boundary changes and confidentiality can be overcome by improved administrative procedures. However this is a short term solution to what is a broader and more complex problem of integrating all forms of planning data including data referenced to networks (utilities and services, transportation and traffic data) and environmental or physical resources data (soils, geology, pollution etc.), none of which can be conveniently or directly referenced to land parcels.

Through the development of planning information systems in the last decade, it has become increasingly apparent that the key to the integration of all forms of planning data lies in the establishment of a common indexing system or common frame of reference for all planning data and the production of information within that frame of reference. The element which almost all planning data have in common is their location. For example, it has been estimated that between 85% (KINZY, 1980) and 92% (MITCHEL, 1976) of all data used or generated by Local government in the United States can be related to a given geographic location. As well, there are many administrative and strategic planning functions for which location is important. A review of data needs in British local authorities (DEPARTMENT OF THE ENVIRONMENT, 1973a) identified several activities in which the spatial element is part of the processing of data into planning information. For example, the location of Council property is needed to organize property maintenance schemes. In addition analyses which identify the spatial distribution of problems aid decisions on the places for remedial action, e.g. knowing where pedestrian accidents are concentrated will show where safety barriers are needed. Finally, long term planning may involve choosing between alternative routes of a new road in which case it is necessary to know how many homes will be affected by each scheme.

Traditionally, data has been referenced to entities whose location and extent have been depicted on maps. The map has not only provided the basis for the integration of various sets of data by overlaying different data sets, based on a common spatial framework, but have also provided the basis on which the data has been interpreted, processed and presented traditionally through the skill and coordination of the human eye and hand. The development of computer analysis techniques and computer graphics equipment in the last decade has now made it feasible to directly relate data to the spatial framework by the attachment of geographical coordinates. The incorporation of these coordinate references permits the computer to perform four types of spatial data processing which are of application to planning (DEPARTMENT OF THE ENVIRONMENT, 1973a).

Spatial Retrieval involves searching a file of data to discover all the relevant records which are located in a chosen area or to find out in which of several areas a particular record is located. The spatial search may be carried out for ad hoc or predefined areas. The former include irregularly shaped polygon whose vertices are defined by coordinate values. Techniques for point in polygon, radial (points lying within a certain radius of a point) and path searches (points lying within a certain distance either side of a central line) have been documented in BRADY (1974) and BAXTER (1976). Grid square summaries of parcel data can be readily generated by spatial retrieval methods. Administrative uses of spatial retrieval techniques include the ability to automatically recognize property or other related records into new administrative areas, e.g. electoral redistributions (DEPARTMENT OF THE ENVIRONMENT, 1973a).

Data Linkage is an application of spatial retrieval techniques for the purposes of integrating different data sources. Individual property records can be aggregated to and compared with larger areal units such as census collector districts, provided that both the parcels and areas are coordinate referenced. The ability to aggregate data is therefore not dependent on the encoding of individual parcel records with their respective areal codes. The flexibility of coordinate referencing overcomes the dependence on collection units and the disruption caused by future changes in areal unit boundaries. Data referenced to non-compatible areal units such as land parcels and soil units can also be directly correlated by polygon overlay techniques.

Spatial Analysis includes a wide variety of data processing from simple calculations of distance to statistical analysis of spatial relationships and modelling. Spatial analysis of existing data records can be used to determine the best place to locate a new facility such as schools, open spaces, libraries etc. Functional areas such as school catchment areas can be delineated by the analysis of data based on distance criteria (such as straight line distance or shortest routes in the street network). Data criteria such as population details can also be used to delineate such areas (HOLM, 1974).

Graphic Display involves the automatic mapping of spatially referenced data which has been retrieved from or analysed by an information system. A variety of computer mapping techniques can be used to present data and information at any selected scale and in any required form, e.g. grid mapping, dot distribution, point symbol, choropleth isarithmic or cartogram form.

The process of describing the location of real world objects (including land parcels) by the attachment of geographic coordinates can be given the general term "spatial referencing". Spatial referencing place in the conceptual model of the LIS depicted in figure 4.1 as a Spatial Referencing System, which is formulated as an adjunct to the LIS through which all land-related data can be correlated with the property-based data contained in the LIS. According to HOLM (1974) the Spatial Referencing System comprises:

- a geographic base file containing some form of coordinate description of the parcels, statistical collection districts, networks and other spatial units to which planning data is referenced.
- procedures for the creation and updating of the base file, and for the retrieval, analysis and display of the data referenced to these units.

Chapter 6 presents a theory of spatial referencing, and compares the alternative methods which can be used to reference land parcels. Based on this comparison, and for the purposes of introducing the following section, the three forms of coordinate references which the Spatial Referencing System must supply are:

- the centroid coordinates of the parcel
- the boundary coordinates of the parcel
- the coordinates of the segment of the street network onto which the parcel fronts.

Section 4.5.5 deals with the design principles associated with the creation of the geographic base file of the Spatial Referencing System.

4.5.5 The Digital Cadastral Data Base

Coordinates for spatial referencing purposes have traditionally been acquired by the authority developing an information system by digitizing existing cadastral maps. The digitized cadastral pattern provides these references directly, in the case of parcel related data, or as a reference frame for other land related data such as transportation, census, utilities and services, and land resources. Chapter 3 described the application of computer technology to the task of transforming existing cadastral chartings and plans into a standard cadastral map series based on the Australian Map Grid. One of the by-products of this process was the creation of a digital data bank of cadastral coordinates which could assist in the ongoing functions of standard map maintenance and special purpose mapping. The advantages of digital mapping techniques to the cadastral mapping system were listed in 3.4 as:

- *increased productivity,* including a lesser demand for skilled personnel.
- *integrity and flexibility* of digital data which is important in map maintenance, compilation and drafting.
- *variety of output* by selecting the required map content, scale, orientation and format.
- *plotting* is rapid, accurate and automatic, eliminating the duplication of effort currently expended within agencies in the continual redrawing of the same cadastral pattern in a variety of different forms.

- *modification* (updating and upgrading) of the cadastral map can be achieved more easily and rapidly.

The significance of the automation of the cadastral mapping system to LIS development, however, goes beyond these immediate benefits to standard mapping. The existence of cadastral map data in digital form permits the introduction of data base technology to the cadastral mapping system. The concept of the Digital Cadastral Data Base (DCDB) is discussed in detail in BULLOCK (1978) and BRIDGES (1981). The DCDB can be defined as a central source of continually up-to-date, compatible and readily accessible digital cadastral map data. The DCDB contents can be shared by any number of user agencies at the same time through remote terminals. Users are able to retrieve, process and contribute to the data base in real time mode. The primary purpose of the DCDB is to eliminate the present problems associated with data duplication, availability, accessibility, accuracy and compatibility in the cadastral mapping system.

Successful implementation of the DCDB depends on the acceptance by cartographic agencies and their customers of a new approach to cadastral mapping, namely, that in the future:

> "all cadastral data should be stored on computer, and the computer version of the data should be considered the master copy, and any hard copy images plotted by the computer should be regarded as duplicates of the master, and plotted only as needed " (COOKE, 1977).

The DCDB therefore replaces our traditional concept of a standard and relatively *static* published map series as a means of disseminating the cadastral spatial reference framework to a variety of users, with a centralised *dynamic*, common source of cadastral data capable of producing graphical products to suit any given purpose. Acceptance of this principle overcomes problems associated with the *availability* and *accessibility* of cadastral map data.

The degree of success that the DCDB can achieve in the elimination of data duplication and incompatibility in the present system depends on whether the DCDB can satisfy all user *accuracy* requirements for cadastral map data, thereby ensuring the use of the same central data source. Accuracy in this context is taken to mean the veracity of the data's spatial and temporal dimensions. This requirement implies that:

- the coordinate references be derived from a source sufficiently accurate to satisfy large scale (1:1000) mapping specifications
- the contents of the DCDB be kept continuously up-to-date to eliminate the need for users to provide their own updating mechanisms.

It has often been suggested (INSTITUTION OF SURVEYORS, N.S.W. 1977a, HILL, 1977) that the requirement for instantaneous and continuous updating to replace the present system of periodic revision (see 3.3), can be met as a by-product of the Land Titles Office procedure in several States for mathematically validating all new subdivision survey plans at lodgement, prior to registration. Such an arrangement can be readily implemented by the provision of some facility for capturing and retaining the survey plan data utilized in this process, rather than discarding this digital data once the check is completed, as is present practice. HILL (1977) describes the operation of such a facility which provides LTO staff with an interactive system of plan checking and calculation of areas and coordinates, initially on a plan origin. Once the necessary control has been established, the coordinates can be converted to the national grid. Updating is therefore part of an existing process, and occurs at the source of parcel creation, the DCDB contents being updated at the earliest possible stage of parcel mutation. The advantages of real-time updating of cadastral map sheets has been cited as the main reason for DCDB creation in at least one cadastral system (DEQUAL, 1976).

In the same way that the DCDB can rationalise present cadastral mapping activity, the centralized creation and maintenance of basic spatial units (bsu's) (see 6.2) through an existing cadastral process has the potential to overcome many of the problems which have been experienced in implementing spatial referencing systems overseas. The DCDB is therefore the logical choice as the geographic base file of the Spatial Referencing System, thereby completing the LIS conceptual model depicted in figure 4.1. The advantages of this approach is fourfold:

1. The DCDB coordinates are obtained as a *by-product of an existing process*. It is now recognized that the DCDB can be economically justified on the grounds of standard map maintenance and special purpose cadastral map production alone (BRIDGES, 1981). The implementation of the DCDB and its continued support is therefore assured, irrespective of its adoption for spatial referencing purposes. The use of the DCDB for this purpose is a logical extension of the traditional role of state cadastral mapping agencies in providing a uniform spatial framework for land related data.

2. The bsu's are *continually updated through an existing process*. Mutation of parcel, street and block boundaries which can only be created through the registration of plans of subdivision in the LTO, are

captured at their source and enter the DCDB at the earliest possible instance. The significance of this feature of the LIS Spatial Referencing System is evidenced by the experience of the US Census Bureau. According to BARB (1974) the topic of DIME file maintenance received increasing attention immediately after their use in the 1970 Census (see 6.3). By accepting Federal and Local funding for DIME file creation and development, the Bureau had up to that time, assumed the responsibility to ensure that these files remained useful and current for local as well as Federal use. Despite very substantial investments in the DCDB files, their maintenance had not kept pace with the rapid changes in urban cadastral pattern and by the late 1960's many had already become out of date. Consequently in 1971 the Bureau assigned the responsibility of file maintenance to local agencies (BARB, 1974) and undertook to systematically establish a standardized methodology under which the local authority could maintain a complete, current and accurate DIME file and Metropolitan Map Series (MMS) on a continuing basis (SMITH & BOMBERGER, 1974). However, since the mid-1970's, the popularity of the use of the DIME files to spatially referenced local address-based records has waned. In 1974, the operational use of DIME files for local applications were relatively rare and instances of frustrated or abandoned attempts were common (McCALDEN, 1974a). However, DAVIS & PAYNE (1979) suggest that the principal reason for this decline in usage was not because the technique did not work, but because the DIME files had increasingly become out of date through new subdivisions, redevelopment and street name changes. The local and regional organisations (often planning agencies) entrusted with file maintenance seldom possessed the manpower or the appropriate institutional connections to undertake the task.

The importance of continuous updating was also a major factor in the decision of the Ordnance Survey to restructure its cartographic data bank for spatial referencing purposes. This task was viewed as a continuation of their traditional role as a servicing agency, with their existing system of continuous revision ensuring that the spatial references were always kept up-to-date (ORDNANCE SURVEY, 1975).

3. The centralized creation of spatial references eliminates much of the *duplication of effort* in the ad hoc and piecemeal digitizing which can occur when separate authorities within the same jurisdiction digitize the same cadastral maps to satisfy their specialized spatial referencing requirements. The accuracy of the DCDB contents and the quality control demanded by cartographic uses of the DCDB ensure that all user requirements are met, thereby avoiding the need for redigitizing when more accurate coordinates than those currently available are required.

4. The one central source of BSU's provides the *compatibility of BSU's* necessary for the integration of data within different land related systems. Even though the same cadastral maps may be digitized to create spatial references, the different BSU definitions for parcels, street segments, block faces etc. used by different agencies can seriously limit data integration. The GISP report in Britain (JOINT LOCAL AUTHORITY STUDY TEAM, 1972) recognized the need for a central organization to create and maintain local gazetteers in order to ensure that each property was unambiguously defined and given a unique spatial reference. A later survey of point referencing activities at the local level (OBEE, 1973) reinforced this concern by reporting that, because of

> the diversity of resolution, convention and units being referenced at that time, the work of individual authorities would be unsuitable for inter-authority exchange or for use by Central Government in future. This responsibility was eventually taken up by the Ordnance Survey as discussed previously.
>
> Similarly, in the United States, the Census Bureau has expended considerable funds to standardize and methodology in establishing and updating the local DIME files. This Federal responsibility was deemed essential, otherwise according to SILVER (1977), instead of a nationwide series of DIME files, there would exist hundreds of independent and large non-compatible local systems.

As with the application of data base technology to the cadastral records system, the implementation of the DCDB represents an attempt to rationalise existing data structures. This process has proven more difficult for cadastral map data because of the conflict of data structure requirements for cartographic and spatial referencing purposes. Chapter 7 formulates an efficient file design for the DCDB designed to serve both cartographic and spatial referencing operations.

4.6 Summary and Conclusions

The majority of problems associated with the existing functionally oriented land data organisation stem from the inability of manual records systems to transmit data to where it is required resulting in a proliferation of individual and remote collections of data. The development of Land Information Systems is an attempt to restructure this organisation through the use of computer technology, and reflects an increasing trend towards the sharing of data within government administration. This trend has occurred in response to the high costs of gathering and maintaining data, and in response to the technology which permits this to occur.

It is the ability of data base technology to bridge this gap between data owners and potential data users which enables the LIS to overcome the problem of data duplication. Australian investigations indicate that up to 65% of land-related data currently held in government data files would become redundant once the LIS becomes operational (MORGAN, 1979). From a technical viewpoint, the data base solution represents a rationalisation of data structures within the existing cadastral system.

The LIS is not developed as a new data gathering agency but is created by integrating existing data sources into a central, readily accessible, non-redundant data source. Successful implementation and operation of the integrated system is dependent on the acceptance of a number of principles. The most important of these principles are the following:

- activities associated with LIS development should be coordinated by a central agency which must be able to enforce conformity within the general LIS framework.

- integration is best achieved in stages, commencing with the creation of the LIS Base File containing the most frequently accessed data items.

- common standards for the definition and classification of data are necessary to ensure the data compatibility necessary for the exchange of data between subsystems. A national land use coding system is of particular importance in this regard.

- in addition to data incompatibility, the security and confidentiality of data are also major causes of data duplication in that they inhibit or prevent the free exchange of data. Clearly defined codes of practice are needed to guarantee the security and confidentiality of data in the LIS.

The primary function of the LIS is as a tool in support of land administration, designed to operate within existing cadastral arrangements. Its secondary function is as an aid for planning.

The ability of the LIS to efficiently perform its administrative functions is dependent on the acceptance of certain principles which will exert a strong influence on system design. The most important of these principles are the following:

- the most suitable land unit for the LIS Base File is the ownership parcel and wherever possible, this parcel (or aggregations thereof) should be adopted as the basic recording unit for all property-based land records systems.
- the Valuation Roll is the most suitable file on which to build the LIS Base File.
- updating of the LIS Base File is dependent on the administrative procedures of the Land Titles Office (namely parcel mutation, parcel identification, changes of ownership).
- existence of a land title register is not a pre-requisite to the development of an effective and efficient LIS.
- reforms of a minor nature are required in the Torrens System in order to ensure the completeness of the register for Base File Creation and Maintenance.
- automation of the Torrens Register and its incorporation into the LIS should be regarded as a long term development and should not be permitted to inhibit the implementation of the basic LIS.
- access to the LIS should be possible via legal description, title reference, valuation number and street address through a Central Index supported by Peripheral Indexes.
- a standard parcel identifier is therefore not required to be included in all land parcel records, integration of property based records being achieved through the above indexes by each record containing at least one of the above identifiers.
- a primary identifier needs to be chosen to serve as the primary key for the Base File records, including the Central Index.

The ability of the LIS to satisfy the data requirements for *planning* is also dependent on the acceptance of certain principles which will influence system design. The most important of these principles are the following:

- the LIS must be designed to facilitate the integration of property-based Local government information systems within the LIS framework, in order to assist administrative planning functions at this level.
- from a Local government perspective, the LIS should be viewed as part of a corporate data base model in which data for administrative purposes is used to support strategic planning functions.
- it is unlikely that the LIS can serve as a fully integrated planning information system (along the lines of the Swedish model) due to the organisational, operational and legal problems associated with the integration of population and economic statistics at the parcel level.
- the ability of the LIS to integrate all land-related data (including land resource and network data) is greatly enhanced by linking it with the Spatial Referencing System.
- the Digital Cadastral Data Base should be developed as the base file for this System.

The conceptual model of the LIS formulated in this chapter (see Figure 4.1) reflects the cadastral reform measures from which it has been derived - the LIS and the Spatial Referencing System representing the application of data base technology to the cadastral records system and to the cadastral mapping system respectively. Within these systems, the Central Index and the Digital Cadastral Data Base represent "administrative" and "geographic" indexes respectively (POPE, 1978) or switching mechanisms through which the data in property-based records and land-related subsystems can be correlated. The following chapters describe these subsystems in detail.

Finally, it is apparent from overseas and Australian experience that the successful design and implementation of the LIS is dependent on *institutional* rather than *technical* reforms. SUMMER (1973) lists the principles essential to the efficient operation of the LIS as:

modularity: operational structure of the system
maneouvreability: the movement of data within the system
flexibility: the ability of the system to react to change

data reduction: the need for detail

expandability: the size of data records

These principles can be readily incorporated into the system design by the enforcement of stringent design standards. Institutional problems (organisational, legislative and political aspects of system development) are less straightforward.

> "Perhaps the single most difficult problem to be overcome in the design and implementation of a comprehensive land [information] system is the mismatch between the typical vertical structure of the existing institutions and the inherent horizontal nature of a comprehensive system......... [M]echanisms which seek to integrate land information have not been successful fundamentally because they rely upon inter-agency cooperation and ad hoc committee approaches without approaching the question of institutional reorganisation" (CLAPP AND EPSTEIN, 1976).

LIS development is affected by and, at the same time, modifies the organisational environment in which it operates. This modification necessarily involves the redirection and exertion of external control over existing data flows which must cut across existing areas of administrative responsibility. In its initial stages, system development must therefore be accompanied by a willingness of government agencies to relinquish their responsibilities in certain areas of data recording and maintenance, and to implement changes in established procedures and regulations. Ultimately, the success of LIS development will depend on the willingness of government to formulate and implement statute amendments in the interests of administrative efficiency in recognition of the principle that:

> " the goal of simplified land administration procedures should not necessarily be constrained by current regulations, statute provisions and defined areas of responsibilities" (P.A. CONSULTING SERVICES PTY. LTD., 1979).

5. THE CENTRAL AND PERIPHERAL INDEXES

5.1 Introduction

A land parcel identifier can be defined as a finite, punctuated sequence of numeric and/or alphabetic symbols that is used as shorthand for referring to a particular parcel and which is used to *index* and *identify* data relating to the parcel (MOYER & FISHER, 1973). Any attribute of a land parcel record can become, by reordering a data file, an identifier for that parcel in that it provides an index on which the file could be ordered. While more than one parcel identifier can be included among the attributes of the base file, and while the file can be organized on any of these keys, a *primary identifier* needs to be chosen to index the LIS base file records. Data files external to the LIS continue to be indexed on the identifier best suited to their needs, while a Central Index provides the facility for enquiries on the LIS via these other keys.

The only essential requirement of the primary identifier for the purposes of integrating data records is that the identifier be unique (see 4.4.3). Generally speaking, none of the identifiers in current usage satisfy this criterion. However, any of them can be made to conform to this requirement once the choice of primary identifier is made. Other desirable characteristics of the primary identifier (principally connected with its efficient use and maintenance) can be used as criteria for choosing the primary identifier.

The criteria under consideration in this chapter are:

1. uniqueness
2. simplicity
3. economy
4. accessibility
5. availability
6. relation to geographic location

These criteria have been drawn from overseas investigations, mainly in North America (MOYER & FISHER, 1973; TESSARI, 1974a, ZIEMANN, 1976a) and Britain (DEPT. OF THE ENVIRONMENT, 1974; SPICER, 1977a, 1977b) and can be regarded as being universal in their application but by no means exhaustive. The influence of local requirements of parcel identification and the nature of existing cadastral arrangements in these countries have been taken into consideration in the adaption of these criteria to Australian conditions. For example, North American studies have tended to place considerable emphasis on improvements to the indexing of title documents in order to facilitate title searching. Choices have also been influenced to a large degree by the high level of geocoding activity at the Local government level during the early 1970's (see 6.2). This is reflected in the recommendation of a centroid coordinate as a standard identifier in the two earlier North American studies. British emphasis has been on identifiers which reflect postal address in order to satisfy the requirements of local government for an identifier which can be used to link various administrative and planning applications files within a local authority and which can order properties, for printout or display, into geographical order within alphabetical street sequence.

The identifiers under consideration in this chapter are those identifiers currently in use:

1. title reference (volume/folio)
2. legal description (plan/lot)
3. valuation number (district/parcel)
4. street address

and those identifiers which could be readily allocated to existing records, namely:

5. tract/parcel number.
6. centroid coordinate.

5.2 Characteristics of the Primary Identifier

1. *Uniqueness* is the only essential criterion of the primary identifier. The identifier must be unique to prohibit any conflict or confusion to the LIS regarding the appropriate record requiring retrieval by users of the LIS. This certainty of identification is dependent on the identifier's one-to-one relationship with the parcel. Uniqueness must satisfy two conditions:

- in a given identifier system, each identifier should be assigned to one and only one parcel, and
- each parcel to which an identifier is to be assigned should have one and only one identifier assigned to it in that system.

Violation of the first condition leads to the erroneous identification of records while required records may not be retrieved if the second condition is violated (MOYER & FISHER, 1973).

The chosen identification system must be able to be easily maintained in order to preserve the uniqueness of original parcel numbers by efficiently accommodating the changes caused by the subdivision and consolidation of land parcels. If this requirement cannot be achieved then subdivision will eventually lead to multiple parcels with the same identifier and consolidation to the use of more than one identifier for a given parcel (TESSARI, 1974b). Ease of maintenance is a function of the simplicity of the identifier, and in particular, its permanency (ALMY, 1973).

2. *Simplicity* is essential if the identification system is to be easily understood and easily usable. Simplicity can be assessed on the number of components of the identifier and the total number of digits or characters required for the identifier (ALMY, 1973). Ease of understanding and use is important to encourage acceptance of the new identifier by the agencies for their own indexing purposes and to encourage its use in accessing LIS records. To ensure its acceptability, the identifier should be designed for use by an average communicator of data to the system. For these reasons and for reasons of efficiency of use, the identifier should not contain too many figures. The principles of application of the identifier must be unambiguous and clerically straight forward without recourse to extensive rule books (SPICER, 1977a).

Permanency is the requirement that the identifier not change so long as the size and shape of the parcel does not change (ALMY, 1973). This requirement, however, should not be allowed to lead to inflexible system. Therefore "reasonable" permanence is perhaps a more suitable chracteristic, the identifier being capable of accommodating change without disrupting the systems it serves (TESSARI, 1974b).

3. *Economy* of an identifier has been described by MOYER & FISHER (1973) in relation to the operating costs of the system.

Efficient computer processing of records depends, in part, on the computer compatibility of the identifier which requires that the identifier have:

1. a uniform format (i.e. the number and sequence of digits in each single identifier) and
2. numeric characters only.

The satisfaction of these criteria may require extensive renumbering of existing parcels. For example, the implementation of the Swedish land data bank system demanded the introduction of a uniform property identification system for urban and rural areas which necessitated the changing of approximately 30% of existing identifiers (WALLNER, 1969). Skilful design of the numbering system can also do much to minimize the scale of financial and technological investment necessary to implement the system (SPICER, 1977a). Economy of operation is also dependent on the ability of the primary identifier to satisfy the requirement of an efficient indexing system (see 4.4.3), in order to facilitate file access, integration and updating.

4. *Accessibility* is concerned with the availability of the data sources and the existence of administrative machinery necessary to determine, allocate and maintain the identifier. In the absence of adequate cadastral arrangements, the data flows which must be assembled in order to allocate numbers to property records correctly and cheaply can be a constraining factor in system implementation and operation (SPICER, 1977a). Availability of the chosen identifier on current maps would facilitate its allocation and general use.

5. *Availability* for usage at the earliest possible time is an important characteristic of the primary identifier to ensure that any new parcel record can be incorporated immediately into the system as it is created (SEDUNARY, 1980). The immediate availability of the identifier is particularly crucial for land registration purposes in that it enables immediate notification of unregistered documents which may affect title searching through the system.

6. *Relation to geographic location* is a specialized criterion which has only been seriously considered as a characteristic of the primary identifier in North American investigations. The requirement that the identifier be directly relatable to geographic location through a coordinate reference system (TESSARI, 1974) necessitates the inclusion of coordinate values in the identifier structure. The only requirement from an indexing and identification point of view is that the location

of the parcel identifier be uniquely defined in relation to adjacent land parcels. This can be readily achieved through the graphic index which displays the parcel identifier and gives an indication of its size (ZIEMANN, 1976a).

5.3 Evaluation of Parcel Identifiers

1. Title Reference

The certificates of title comprising the Torrens Register have traditionally been bound as folios within a volume. The folio and volume numbers are assigned according to the time sequence of registration. The number is arbitrary from the point of view of the location of the property but the sequential structure of the system is particularly well suited to the indexing and archiving of title documents. Past practice has permitted the registration of consolidated titles. In order to meet the uniqueness criteria, those titles containing more than one parcel, about 4% of all titles in N.S.W. (GRIFFITH, 1974), would need to be broken up or recatalogued as single entities. Experimentation with an automated model of the Torrens Register indicated that it may prove more costly to process consolidated certificates of title automatically, rather than breaking these up or recataloguing them as single entities (GRIFFITH, 1975). Measures to ensure that all future certificates of title refer to only one land parcel have already been initiated in Alberta (TESSARI, 1974b)

The adoption of title reference as a primary identifier also fails to meet the permanency criterion. The traditional use of bound volumes meant that, when no further room for endorsing notifications was available on the folio, a new edition of the title would be issued. The introduction of loose form certificates of title in 1961 now permits the same volume/ folio reference number throughout subsequent editions so long as the identity of parcel referred to therein remained unchanged. Even with these reforms, the title reference is not a suitable primary identifier because of its inherently manually oriented structure. Within a computerized system in which direct access to parcel records is possible, this identifier becomes redundant and could be replaced by the legal description (GRIFFITH, 1975). Another major drawback of using the title reference as the primary identifier is the time delay between the creation of the parcel and the availability of a title reference (RAINSFORD, 1976).

2. Legal Description

A fundamental feature of the Torrens System is the requirement that the boundaries of each land parcel be adequately defined in a plan of survey which is registered in a separate plan series and which is used as the legal description of the parcel. Different plan registration practices within the Crown and Torrens Titles Systems in N.S.W. have lead to a variety of legal descriptions. Although lacking uniformity, these descriptions have provided a unique identification system for parcels in Crown subdivisions in urban areas (as an allotment in a section within a town) and, in rural areas (as a portion within a parish). The town and parish comprise the recording district within which the parcel numbers are consecutively numbered (see SMAILES, 1966). Within the LTO, special provision had been made for the recording of plans comprising old system and Real Property Act land, plans lodged by government instrumentalities and different plan sizes. These practices saw the creation of some eleven different categories of plans and the filing of multiple copies of plans (HALLMANN, 1973). Acute storage problems, searching difficulties and proposals for metrication of plans lead to refiling of plans into the one sequential series in preparation for plan microfilming (GRIFFITH, 1972). These recent reforms have meant that 95% of the approximately 2,000,000 parcels under Torrens Title and probably some 48,000 of the estimated 150,000 parcels under the Old System Title have unique identifiers in the nature of the plan/lot number, portion in Parish, allotment of Section in Town. A current programme is underway to economically allocate a unique identifier to the remaining 5% as they come to the notice of the LTO staff during their day to day operations (CRONAN, 1977). The remainder of unsurveyed Old System land will be identified as part of the programme to eliminate this form of title (GRIFFITH, 1976). Recent legislation has discontinued the use of recording district concept for Crown subdivisions and required the identification of land within the plan/lot series. Current regulations are directed at achieving further uniformity in legal description by prohibiting the use of letters, suffixes and supplementary section numbers in plans submitted for registration (HALLMANN, 1973). It has been shown that the plan/lot number can be adequately coded in 16 alphanumeric characters (GRIFFITH, 1975).

In contrast to N.S.W. approximately 40% of land parcels in South Australia are not uniquely identified due to a deficiency in LTO registration procedures which permitted the erosion of the unique identification afforded by the original Crown grant. This erosion had occurred because the identifiers used on certain plans had not been accepted as the legal description. A land parcellation programme involving the amendment of existing plans and production of new plans is now underway to rectify this deficiency (RAINSFORD, 1976).

As with the title reference, the principal deficiency of the legal description, is its arbitrariness with respect to location. Plan numbers are allocated in the sequence of registration. Given that most States operate only the one centralized titles office, records for adjacent parcels may be located in different places within the system, reducing the efficiency of data retrieval and integration.

3. Valuation Number

Valuation numbering systems differ between the States, but generally valuation parcels are numbered consecutively within each valuation district. In New South Wales, the Valuation of Land Act, 1916 designates each shire or municipality as the valuation district and requires, accordingly, that "as changes in the boundaries of such shires and municipalities are made, similar changes shall be deemed to be made in the boundaries of the districts." Thus, the valuation number is not permanent. The number is also not familiar to most users and is not immediately available as parcel mutation takes place. However, the main deficiency of the valuation number is that it violates the uniqueness criteria for the basic recording unit because more than one ownership parcel may possess the same valuation number. Its only advantage is that it is unique within each valuation district which permits efficient record retrieval.

4. Street Address

The street address is the sequence of numbers allocated to each residence in urban areas by local authorities. The advantages of using the street address as a primary identifier are:

- it is the only identifier presently readily displayed in public on existing buildings in urban areas and has become indispensible for property identification for

government agencies connected with provision of services and by the general public;
- it is the most easily understood identifier;
- it can be readily shown on cadastral and other large scale maps; and
- it is almost exclusively used to identify data collected for statistical and planning purposes (ZIEMANN, 1976a).

The disadvantages of street address are:
- the street address is only available for urban areas. Within urban areas, not all parcels are identified in this manner, e.g. vacant lots, drainage reserves, parks;
- the relationship between the land parcel and building is not necessarily unique and unambiguous. Several addresses may apply to the one parcel and several parcels may comprise one address;
- the street address is not permanent. Political decisions at the local level may change street names or the street section may become independent of or part of another street; and
- the format of the street address is not uniform, making its processing (reading, matching, storage etc.) difficult and its use as an enquiry key complicated (ZIEMANN, 1976a).

The familiarity of street address and its widespread usage in a variety of data files is potentially the most flexible and easily related identifier to all other keys, provided that measures are taken to improve its reliability and precision. Within urban areas problems of incompleteness and uniqueness can be overcome by the systematic allocation of house numbers to currently unnumbered properties (COLLIER, 1979) and to ensure a unique relationship between parcel and building. Problems of permanence and uniformity can be overcome by the use of a numeric code for the street name and the inclusion of an internal subdivision field in the identifier to accommodate any further subdivision of the ownership parcel, either vertically or horizontally e.g. the legal subdivision of the parcel or a flat in a block of flats. The use of numeric street codes and subdivision field or establishment number in addition to the house number is a common feature of the NGPS and LAMIS identifiers.

The main deficiency of the street address is the lack of certainty and precision in the allocation and use of the identifier due to the lack of reliable arrangements for its maintenance. While the assignment of new legal descriptions is the function of a central Land Titles Office, responsibility for assigning street names and house numbers generally lies with local government.

Problems of permanence and uniformity can be overcome to some extent by the use of numeric codes for street names within a structured identifier format. In his comparison of property numbering systems used in the NGPS and LAMIS Systems in Britain, SPICER (1977b) highlighted the similarity of their hierarchical structure based on the subdivision of the street within a given district. The format consisted of three basic fields:

1. street field - 5 digits
2. property or house field - 4 digits reflecting postal numbers
3. subdivision field - 3 digits used for internal subdivisions of buildings.

The use of street numbers accommodates changes in street name while the subdivision field permits the identification of flats and other addressable establishments within the property or building and allows for the future subdivision mutation of the parcels themselves without disrupting the established walking-order sequence of properties within the street. However, street numbering cannot overcome the discontinuities in parcel identification caused by changes in the street pattern which can occur for a variety of reasons. Such changes would require the repeated renumbering of properties which have not changed in size or shape, thereby failing to satisfy the criteria of permanence (ZIEMANN, 1976a). Therefore, the inherent deficiencies of street address prevent its use as the primary identifier for the LIS, although its widespread use demands that it be made available to users as an access key to the system.

5. Tract/Parcel Number

The division of the early Australian colonies into administrative districts such as counties, parishes or hundreds and the allocation of unique portion or lot numbers within this district provided an efficient method of parcel identification for all Crown subdivisions. However, this practice was abandoned by the various Land Titles Offices for freehold subdivisions in favour of plan/lot identification and this form of identifier eventually disappeared as original Crown grants were subdivided.

The advantages of this form of hierarchical code as the primary identifier are that it is easy to remember and gives an easily understandable indication as to the position of the property (ANDERSSON, 1977). CARLIN (1972, 1974) describes the reasons for its adoption in the Maritime Provinces System as its ability to ensure uniqueness and to provide effective access to computer and manual files.

Its main disadvantage is that the boundaries of the municipal districts are subject to change due to political influence and socio-economic forces which affect its permanence and ease of maintenance.

To overcome these deficiencies ZIEMANN (1976a) has proposed the creation of a hierarchical land parcel identification system based on tracts-recording units designed specifically for parcel identification purposes whose boundaries are permanent. The higher order fields of the identifier within a state comprise:

county (3 digit)
tract (3 digit)
group (3 digit) and
4 digit source parcel

The numbering of new parcels can be achieved by the allocation of an independent new number (free numbering) or the use of single or multiple affixes in order to maintain a connection with the mother or source parcel fraction or filiation systems (see HENSSEN, 1975b).

The retention of the source parcel as an integral part of the identifier is designed to facilitate the filing and searching of documents connected with the source parcel. In this sense, the source parcel serves as a tract index for filing subsequent parcel mutation documents. In addition, since the number of the source parcel is maintained, all parcels can be located relatively easily on an index map as the original systematic numbering sequence is undisturbed. The need to further localize identifiers within the tract or group in this fashion is a desirable feature of records system in which it is required to search a chain of title or survey documents connected with a parcel.

Independent or free numbering in which the newly created parcel is allocated the next unused number of the group in which it is situated, is recommended by DOWSON & SHEPPARD (1956). The disadvantages of free numbering are:

- the creation and maintenance of a number list on the next available number within the tract;
- the creation of an index giving historical connections between parcels; and
- the need for grid indexing to facilitate the location of a parcel on the graphic index (ZIEMANN, 1976a).

The two fundamental principles of the Torrens Registration System - the mirror and curtain principles - require that the certificate of title reflect the current ownership and that no searching beyond the current title is required. Present day experience has shown that access to information behind the Torrens Register is seldom needed but must be made available when needed (GRIFFITH, 1975). The creation of a historical file providing a chronological list of actions (dealings, plans etc.) would be sufficient to meet this requirement. It is therefore not necessary for the system to maintain references to past dealings, thereby eliminating the requirement for the primary identifier to maintain a connection to the source parcel.

It is recognised that the tract/parcel numbering system is a more efficient indexing and identification system for title and plan records than the current legal description of plan/lot. However, there would appear to be little justification for the introduction of the former system where unique identification has been achieved for most parcels in most states under the latter system. Failure to satisfy the accessibility criteria would therefore preclude the introduction of the tract/parcel as the primary identifier.

6. Centroid Coordinates

A centroid can be broadly defined as the centre of an area determined by specified criteria (DEPT. OF THE ENVIRONMENT, 1973) and which, for the purposes of parcel identification, will be taken to mean the visual or para-centroid - (the point determined by eye as the approximate centre of the parcel). The advantages of adopting the plane or geographic coordinates of the parcel centroid as a primary identifier, stem mainly from its ability to directly reference the parcel to its location within the standard map coordinate system. The coordinate structure is not tied to jurisdictional subdivisions, unlimited in view of further extension and offers significantly more information than conventional forms of sequential numbering (ZIEMANN, 1976a). As a spatial reference, the centroid coordinate greatly facilitates the retrieval, analysis and output of data contained within the system. The suitability of the centroid as a linking field for the integration of different data is supported by LONGLY (1977) who argues that the centroid can be readily appended to all data files in different data systems but need not be used by any of them as a standard reference number or key as an identifier does not have to be meaningful in any system to perform this function (see TESSARI, 1974a). MOYER & FISHER (1973) claim that the inevitable adoption of coordinate centroids by the system for spatial referencing purposes supports the argument that it be adopted as the primary identifier. Postponement of the input of coordinate can only increase the total investment in the system because of the need to standardize one of the existing identifiers or create a new numbering system to serve as the primary identifier and the operating cost incurred until the coordinate information is available. More recent proposals for the adoption of the centroid coordinate as a standard identifier for all land parcels in North America (KERR & GOOD, 1977) and in Australia (INSTITUTION OF SURVEYORS, 1979) indicate that these arguments continue to attract support.

The use of the centroid as an identifier arises from a failure to appreciate the difference between entity identification and location identification. Much of the inspiration for the centroid as an identifier stems from its use in the Swedish Land Data Bank and the incorrect interpretation placed upon it as a parcel identifier number (see MOYER, 1973). As ANDERSSON (1977) has stated, the point coordinate used in the Swedish system is not used as an identifier or official designation, but remains an attribute of the parcel record for spatial referencing purposes.

Despite its data integration and analysis capabilities, the centroid coordinate is not a suitable choice as a primary identifier because of its failure to adequately satisfy all but the last of the established criteria. Some of the disadvantages of coordinate based identifiers have been discussed by TESSARI (1974a), ZIEMANN (1976a),HARRISON (1978) and CARLIN (1974) and these are summarized as follows:

(i) Subdivision and consolidation may result in one of the newly created parcels having the same centroid coordinate. Measures to ensure uniqueness include introducing a one metre (last digit) shift to the coordinate value or the addition of a temporal reference. These modifications introduce problems of uncertainty and additional length respectively.

(ii) The coordinate reference is not commonly used or known as an access key and can only be accurately recreated by reference to a listing or map. The complexity and unfamiliarity of the coordinate value means that it will be seldom used to access the system. The primary identifier will also be subjected to continuous manual and verbal processes. The complicated structure of the coordinate identifier, in contrast to hierarchical systems, is therefore more susceptible to misquoting and misidentification.

(iii) The primary identifier should be designed to facilitate fast and efficient access to the computer and manual records. Files ordered on the basis of rectangular coordinates are not the most efficient in many computer processing applications and are most awkward for manual processes (such as filing and archiving) and associated functions (such as microfilming). Problems of permanence may also occur with the readjustment of the geodetic network on which the coordinate system is based.

(iv) Unless the centroid is generated by one central authority, different centroid coordinates for the one parcel may be derived. Unless the identifiers agree down to the last digit, problems of non-uniqueness in file merging may occur. Recommendations that the Land Titles Office determine the identifier and record it on official title documents (TESSARI, 1974b) create an unsatisfactory situation in which legal significance is given to data which is external to the immediate requirements of title registration. The definition of an identifier for flats within multi-storey buildings will also present difficulties because of the need for the third spatial dimension. This problem highlights the unsuitability of the coordinate for identification purposes as the one parcel coordinate value would generally be sufficient to spatially reference each flat within the building.

These deficiencies clearly outweigh the one advantage which the centroid coordinate may have to offer the primary identifier in its relation to geographic location.

5.4 The Primary Identifier

The tract/lot number is the most suitable choice as primary identifier for the indexing of Base File records (including the Central Index) and for display on the graphic index to the system. The plan/lot number also satisfies most of the criteria for the choice of primary identifier. Its main deficiency is that the plan number indexes new parcel records in the Base File according to the time sequence of their creation within the state, rather than confining parcel records to the recording district in which they are located to facilitate searching on the graphic index and in the Base File The remaining alternatives fail to adequately satisfy the given criteria due to some inherent feature of the identifier structure or due to difficulties in the maintenance of the identifier.

In the Australian context, the choice between these two identifiers will, ultimately, be decided on the criterion of accessibility. In those jurisdictions with incomplete or non unique legal descriptions, the creation of a new tract/lot system to relate all existing identifiers may be justified. Where the majority of parcels are already uniquely defined by legal description and shown on current cadastral maps as in N.S.W., the plan/lot number (despite its indexing deficiencies) should be adopted as the primary identifier.

The remaining non-coordinate identifiers are, like the street address in the Swedish system, search arguments to find the primary identifier through Peripheral Indexes (ANDERSSON, 1977). The centroid coordinate should reside within the Digital Cadastral Data Base (DCDB) as one of several spatial references for the parcel (see chapter 6). The linking of the Central Index to the DCDB files is discussed in chapter 7. The creation of the Central and Peripheral Indexes with the plan/lot number as primary identifier is now discussed.

5.5 Creation of the Central and Peripheral Indexes

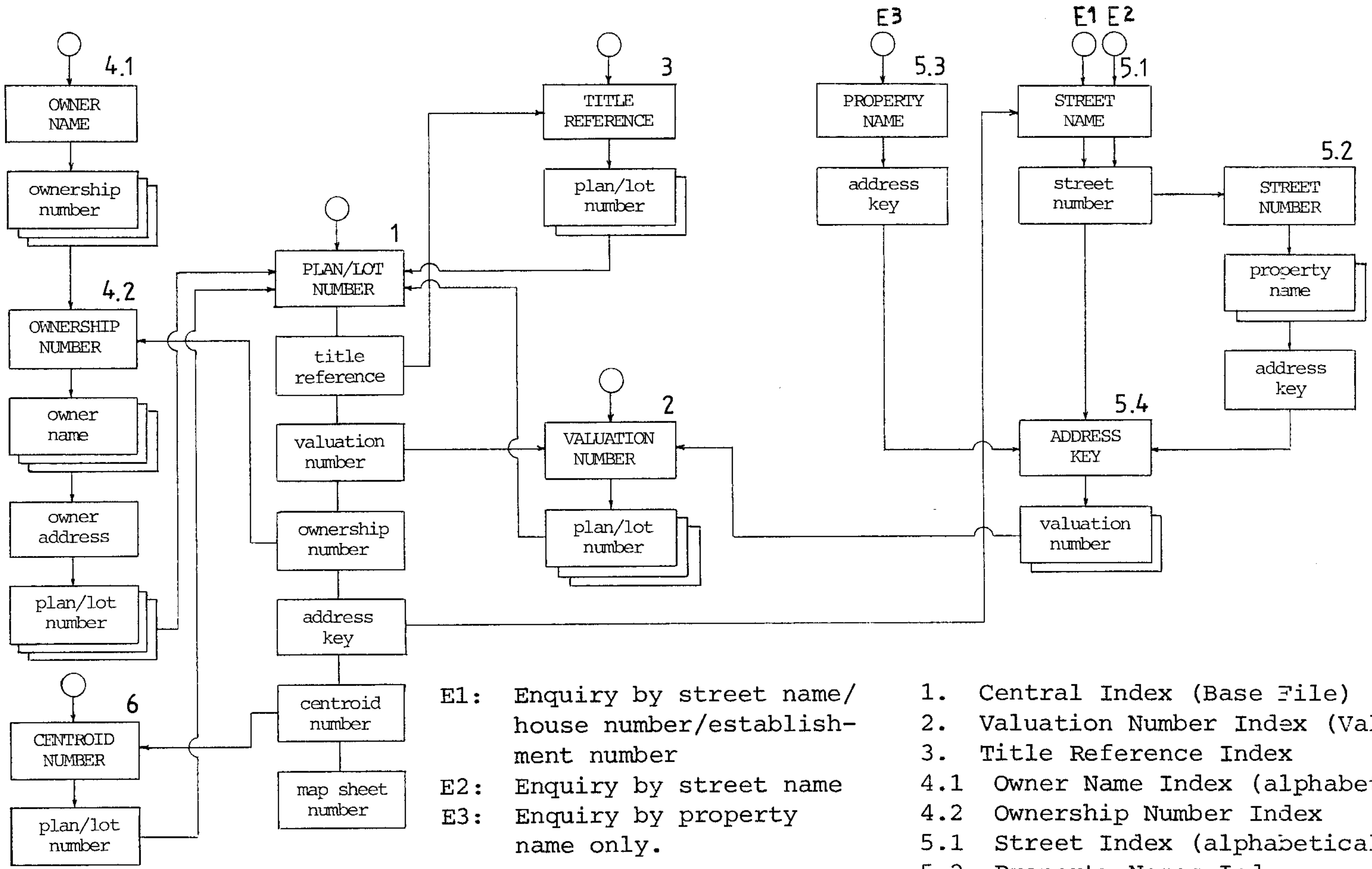
The file interaction for the Central and Peripheral Indexes within the LIS conceptual model, is depicted in figure 5.1. The configuration has been designed to permit rapid access to the LIS Base File via plan/lot (the primary identifier) valuation number, title reference, owner name and street address (in its various forms). Access is achieved directly via the appropriate Peripheral Index or indirectly via a second Peripheral Index in the case of owner name (via ownership number) and address (via valuation number).

1. Central Index

The Central Index can be viewed within the conceptual model of the system depicted in figure 4.1 as a sub-file of the LIS Base File which is indexed under the plan/lot number as the primary identifier (see figure 5.1). Compilation of the Central Index is the first stage of LIS development in the sense that, once created, the Index can automatically integrate all data files which are indexed under any of the alternative keys. Rather than being compiled in a centralised, systematic manner, the Central Index is best compiled in stages, as each of the Peripheral Indexes is completed.

2. Valuation Number Index

The Valuation Number Index can be viewed as a sub-file of the Valuation File linking the plan/lot number to the valuation number. Because



E1: Enquiry by street name/ house number/establishment number
E2: Enquiry by street name
E3: Enquiry by property name only.

1. Central Index (Base File)
2. Valuation Number Index (Valuation File)
3. Title Reference Index
4.1 Owner Name Index (alphabetical)
4.2 Ownership Number Index
5.1 Street Index (alphabetical)
5.2 Property Names Index (named properties only)
5.3 Inverted Property Names Index (alphabetical, named properties only)
5.4 Street Address Index
6. Centroid Number Index (Digital Cadastral Data Base)

FIGURE 5.1 File interaction for Central and Peripheral Indexes in which the legal description (plan/lot number) is the primary identifier (after SEDUNARY, 1977 and BRADY, 1978).

a valuation parcel may comprise several ownership parcels, each record of this Index may contain more than one plan/lot number. The Index can be derived from the existing Valuation Roll, which already contains the legal description(s) for each valuation parcel.

3. Title Reference Index

This index facilitates access to the LIS via the volume/folio number of the current certificate of title. The index can be constructed by inverting the existing computerized land index which is currently maintained to link the plan/lot reference depicted on the current graphic index to the certificates of title recorded in the Torrens Register (GRIFFITH, 1975). This index need only be considered as a temporary file required only to facilitate the smooth transition to an automated title system. As title records in an automated title register can be directly accessed via the legal description or other unique identifier, the need for access by title reference will be dramatically reduced and eventually phased out.

4. Owner Name and Ownership Number Indexes

GRIFFITH (1975) has recommended that provision for access to an automated titles system by owners name is not justified, as on average only 30 enquiries of this nature are received each day, as against 7,000 in terms of the legal description or title reference. A computer produced annual purchasers index in microfilm form could be used for this purpose.

If this form of access can be justified for enquiries other than title details, the creation of an Owner Name Index and an Ownership Number Index is necessary. The ownership number is an arbitrary number allocated to each individual owner or ownership combination in order to minimize the multiple storage of names and addresses.

5. Street Address Index

The Street Address Index, in its simplest form, links the street address (street name and house number) to the valuation number. Access to the LIS Base File is then achieved through the Valuation Number Index. This configuration has been adopted because of the fewer linkages between the address and valuation indexes and because the majority of address based enquiries will be requesting the real property data items (contained in the Valuation File) rather than ownership details.

The lack of a standard format for postal addresses complicates both the use of this identifier as an access key and for the creation of the Central Index and linkage to addressed based files. Other problems also arise from duplicate street names, alternative spellings of street names, the lack of street names as part of the address and simple misspellings (HARRISON, 1976). Because of its use of address as the master identifier or data base index, the LAMIS system has developed a sophisticated structure which permits access to the system by street name and house number, the property name (where the street name is known) and property name (where no street name exists, for example, in rural areas) by the interrelation of a street file, a named properties file and an inverted names file respectively (HARRISON, 1976; BRADY, 1980; NASH & MOLL, 1976). A similar configuration has been adopted for the street address index depicted in figure 5.1.

When an address is input, a match is first made on the streets file. If more than one street exists with that name, a choice is offered to the enquirer with the suburbs displayed. Once matched, the address code is built up from the house and establishment number or generated from the inverted names file. The names and inverted names files are created only for those properties which are either commonly known by several names or known only by a name (mainly in rural areas). Access to the street index and inverted names file is supported by a "Soundex" version of each file which provides for the automatic matching and recognition of alphabetic strings (THORNTON, 1979). These files and Soundex routines enable a correct address to be generated for each property without duplicate copies of the address being kept within the system or within external data files (BARNES, 1980).

The adoption of conventions for the coding of addresses is crucial to the efficient operation and maintenance of the address index. Street numbers in the NGPS identifier are allocated in the alphabetical order of street name, with the terminal (5th) digit initially zero to accommodate new insertions (DEPT OF THE ENVIRONMENT, 1974). Alphabetical order is maintained by a resequencing mechanism when required (SPICER, 1977b). Such a convention creates gapping in street numbers which, according to HARRISON (1978), is an undesirable attribute of an identifier because of the increasing effort expended in key changing as part of the resequencing process. The LAMIS approach of adopting a 5 digit ungapped street number in which alphabetical order is maintained by alphabetical sorting (SPICER, 1977b) is a superior method of street numbering for the address index. In addition to a 5 digit street code and 4 digit house number code, the structure of the LAMIS unique property reference number (UPRN), provides for an establishment code which enables further expansion of the identifier to incorporate establishments within the given property and address e.g. individual flats within a block of flats (NASH & MOLL, 1976). An indicator field is also provided which describes whether the house and/or establishment is also named, indicating that a record exists for this property in the names and inverted names file.

The creation of the address index from the existing unformatted computer readable valuation files can be achieved using address matching software. TURNER (1977) reports the automatic generation of street address codes from existing rate files in British local authorities with success rates of 75% and 95%. COLLIER (1979) claims that most of the data initially required for the Central Index for the city of Brisbane, Australia, could be extracted from existing rates files, as addresses are correctly coded for approximately 80% of properties. DAVIS & PAINE (1978) (using a version of the ADMATCH computer programme originally developed by the U.S.Census Bureau) have reported a 95% success rate in matching addresses contained in existing valuation files to street segment reference files created for the city of Orange N.S.W. The software is application independent (PAINE & DAVIS, 1980) and could be readily used to match addresses to a given street names file, thereby creating the address index. More flexible software has been recently developed in Britain to handle misspellings, lack of structure in the arrangement of address sub-fields and missing or redundant information (OPENSHAW & RAMSEY, 1978).

5.6 Summary and Conclusions

Land parcel identification is the process which permits the integration of all property based data within the LIS framework. Early investigations into land parcel identification for LIS development concentrated on the choice of a standard identifier which, by its adoption by all land record agencies, would serve as a linking field for all records. Difficulties in choosing or designing such an identifier stemmed from the requirement that it needed to satisfy the indexing requirements of as many agencies as possible so that it would be adopted by them as an index for their records or included in their records as the common integration key. The principal deficiency of this approach to land parcel identification is that it fails to separate the function of data integration from the indexing function of parcel identifiers. The standard identifier approach represents an attempt to achieve data integration by institutional reforms which, as discussed in 4.6, are the most difficult reforms to implement successfully. The approach fails to recognise that (with the aid of a series of cross-indexes) the integration of land parcel records can be achieved without disrupting the practices of all land recording agencies. The Central Index approach represents a technical, rather than an institutional reform. Data integration is achieved through a Central Index supported by a series of Peripheral Indexes which permit access to the LIS via any of the major parcel keys. In practice, the street address will be the most common data linkage through which records will be accessed and matched. The Central Index and LIS Base File are indexed by the primary identifier which need not necessarily be acceptable as an index or identifier to any of the LIS subsystems, although this would facilitate access to the LIS. To facilitate data integration and access, the street address should also be shown on the graphic index to the LIS in addition to the primary identifier.

The legal description (plan/lot number) is the most suitable choice of primary identifier for the LIS in Australia. Its main advantages over other identifiers stem from the fact that it has been designed to serve an existing administrative function which cannot tolerate errors in the identification of the entities with which it deals. This choice of identifier therefore ensures that it is created and maintained by the one authority under sound, established procedures.

Centroid coordinates are not a suitable identifier for this purpose because they are an unsatisfactory record index for administrative purposes. Its use as a record index for the DCDB is discussed in Chapter 7.

The Valuation Roll is the most suitable file on which to construct the Central Index because each record contains the legal description, valuation number and address for each valuation unit.

6. THE SPATIAL REFERENCING SYSTEM

6.1 Introduction

The concept of the Spatial Referencing System was presented in 4.5.4 as an adjunct to the LIS, designed to spatially process (retrieve, correlate, analyse and display) all land-related data contained in the LIS and its subsystems. The theory of spatial referencing has its origins in the late 1960's and 1970's, initially with the development of techniques for the processing of census data in the United States and later for the processing of the data contained in the planning information systems being developed by planning agencies in North America, Europe and Britain. Similar developments did not take place in Australia until the late 1970's, due mainly to the sharing of responsibilities for strategic and administrative planning between State and Local government (see Chapter 1). These overseas experiences can therefore provide useful lessons for the development of the Spatial Referencing System in Australia, and possibly prevent the repetition of past mistakes.

A theory of spatial referencing is presented in 6.2. Alternative methods for the spatial referencing of land parcels are reviewed and compared in 6.3 and 6.4. Recommendations are made as to methods which the Spatial Referencing System should provide in order to enhance the ability of the LIS to satisfy administrative and strategic planning functions.

6.2 A Theory of Spatial Referencing

Geographic coding (geocoding) can be broadly defined as the process of describing the location of real world objects (and the events connected with these objects) by the attachment of numerical code to these objects in a data base. The numerical code has been referred to as a geographic code or geocode. The principles of geocoding have been described in detail in SALOMONSSON (1972), HOLM (1974), BLACK (1974), BARB (1974), and HART (1975). The purpose of geocoding is to enable data from a variety of sources to be manipulated flexibly to meet a range of spatially related needs in planning. It operates on the principle that if all data is spatially referenced to a common spatial framework, then it is possible to correlate different sets of planning data.

In its most primitive form, spatial referencing involves the manual allocation of area codes (depicted on a map) to parcel based records, a process described earlier in relation to demographic and housing data. Naturally, the ability of the computer to rapidly identify and match data items and to manipulate large amounts of data invoked its early application to this allocation task. An early example of this form of geocoding is the use of address coding guides (ACG) by the U.S. Census Bureau in the late 1960's which were designed to automatically match addressed census returns to their corresponding block and census tract (see SMITH & BOMBERGER, 1974). In this form, spatial referencing is still dependent on the use of maps to reference the data to a common spatial framework. Any variation in the areal units requires the manual amendment of the coding guide. According to MCCALDEN (1974) this use has often been taken as the complete definition of the term. However, the concept has since been expanded to the referencing of data not associated with address, to a common spatial framework by the use of geographic coordinates. In response to this broadening of the concept, the more general term "spatial referencing" has been used in this paper to describe the process of geocoding and the term "spatial reference" (sometimes referred to as a locational reference) used to denote the geocode.

The theory of spatial referencing which was developed during the early 1970's from this early work in the United States, differentiated between coordinate and non-coordinate methods of spatial referencing.

The classical theory of spatial referencing defined the spatial reference as a code assigned for a data item which locates the data in space by direct or indirect use of coordinate references. The two main types of spatial references were:

- external index; and
- coordinate references.

The external index is a nominal code identifying the data as belonging to a particular area or location, e.g. street address, census district, traffic zone. The code does not convey location directly but must be used in conjunction with a master index, typically a map. The external index is useful for grouping data but has limited manipulation capabilities. The coordinate reference is a positional code which directly relates the object to its absolute location in space in terms of two-dimensional coordinates and therefore its spatial location is relative to other objects referenced in the same spatial framework. It is important to recognize that in this definition an external index does use coordinates indirectly in the sense that the code refers to a map which is constructed on the basis of a coordinate system.

MASSER & WILLIS (1974) have pointed out that the distinction between external indexes and coordinate references has been inherited from the early days of nominal spatial referencing systems. Today, it is generally accepted that the use of a coordinate reference is now an implicit feature of a spatial referencing system, with the external index used to identify the object. Although HOLM (1974) has noted that some forms of spatial analysis can be carried out without coordinate references (for example, by storing distance as an attribute of a street network), and that spatial retrieval is possible by defining an area by the streets surrounding it, the extended manipulation capabilities of coordinate references have now made them indispensible in spatial referencing. This view is adopted in the following design of the spatial referencing system.

Because a large amount of planning is related directly to the land parcel or to aggregations of land parcels, a Spatial Referencing System is an important adjunct to an LIS as formulated in the conceptual model in figure 4.1. A spatial referencing system can be defined as that part of an information system which assigns spatial references to real world objects and which makes it possible to work in the spatial dimension. The system enables the LIS to integrate diverse data sources and to retrieve, analyse and display data using spatial criteria. The system comprises:

- a geographic base file (GBF) containing some form of coordinate description of the various parcels, statistical units, networks and other spatial units to which planning data is referenced; and
- procedures for the creation and updating of the GBF and for the retrieval, analysis and display of the data referenced to these spatial units (HOLM, 1974).

6.3 Alternative Methods of Spatial Referencing.

Design of a spatial referencing system begins with an application of the difference between a *spatial referencing system* and a *spatial referencing method*. The former facilitates the spatial referencing of real world objects and their attributes. The latter is one of many different ways that objects and data can be spatially referenced. While there are many spatial referencing systems, there are relatively few viable spatial referencing methods.

Real world objects can be classified into the following categories:

- administrative areas, areas with defined boundaries e.g. countries, parishes, tax districts;
- functional areas, areas with less defined boundaries e.g. school districts, retail hinterlands;
- networks, lines which serve as links for the transportation of goods, people, energy etc., e.g. roads, rivers, pipelines, transmission cables; and
- physical objects, fixed objects which can be precisely located, e.g. buildings, land parcels, monuments, (BLACK, 1974).

Significantly, land parcels have been classified by SALOMONSSON (1972) as administrative areas. The difference reflects the different views of the land parcel as both an object with areal extent and as a discrete entity which can be aggregated to form administrative and functional areas. For the purposes of this thesis the latter view is adopted.

The essence of a spatial referencing method is first to develop a simplified perception of these real world objects or data items. Real world objects can be perceived either as points, lines or areas. For the purposes of representing these objects in the spatial referencing system, this simplified perception is further abstracted by their spatial representation as points, segments or polygons within a data bank. In this regard, it is possible to distinguish between the Basic Data Unit (BDU - the object about which data is collected) and the Basic Spatial Unit (BSU - the geographic unit which fixes it in space). While it would seem appropriate to obtain a hom eomorphic correspondence between the BDU and the BSU, that is, between objects and their spatial representation (by representing point data by a point, a linear or network structure by a chain of segments, and areas by polygons), there are in fact alternative forms of representation which are worth consideration. Whether alternative approaches are more attractive depends on the nature of existing administrative structures on the resources available for data capture, and on the nature of the manipulations that the spatial referencing system is to perform. The choice of method will directly determine: the minimum level of spatial aggregation; the accuracy of location of data; the flexibility of spatial analysis; and whether there is a reduction of information, or whether there is the scope for possible integration of different data items (see figure 6.1).

Figure 6.2 depicts the important characteristics of alternative methods of spatial referencing in terms of the theoretical relationships between real world objects and their spatial representation.

Although all forms of representation are possible, in practice only six of the theoretical possibilities appear to be useful. Spatial referencing methods can be grouped under the following headings:

- point methods;
- area methods; and
- segment methods.

An examination of the principles of these methods are important not only to appreciate their applicability to the spatial referencing of parcel related data, but also for their use for land resources, utility and street networks and other "non-parcel" data objects.

1. Point Method

Point methods use a pair of coordinates representing the location of the BSU. The best known applications of this method are the National Swedish Land Data Bank and the British Local Authority Information Systems. In these cases, the land parcel is both the BSU and the BDU.

In the Swedish system, the central point of every land parcel and of the buildings on the property were digitized from cadastral maps at scales of 1:2000 and 1:10000 to an accuracy of one metre and 10 metres in urban and rural districts respectively. For smaller parcels only the building point was registered. Coordinates are referred to a uniform

<table>
<tr><th>SPATIAL REPRESENTATION / REAL WORLD OBJECTS</th><th>POINT</th><th>SEGMENT</th><th>POLYGON</th></tr>
<tr><td>POINT DATA</td><td>CORRESPONDENCE</td><td colspan="2">POSSIBLE INTERGRATION</td></tr>
<tr><td>LINEAR DATA</td><td rowspan="2">REDUCTION OF INFORMATION</td><td>CORRESPONDENCE</td><td></td></tr>
<tr><td>AREAL DATA</td><td></td><td>CORRESPONDENCE</td></tr>
</table>

FIGURE 6.1 Spatial representation of real world objects (after BLACK, 1974).

REAL WORLD OBJECTS STATIONARY	SIMPLIFIED PERCEPTION OF THE REAL WORLD	SPATIAL REPRESENTATION			
		POINT ∘	SEGMENT	POLYGON (IRREGULAR)	POLYGON (REGULAR)
BUILDINGS LAND PARCELS STREETS INTERSECTIONS UNDERGROUND CABLES RAILWAYS ENUMERATION DISTRICS TRAFFIC ZONES ELECTORAL AREAS ETC.	POINT +	POINT METHOD	ADDRESS OR STREET SEGMENT METHOD	BOUNDARY METHOD	GRID CELL METHOD
	LINE		NETWORK METHOD		
	AREA	POINT METHOD	SEGMENT SIDE METHOD	ZONE METHOD OR BOUNDARY METHOD	GRID CELL METHOD

FIGURE 6.2 Alternative methods of spatial referencing (after HOLM, 1974 & MASSER & WILLIS, 1974).

national coordinate system. WALLNER (1969) writing about the Swedish system, states that whether such an accuracy was warranted in actual usage was difficult to gauge at the commencement of the program but that the decision was made because of the desire not to limit the range of the method. By integrating the parcel identifier and the personal number of an individual, it is possible to indirectly spatially reference the data records in the population, taxation, motor vehicle and other personalized registers. A variety of statistics can therefore be produced for small areas, independently of administrative boundaries, and retrieved and analysed on a spatial basis.

The 1972 GISP report in Britain (JOINT LOCAL GOVERNMENT AUTHORITIES, 1972) concluded that planners needed to be able to analyse data for geographical areas and, as a first step in this direction, it recommended the point referencing of properties through the creation of a gazetteer - an index linking each postal address to a digitized parcel centroid. The point reference was seen as an adequate representation of location because it was considered that for most analyses required by ocal government, spatial distribution of data associated with properties was more important than shape or area of the units themselves (DEPARTMENT OF THE ENVIRONMENT, 1973a). This recommendation was also heavily influenced by reports of the Swedish programme (WILLIS, 1978), and was to form the basis of British information system development until the late 1970's. A manual on point referencing (DEPARTMENT OF THE ENVIRONMENT, 1973a) was produced and, under the coordination of the Central Government, a National Gazetteer Pilot Study (NGPS) was undertaken to investigate the costs and benefits of gazetteers to Local government (DEPARTMENT OF THE ENVIRONMENT, 1979).

2. Area Method

In the area or polygon method, the BSU is considered to be an enclosed figure having location in space, areal extent and perimeter configuration In practice, it is possible to distinguish between areas of regular size and shape and areas of irregular size and shape, e.g. city blocks.

The former method has been called the *grid cell* or *grid net* method (BLACK, 1974). This method is usually associated with the superimposition of grid lines on a map and the allocation of the same spatial reference to those points, lines and areas falling within each cell. Grid cells are a convenient BSU for the organization, analysis, storage and presentation of large volumes of statistical information and are often used to spatially reference land resource data. They have also been used to spatially reference census data in Britain (GREAT BRITAIN, 1970). The principal disadvantage of the grid cell method is that it cuts across well defined administrative or functional area boundaries.

The latter method is called the *zone* method if external indexes are attached to BSU's and the *perimeter* method where coordinates are allocated to the corner points and changes in direction of the areas perimeter (BLACK, 1974). HART (1975) has suggested that the perimeter method is better considered as a segment oriented method in which the points along an area perimeter are considered as segments. However, a more appropriate distinction can be made between those perimeter methods in which the area code is used to identify a closed string of coordinates defining the area's shape and location (*boundary* referencing) and those methods in which the area polygon can be constructed through an inspection of adjacent area codes attached to each segment record, (*segment side* referencing). The latter method is distinctively segment oriented and is discussed in the following section. The most successful use of boundary referencing for the spatial referencing of land parcels has been in the LAMIS System implemented in several local authorities in Britain (HARRISON, 1979) and in Australia (BRADY, 1978; WILLIAMS, 1980).

3. Segment Oriented Method

Segment methods can be divided into two groups, according to whether they are used to bound areas (*segment side* method) or whether they are used to represent open-ended linear objects within a road or utility or other network (*network* method). Each segment forms a BSU which can be defined by the nodes at each end.

The most significant application of the segment method for spatially referencing land parcels was the development of *address* or *street segment* methods, the most famous of these being the Dual Independent Map Encoding (DIME) System in the United States. In the late 1960's, the United States Census Bureau developed the DIME geocoding system to assist with the processing of the returns of the 1970 Census. The main concern of the Bureau at that time was to develop a street address conversion system which could be used to assign areal codes to census returns distributed and returned by post. Benchmarks in the development of the DIME System are described in BARB (1971) and SMITH & BOMBERGER (1974).

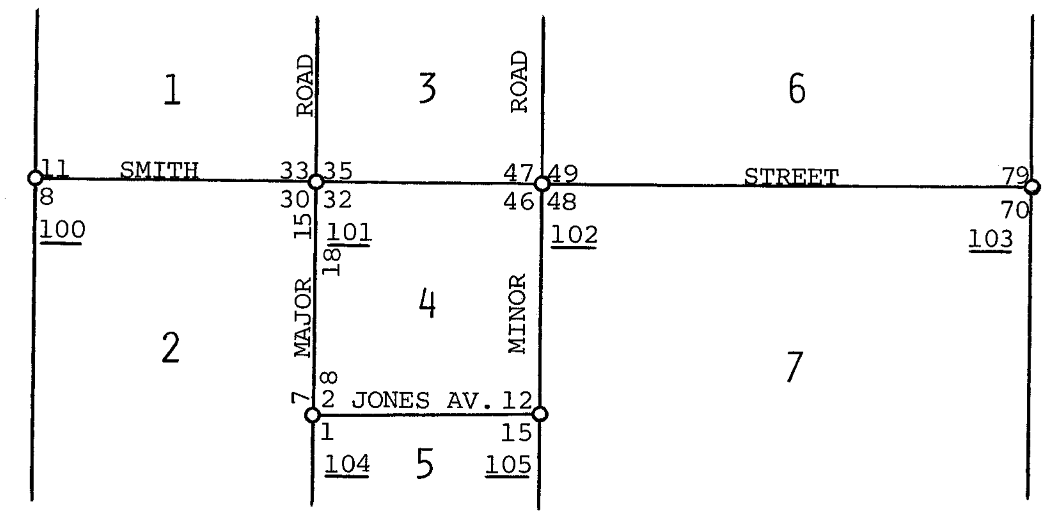
In its general usage, DIME is a method of encoding the segments of a network such as a street system and the areal units bounded by the segments. In its specific application, DIME refers to the street segment files created for urban spatial referencing purposes. The DIME file for a given area is created by considering the urban street network as a series of lines and each intersection as a node. Other features such as rivers and administrative boundaries may also be defined in terms of segments and nodes. A node is defined as a point on the street map where streets or other linear features intersect, end or sharply curve. Each record in a DIME file describes a street segment between two consecutive cross streets (nodes). For each segment of a street, the record contains the"from"node, the"to"node, the street type, the address range either side of the street, the block number and census tract number either side of the street (see figure 6.3).

The main use of the DIME files from the point of view of the Census Bureau was to by-pass the tedious and error-prone manual allocation of each address to its appropriate block or census tract and when compiling summary statistics. The automatic allocation of addresses (address matching) was achieved through the DIME files using a program called ADMATCH.

The term DIME refers to the fact that the basic file is created by coding two independent matrices:

- the nodes at the end of the line segments; and
- the areas defined by the nodes and segments.

By coding each of these sets independently of the other, computer editing procedures can be applied to check for errors and inconsistencies and thereby ensure that the network is completely represented. Network topology is established through the numbers of the nodes and/or the segments while network/area topology is established with the addition of



Origin Node	Destination Node	Street Name	Street Type	Block Left	Number Right	Left Low	Address High	Right Low	Address High
0100	0101	Smith	Street	1	2	11	33	8	30
0101	0102	Smith	Street	3	4	35	47	32	46
0102	0103	Smith	Street	6	7	49	79	48	70
0104	0101	Major	Road	2	4	7	15	8	18
0104	0105	Jones	Avenue	4	5	2	12	1	15

FIGURE 6.3 Example of a DIME (Dual Independent Map Encoding) street segment reference file (after PAINE & DAVIS, 1980).

the codes of the areas bounded by the delimiting nodes and segments. When coordinate references are used, they are generally attached to the nodes.

DIME technology, which grew out of Federal needs for census data, was soon found to have applications for local users as well in the geocoding and integrating of local files and records via street address. Local data could also be efficiently related to census data at various spatial levels and information easily retrieved by the computer. In 1974, DIME files were available for almost 200 Standard Metropolitan Statistical Areas (SMSA's) covering 70% of the population of the United States (SMITH & BOMBERGER, 1974) and in 1979, 280 Systems had been created covering every major metropolitan area in the U.S. in preparation for the 1980 Census (KINZY, 1980). By the mid-1970's the DIME concept has been fully adopted and implemented in France, Spain and Israel and, with some modifications, in West Germany (MCCALDEN & JARVIE, 1976).

The referencing of parcels to street segments has been utilized in many planning information systems for several reasons:

- street address is the principal method of collecting and organizing land use data;
- few land parcels are inaccessible from the road network;
- the road network is used for communication between individual parcels (WALKER & DAVIS, 1978).

The significance of the last reason is discussed in the next section.

6.4 Comparison of Methods

The preceding theory of spatial referencing, together with experience in the implementation and operation of spatial referencing systems overseas, provide the basis for a comparison of the methods to be used in the spatial referencing system of the LIS. Undoubtedly the most significant development in the brief history of geocoding has been the apparent failure of point referencing to satisfy the needs of planners, and its virtual abandonment in favour of street segment or address methods.

The use of the DIME street segment files in the United States as a coarse form of spatial reference for local parcel or address based records in local government in preference to centroid coordinates could be attributed, in part, to the lack of large scale cadastral maps. HANSSEN & GOTTLIEB (1973) claim that the DIME files were used in the Wichita Falls Urban Information System project because "the quality of locally produced maps was not sufficient to assign a precise centroid coordinate to a parcel". The fact that point referencing was considered a more desirable form of spatial reference for parcels in the United States was evidenced by its inclusion in the CULDATA model (see COOK, 1969) and by the recommendations of a national conference on land parcel identifiers (see MOYER & FISHER, 1973). Both were undoubtedly influenced by the Swedish proposals. In contrast to the United States, the existence of large scale cadastral maps in Sweden and Britain meant that point referencing would present itself as a satisfactory compromise in lieu of full boundary referencing which, given the low level of cadastral digitization activity at that time, could only be considered as a long term development (ANDERSSON, 1971).

Despite the theoretical advantages of point referencing for planning purposes, planners in Sweden have made little use of the coordinate register of the Land Data Bank (WALLNER, 1974). In 1973, the Central Board for Real Estate Data (CFD) launched a concerted effort to promote the use of the coordinate register and to investigate the possible uses of the register in planning, particularly in linking the coordinates to the population, taxation and other registers outside the land data bank. Research applications included the automatic grid mapping of demographic data, the production of real estate lists for land consolidation, the calculation of the best position of service facilities such as industry, schools etc., and the integration of road network data. The activities of the CFD in this regard are described in detail by RYSTEDT (1977a, 1977b).

A similar lack of success was being experienced in Britain where the provision of point referencing had been an integral component of gazetteer creation dictating the very organization of files and parcel numbers. Following the successful completion of the National Gazetteer Pilot Study (NGPS) in 1976, the final report of the NGPS (DEPARTMENT OF THE ENVIRONMENT, 1979) recommended the delaying of point referencing in future gazetteer creation. This conclusion was based on the experience that spatial analysis capabilities based on point referencing were expensive and difficult to justify. WILLIS points out that this finding did not mean that point referencing was not a useful tool for planning, but merely questioned the "cost effectiveness of point referencing compared with the pay-offs from less complicated and less expensive applications " (WILLIS, 1978)

MCCALDEN (1974b) has also cited the apparent lack of interest by planners in the point referenced system developed by the National Capital Commission in Ottawa (SYMONDS, 1972, 1974).

Dissatisfied with point referencing, planners in Sweden and Britain began to develop their own street segment orientated systems based on the DIME system. In Sweden, an experimental information system known as NIMS was developed in which each segment record contained the address range and land parcel identifiers associated with one side of each road, street and footpath segment. These networks were coded and digitized from maps at scales of 1:4000 in urban areas and 1:5000 and 1:10000 for rural areas (RONNBERG et al, 1974). Applications of NIMS are described in MASSER & WILLIS (1974), and SALOMONSSON (1977). The use of the property identifier and standardized address enables NIMS to geocode the data contained in the property, person and establishment registers.

A similar system known as TRAMS (Transportation Referencing and Mapping System) was developed for transportation planning in Britain (TRRL, 1977). By incorporating the features of the computer mapping system known as GIMMS (WAUGH, 1974), TRAMS provided a powerful spatial referencing, analysis and mapping system. The linking of TRAMS to LAMIS has already been attempted by one local authority in Britain (THOMPSON, 1977) with a view to combining the spatial analysis potential of the former with the administrative applications of the latter. The possibility of using TRAMS files to assist in the creation of gazetteers is also being seriously considered (BURR, 1977) while the automatic linking of the JIS (formerly NGPS) point referenced gazetteer to TRAMS files has successfully been carried out in Tyne and Wear district in Britain (PERRETT, 1978).

The abandonment of point referencing in favour of less precise address based methods can be explained in terms of the inherent deficiencies of point referencing from the planners viewpoint. These shortcomings can be generally attributed to:

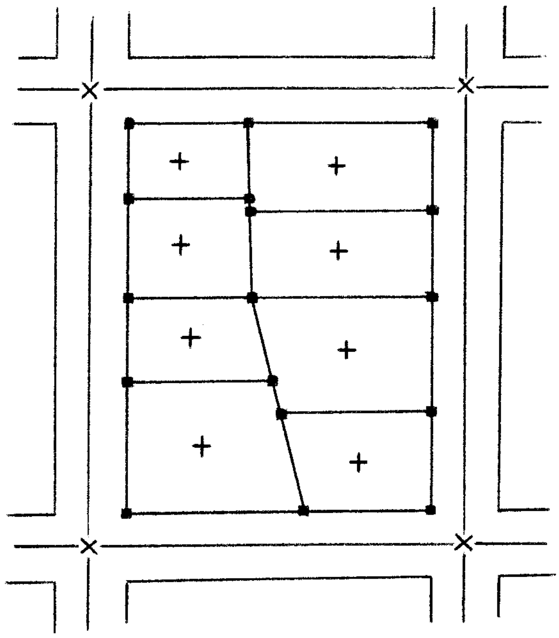
- the higher costs involved in the creation and maintenance and use of point references; and
- the lack of connection to the street network.

Creation and Maintenance Costs

HOLM (1974) states that it is the number and characteristics of the BSU's in a spatial referencing system that are the prime source in cost differences in maintaining and operating the system. The number of coordinates needed to locate the BSU is therefore critical in their establishment and updating. Figure 6.4 shows the number of coordinates needed to locate a block of eight properties using the point, area and address methods, and clearly depicts the superiority of the address method in this regard. This method is also said to be up to 20 times cheaper than point referencing to develop and maintain (WILLIS, 1978), although KINZY (1980) claims that DIME files would be only 10 to 15 times cheaper than full boundary referencing. In any case, creation costs are substantially reduced and a parcel spatial referencing system developed far more rapidly than by the other methods. The method also requires only a moderate level of map coverage. With regard to updating, the stability of the street segment units is also an advantage. Subdivision or consolidation of properties located along a street segment does not require new coordinate values unless new streets are created or old ones closed. Similar mutations may require several new point references to be obtained, although British experience show that only 1 to 3% of parcels generally require new point references annually (DEPARTMENT OF THE ENVIRONMENT, 1973a).

The choice of the street segment is further supported by the fact that the more applications the BSU has, the cheaper the system will be to establish and run. The same street network can also be used to spatially reference administrative units such as census tracts or collector districts (segment side referencing) as well as for the referencing of traffic counts, type of pavement, and traffic accidents (network referencing).

Although point references provide more precise location of parcel data, the street segment or block face is generally small enough to aggregate to almost any area desired in strategic planning applications. As well, the segment is large enough to provide some degree of protection for



■ 17 coordinates registered with boundary method

\+ 8 coordinates registered with point method

x 1 coordinate registered with address or street segment method (each of the 4 coordinates are shared with 3 other blocks).

FIGURE 6.4 Number of coordinates registered with different spatial referencing methods (after HOLM, 1974).

confidential information of an individual (BLACK, 1972) (a feature which lends the method to census statistics applications). If an even distribution of the addresses along each segment side is assumed, it is possible by interpolation techniques to compute a representative point reference for each address. Figure 6.5 shows how this technique has been used in the Danish VEJKOS road network geocoding system for the registration and analysis of traffic accidents (BLACK, 1972a).

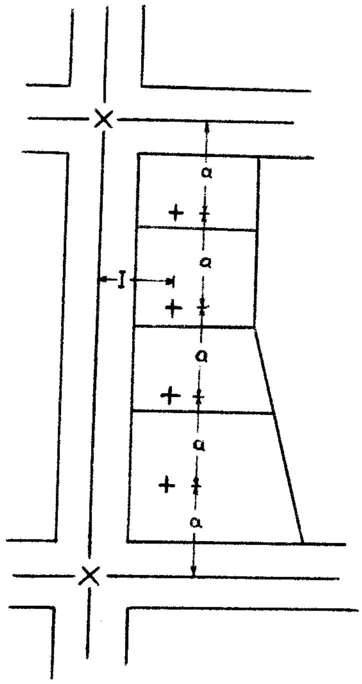
MASSER & WILLIS (1974) also report that a major problem with point referencing has been the costs of retrieving spatial data sets through point-in-polygon algorithms. Retrieval is slow and expensive if whole files have to be searched to assemble the data for parts of a polygon spread over the length of the file. Unlike point referenced files, which are generally ordered on the basis of coordinate values which bear little relationship to the functional areas on which most enquiries are based, street segment files are ordered with some intrinsic topology of the urban area, as expressed in the network. Contiguity relationships incorporated in the file sequence can be exploited for more economical spatial searching (WILLIS, 1972).

Connection with Street Network

The second fundamental deficiency of point referencing relates to the property based nature of the records to which they were derived. SALOMONSSON (1972), no doubt referring to the Swedish experience, stated that:

> "if geocoding is introduced to a system in order to improve its capacity for planning purposes, the basic spatial units chosen must be adapted to and basic to the planning methods rather than suitable for integration purposes and system design. Otherwise, the result will be more or less beautifully integrated systems of only limited assistance to the planner."

The Swedish Land Data Bank was developed primarily for administrative purposes by the national cadastral authority. Within this context, spatial referencing was viewed simply as the inclusion of a point reference as another data item in the parcel record and the integration of parcel or person based records via the land parcel identifier or person number.



I setback distance

a interpolation distance

X coordinates registered

+ coordinates computed

FIGURE 6.5 The VEJKOS address spatial referencing method (after HOLM, 1974).

In contrast, the planner's view of the urban environment is described by MCLOUGHLIN (1969) as an ecological system with human activities occurring at specific locations, and the interaction of these activities through communication channels. In his classification of the components of an urban system, CHAPIN (1965) also distinguished between the activities and the adapted spaces which are the physical expression of these activities. Activities could be classified as either within-place or between-place. Figure 6.6 depicts an example of this classification, where the within-place activity and adapted spaces are residential and houses respectively, and the between-place activity and adapted space are the journey to work and the road respectively.

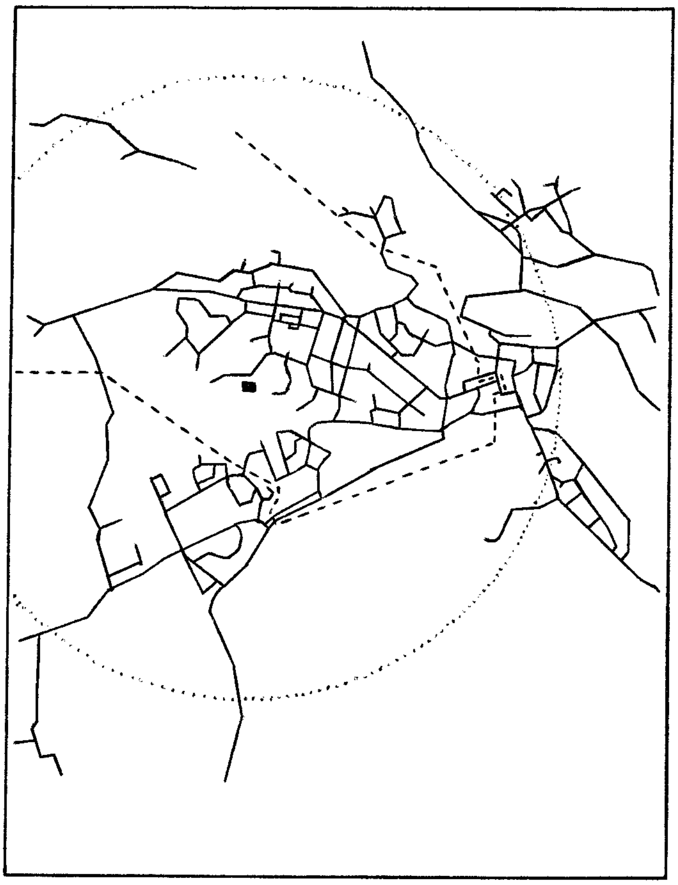
The principal deficiency of the use of point referencing within this model of the urban system is that distances across urban space can only be computed and measured as straight line (geometric) distances, whereas planners require shortest route distances and accessibility measures to be calculated via the street network. The allocation of school children to the nearest school (determination of school catchment areas) is a typical planning example where the use of "geometric space" distance criterion can give misleading results (see figure 6.7). The ability of street segment methods to more effectively model urban systems stems from their conceptual departure from point methods by separating the BDU (the land parcel) from the BSU (the street segment). Since the street segment serves as the same BSU for within-place and between-place data, street segment methods enable data concerning residences to be fed directly into the transportation network at the point at which they have access. This facilitates such specialised planning applications as car pooling, bus routing and journey to work studies. An address spatial referencing system therefore has the potential to integrate property based and street network data as depicted in figure 6.8.

6.5 Spatial Referencing for Land Information Systems

Undoubtedly, the most significant event in overseas experience in spatial referencing, from an Australian viewpoint, has been the apparent

		SUBSYSTEM EXAMPLES	VARIABLES THAT COULD BE USED TO INDEX THE SUBSYSTEMS EXAMPLES
WITHIN-PLACE	ACTIVITIES	RESIDENTIAL	FAMILY COMPOSITION
	ADAPTED SPACES	HOUSES	TYPE AND SIZE
BETWEEN-PLACE	ACTIVITIES (FLOWS)	JOURNEY TO WORK	NUMBER OF PERSONS MAKING JOURNEY
	ADAPTED SPACES (COMMUNICATION CHANNELS)	ROADS	ROAD CAPACITY

FIGURE 6.6 A classification of the components of the urban system (after CHAPIN, 1965 and CATER, 1972).



■ School
---- Distance in street network
.... Geometric (radial) distance

FIGURE 6.7 Difference between geometric (radial) distances and actual distances in the street network (SALOMONSSON, 1972).

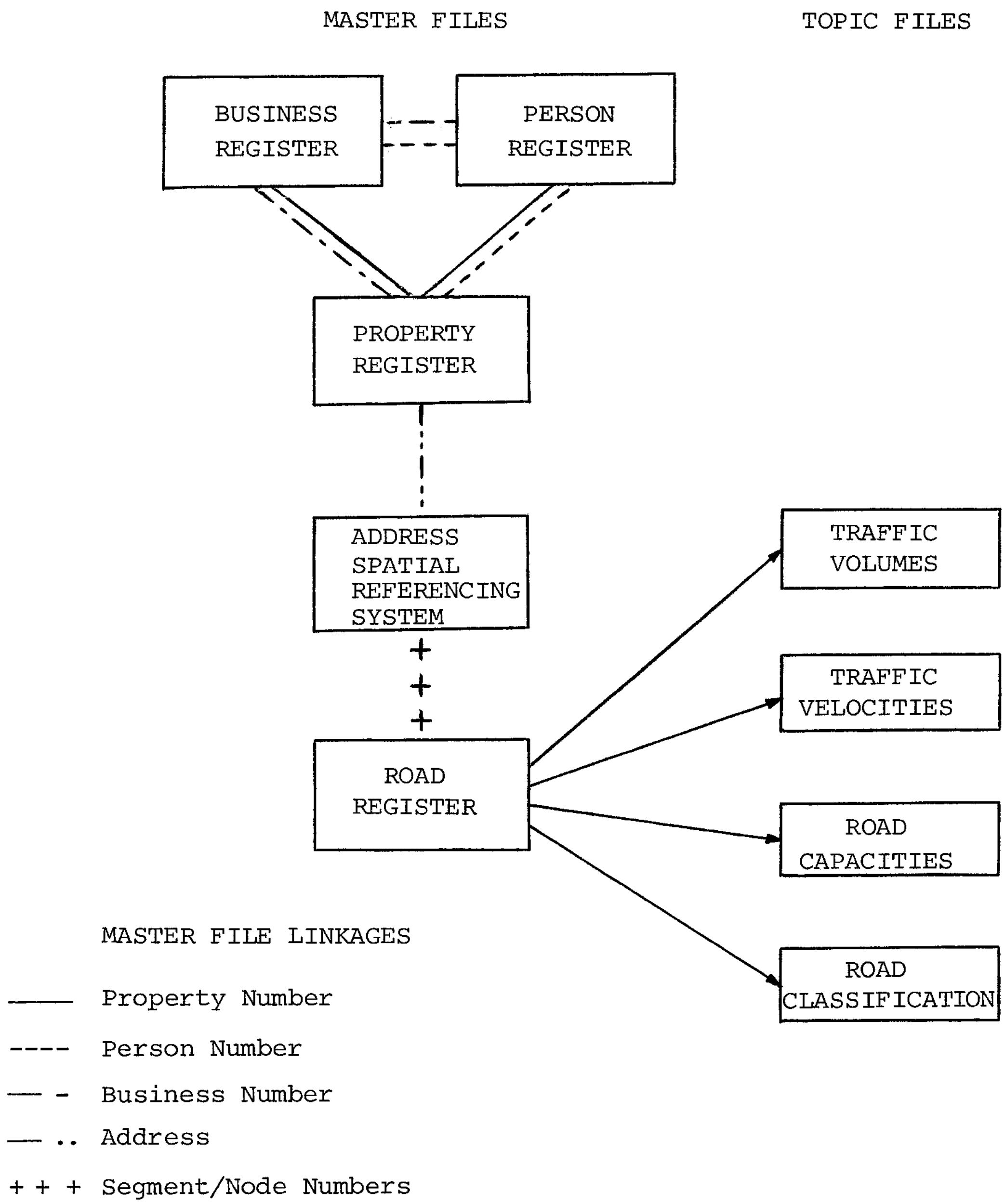


FIGURE 6.8 Generalised concept of using an address spatial referencing system to integrate property based registers with transportation network data.

failure of point referencing to fulfill the needs of administrative and strategic planning. Point referencing failed partly due to its technical limitations described in 6.4 and partly due to the fact that the computer graphics hardware and software available in the 1970's were not sophisticated enough to permit the economic capture, manipulation and display of digital map data.

In Britain, the failure of point referencing to fulfill its early promise saw a distinct movement away from the early conceptual work formulated in the 1972 GISP report (JOINT LOCAL AUTHORITY STUDY TEAM, 1972) in which the need for spatial referencing had dominated most aspects of system development. This change of emphasis was reflected in the final report of the NGPS (DEPARTMENT OF THE ENVIRONMENT, 1979) which recommended that spatial referencing play a less significant role in system design, and be implemented as a later stage in system development. Its specific recommendation was to progressively implement the property based information system in the following order:

1. creation of a street map index linking street name and number,
2. creation of a property index with unique identifier, postal address etc.,
3. addition of a coordinate reference.

SPICER (1977a) summarises this recent change in the British approach to system development as a:

> "significant move away from the original GISP philosophy of creating a spatially-based index system to which individual property records can be attached, towards the creation of a record indexing system to which a spatial indicator can be attached".

Within this new approach, point, boundary and street segment referencing merely represent alternative levels of detail or fineness in a data field, rather than fundamentally different design philosophies.

This new philosophy allowed spatial referencing to be implemented in an incremental or staged manner, beginning with street segment referencing, then at a later stage the addition of centroids and/or boundary referencing. This staged approach has already been implemented in several local authorities in Britain as described in 6.4. A similar approach has also been proposed in the United States by KINZY (1980) who sees the existing DIME files as constituting the first stage; and in

Australia by WELLS (1976) in which the street segment files being created for road data banks and utility information systems, would be adopted as the first stage of development.

A major determinant of the staged approach to spatial referencing has been the high costs of providing boundary references in early stages of system development. For example, WILLIS (1978) has observed that the high establishment costs of the LAMIS system in Britain have been dominated by the provision of boundary references (WILLIS, 1978). In Australia the staged approach has been seen by many of the smaller Local governments as the only economically viable means of developing a spatial referencing capacity. This is despite the fact that boundary referencing is recognised as the most desirable form of referencing for their immediate needs, particularly for their administrative planning functions (EVANS, 1976). BRADY (1979) lists the advantages of boundary referencing for planning applications in Local government as:

1. *Audit and control:* monitoring urban land stock by summing individual land parcels and comparing them to the known finite total area.
2. *Aggregation and spatial search:* including the use of boundary-on-boundary searches to facilitate some of the more complicated administrative functions, e.g. when planning applications overlap more than one property.
3. *Presentation:* including the thematic display of land parcel attributes, e.g. land use.
4. *Integration of zone and network data structures:* theoretically, within-place and between-place data can be linked by spatial search techniques without the need to maintain a logical connection between the two data sets, e.g. loading of traffic flow data into the transportation network by spatial searching of property based data around street segment nodes.

The prospect of boundary references being made available through the Digital Cadastral Data Base (DCDB) in the near future (see 4.5.5) would seem to suggest that spatial referencing at the local level can now bypass the more primitive forms of referencing (street segments and centroids). However, the unique properties of street segments and

(Blank)

centroids demand that the DCDB also provide these basic spatial units for specific spatial referencing applications. Boundary referencing does not make them redundant. For example, centroids would constitute the most appropriate form of referencing in those less demanding spatial retrieval and analysis applications where the shape of the parcels is not required and where street segments may not be sufficiently accurate. Similarly, it is doubtful whether boundary referencing can model the urban system as efficiently as street segment referencing, due solely to the simplicity of the address range structure, which is a convenient and compact means of linking parcels to the transportation network. The lower operational and computational costs of this method, together with the requirements of road and utility authorities for a digitized version of the street network for their own network referencing purposes, makes this form of referencing an indispensible component of an efficient Spatial Referencing System.

6.6 Conclusions and Recommendations

The following conclusions and recommendations apply to spatial referencing in urban areas:

1. The Spatial Referencing System should be viewed as an indispensible adjunct to the LIS, designed to assist in the processing of property based data for administrative and strategic planning functions.

2. The provision of spatial references has proven to be an expensive process which yields few tangible benefits in the short term. Despite the recent availability of sophisticated computer graphics hardware, the costs of spatial referencing remain prohibitive for most local governments. This is due to the lack of adequate software for many of the specialised spatial retrieval and analysis routines, and because of a lack of expertise in this field. For these reasons (in addition to the advantages of adapting the DCDB for spatial referencing purposes described in 4.5.5) local government should defer the provision of spatial references for their property-based information systems until the DCDB is created (as a by-product of cartographic digitization at the State level). Such an approach should ensure the cost effectiveness of spatial referencing in the long term.

3. If local government must develop their own system then point referencing alone should not be developed as an interim measure in lieu of boundary referencing. This is because, in most urban applications, street segment referencing would offer a more satisfactory solution on at least 4 counts:

- *costs* of providing and maintaining point references are 10 to 20 times that of street segments.
- *manipulation* of point references is generally more *complex* than street segments because of their spatial arrangement and the greater number of units.
- *analysis* using point references is more *limited* than street segments because of their inability to adequately model the urban system.
- *resolution* provided by point references is *too coarse* for most administrative planning applications but is little better than that provided by street segments which are adequate for most strategic planning applications.

4. The provision of boundary references does not make the inclusion of centroids and street segment referencing redundant in the Spatial Referencing System. These BSU's are necessary alternative forms of referencing which the DCDB should provide. Fortunately, the inclusion of these units can also be justified for such cartographic applications as derived mapping and map annotation (see 7.6).

7. THE DIGITAL CADASTRAL DATA BASE.

7.1 Introduction

The Digital Cadastral Data Base (DCDB) was defined in 4.5.5 as a central source of continually up-to-date, compatible and readily accessible digital cadastral map data. The DCDB is primarily a cartographic tool, implemented to overcome problems of duplication in the existing cadastral mapping system. The adaption of the DCDB as the geographic base file for the Spatial Referencing System, and the advantages of this approach to spatial referencing were also outlined in 4.5.5. From a spatial referencing perspective, the DCDB can be viewed as a series of interlinked files relating each basic spatial unit (BSU) to the coordinates defining it, and to other BSU's. In essence, the use of the DCDB for spatial referencing purposes is a logical extension of the traditional function of the cadastral mapping system, in supplying the spatial cadastral framework in the form required by its users.

In practice, however, the ability to derive spatial references as a by-product of existing digital cadastral mapping programmes may be severely limited by the unstructured nature of the data generated by the digitizing procedures currently employed in the creation of cartographic data banks. NAGY & WAGLE (1979) contrast the *data bank* and *data base* approaches to the capture and storage of digital map data. The former is "separation" oriented in which data is segregated on the basis of the type of entity or on a spatial basis or both. The latter is "integration" oriented in which inter-entity relations(data linkages) are added to the data. The augmented relational data increases the usefulness and versatility of the data. Instead of every item being an "island" within the data bank structure, the data base explicitly records the relationships between each entity. These data linkages enable any data item to be directly related to others, thereby cutting across any "natural" ordering existing in the data storage arising from the data capture (digitization) process.

While the data bank structure may be capable of meeting the requirements of the cartographic agency for map production and maintenance, it may not be sufficiently flexible to serve the needs of spatial referencing.

> "In order to interrogate and manipulate data at interactive speeds, to provide for selective extraction and display of data and to facilitate correlation of related data sets, the data must be stored in a structured form. The ease and speed with which such operations can be carried out is totally dependent on that structure" (BRIDGE, 1980).

The development of the DCDB can therefore be viewed as a rationalisation of existing cartographic data structures, in a similar manner to the application of data base technology to the existing land records systems.

The digitizing procedures which result in a lack of structure in the cartographic data bank, and the problems arising from the inflexibility of this data can be illustrated by the experience of the Ordnance Survey Digital Mapping System. The digitization of the contents of the Ordnance Survey large scale topographic maps (including defacto property boundaries and street centre lines) was primarily aimed at achieving long term benefits in the areas of derived mapping, map revision and reduced storage requirements (GARDNER-HILL, 1971; IRWIN, 1971). The digitizing procedure was line-oriented which reflected the immediate requirements of the digital mapping programme that the lines be stored in a digital form permitting them to be accurately portrayed when plotted from the data bank. The digitizing procedure did not recognize the significance of the areal entities which are defined by these lines, as relatively few cartographic applications necessitate the storage of parcels and other areas as closed polygons (RHIND & TREWMAN, 1975). As a result, a straight line (which may include segments of several land parcel boundaries) was digitized by joining the two end points rather than joining all the points (or line intersections) along the line that would otherwise be required to define each segment, and which may result in small deviations from the straight line. As WILLIAMS (1974) explains, the method of digitizing employed by the Ordnance Survey required only a minimum of effort at input stage, and was eminently suitable for cartographic purposes since each line can be separately identified and revised where necessary. To the average user, the cartographic product was undistinguishable from the conventional map. The resulting data bank consisted of a series of records containing the coordinates defining the alignment of a feature, and a code for describing the feature.

These records were arranged in the order in which the features were digitized. For plotting and other outputs of the data, the relationship between items in the data bank followed the order of digitizing and it was therefore necessary for the whole file to be accessed sequentially (THOMPSON, 1979a). Consequently, the data structure of the cartographic data bank had no significance beyond being able to plot the data in the order that it was digitized.

With the emergence in Britain of; the point referenced Gazetteers, the LAMIS system and its requirement for boundary referencing, and the development of TRAMS and other street segment oriented systems, the Ordnance Survey accepted the responsibility for providing these spatial references from its own digital data (see 4.5.5). However, these systems required digital map data in a form usable in its own right without necessarily producing a graphical output at all. Although the Ordnance Survey digital data provided for this requirement, in the sense that the information required exists either explicitly or implicitly, it was not readily available in the form required by the user. The problem caused by the cartographically oriented data structure was the inability to extract the individual points, line segments and areas required for boundary polygons and street segment networks.

It was readily recognized that this problem stemmed from the fact that data acquisition was done in a form that mirrored the final output, rather than attempting to model the data objects depicted on the map. Consequently, a programme was undertaken to restructure the data for spatial referencing purposes (ORDNANCE SURVEY, 1975, 1977a). Some of the procedures employed in this programme are reviewed later in this chapter.

This chapter addresses the two main issues in the rationalisation of data structures for the successful implementation of the DCDB and Spatial Referencing System:

1. The formulation of a *flexible* and *efficient* DCDB file design in which BSU's are explicitly encoded as discrete entities, providing direct linkages between BSU's and the coordinates defining their shape and location and which is amenable to rapid updating, retrieval, linkage, analysis and display of data base contents. Design principles for the development of a DCDB which is to

satisfy cartographic and spatial referencing requirements, are developed in 7.2. A file design for the main DCDB files is presented in 7.3 and 7.4. The design is preliminary only, and is presented as a framework for future DCDB development. Its performance in satisfying specific cartographic and spatial referencing applications has not been tested, but the design incorporates many of the features of successful overseas spatial referencing systems two of which are depicted in Appendix B.

2. The formulation of an efficient digitization procedure for the creation of the basic DCDB files, which is capable of providing an explicit description of the BSU's required for spatial referencing. A necessary feature of the procedure is that it capture the necessary data linkages without complicating or significantly disrupting existing digitization procedures, so as to lend itself to adoption by the cartographic agencies currently involved in cadastral digitization. The procedure described in 7.5 draws on the experience of several digital mapping programmes which have attempted to construct cartographic data bases, and has been partially tested in an experimental model described in Appendix C.

7.2 DCDB File Design

File design for the Digital Cadastral Data Base (DCDB) is taken to mean the process of determining the *structure* of these basic file series and their *interaction* within the DCDB configuration. DCDB File design can be achieved in two stages:

- the identification and classification of BSU's contained in the DCDB, leading to the definition of its basic file series
- the integration of the different data structures within this file series.

7.2.1 A Classification of Basic Spatial Units

The *first* stage in the formulation of a flexible DCDB file design is the identification of the BSU's that the DCDB should provide. Chapter 6 argued that irrespective of whether the DCDB is created in stages or by the digitization of the complete cadastral pattern, an efficient DCDB should contain at least the following three types of BSU's:

- land parcel polygon (with identifier)
- land parcel centroid (with identifier)
- street segment (with address ranges).

In addition to these fundamental units, the DCDB must also supply other BSU's which can generally be formed by the aggregation of these former units.

For the purposes of DCDB file design and creation, basic spatial units can be classified into two groups:

- *primary units:* those units which are the smallest manageable units into which all urban space can be subdivided
- *secondary units:* those units which are formed by the aggregation of these primary units.

Primary spatial units can be further divided into:

- those comprising *occupied space* (land parcels)
- those comprising *transportation space* (street parcels).

Land parcels and *street parcels* can be treated as areal units and encoded as polygons by boundary referencing. These areal units are complementary and together comprise all urban space. The differentiation of occupied and transportation space is also compatible with the model of the urban system described in 6.4. Each of these primary units can also be represented by a lower resolution BSU:

- *land parcel centroids* and
- *street segments,* respectively.

Secondary spatial units can be differentiated into:

- those units whose structure is *implicit* in the cadastral pattern *(blocks and block faces)*

- those pre-defined or *special areas* which are created by an agency for a *specific* data recording or analysis purpose, and which are subject to variation for reasons connected with their use e.g. census collector districts, transportation zones, administrative districts, suburbs and municipalities.

A block can be defined as the unit formed by a group of parcels surrounded by transportation space or other extended linear features, and is an aggregation of undivided parcels. An alternative definition is the space enclosed by a polygon formed by connected street segments. The block is comprised of adjoining *block faces* which are units formed by adjoining parcels fronting onto a particular side of the street or section. Block and block face centroids may also be included in the DCDB files as lower resolution BSU's.

Figure 7.1 depicts this classification of BSU's for file design and file creation purposes. The various BSU's depicted in this figure have been drawn from several overseas systems and are referred to in subsequent sections of this chapter. The significance of this classification from the viewpoint of file design and creation is that, as secondary units are formed from the aggregation of primary units, coordinate references need only be acquired for these latter units, and linkages provided to create the former. For example, the DCDB should be able to aggregate the *parcel* to the *block face,* the *block face* to the *block,* and the *block* to the *special area*.

This aggregation of primary units in geographic base files can be achieved explicitly by the use of hierarchical numbering systems or other similar indexing systems which can be used as identifiers for these different units (see ZIEMANN, 1977b). However, a more convenient, compact and flexible linkage system can be devised. Figure 7.1 shows the ability of a street segment with address ranges encoded for each side, to aggregate parcels to block faces and blocks; and to aggregate parcels or block faces to the special areas encoded on each segment side (see also figure 6.3).

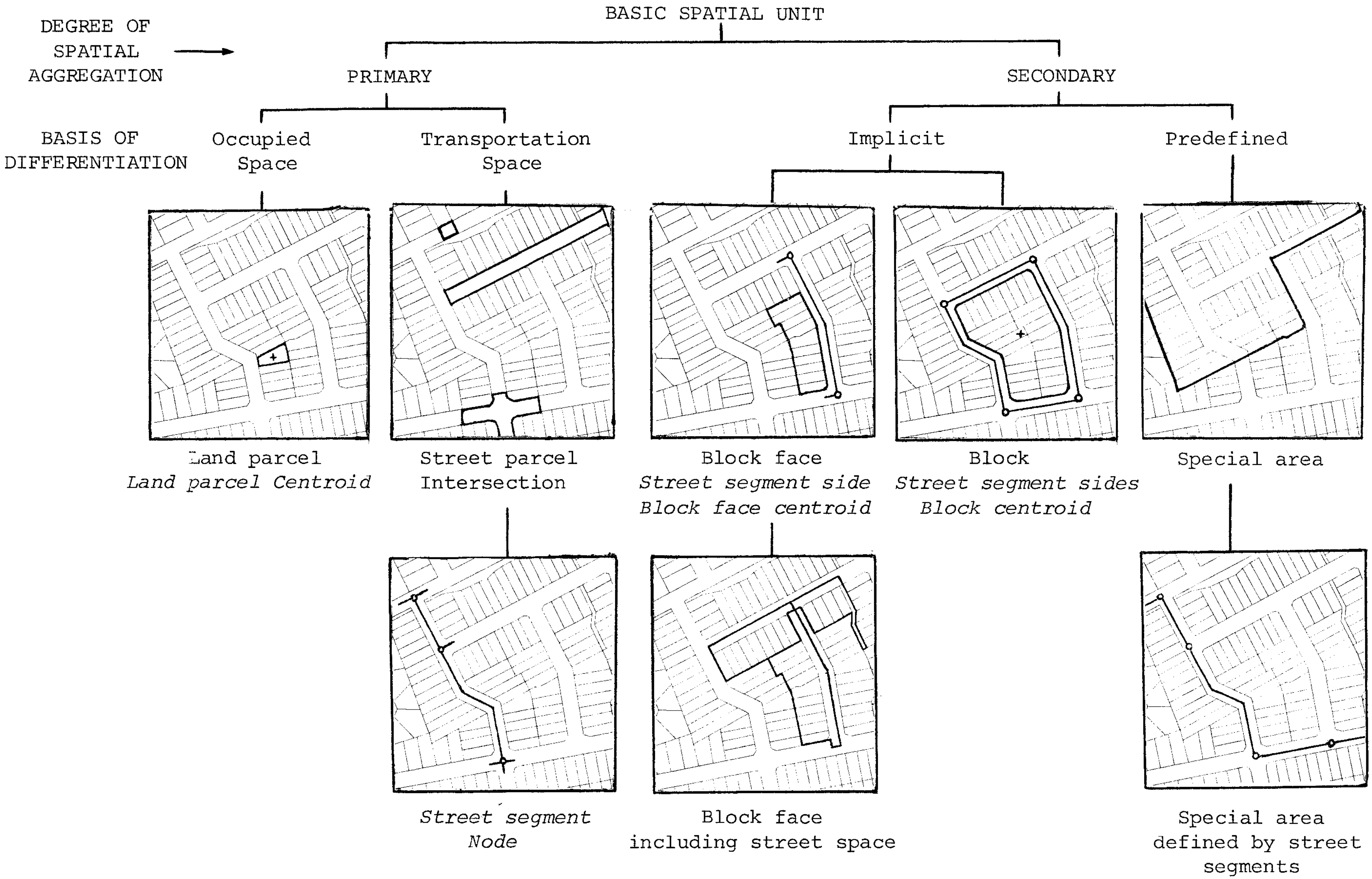


FIGURE 7.1 Classification of basic spatial units for DCDB file design and file creation. *Lower resolution units shown in italics.*

Based on this principle, and on a study of the file design of the TRAMS and NIMS spatial referencing systems (see Appendix B), it is proposed that the linking of spatial units within the DCDB can be achieved through the creation of three basic file series:

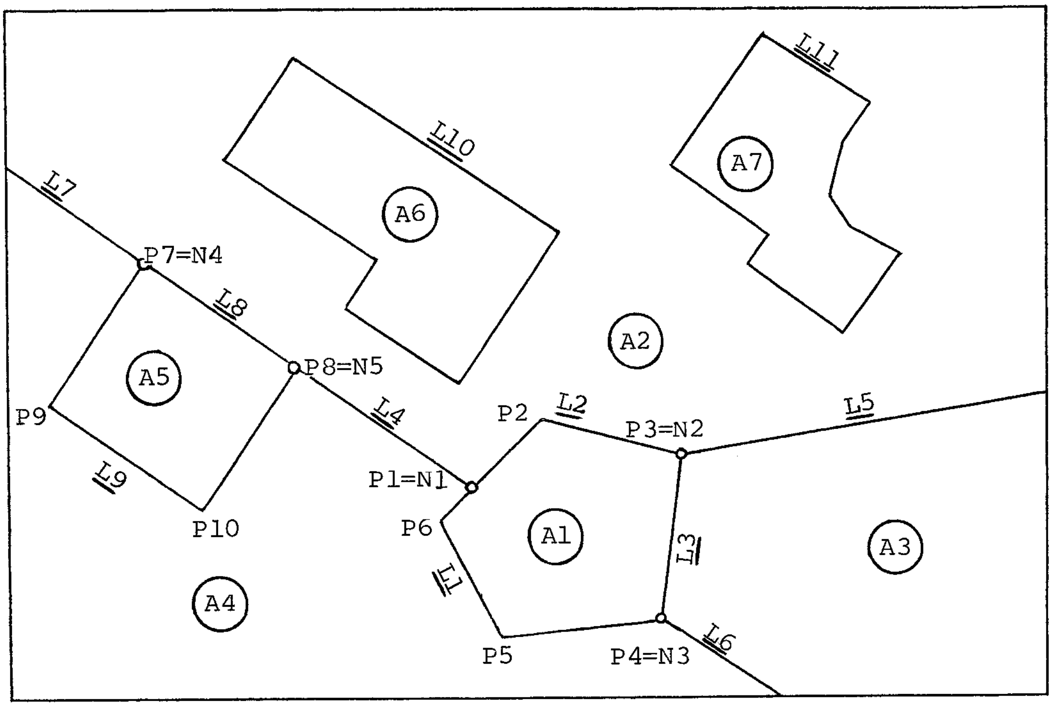
1. Parcel Polygon and Centroid Files
2. Street Segment Files
3. Special Area Files

The Street Segment Files enable the DCDB to aggregate parcels to block faces, blocks and special areas by providing a direct linkage through the coding of the segment side. However, as figure 7.1 shows, not all special areas can be completely defined by street segments. The Special Area Files enable the DCDB to aggregate parcels to these areas as required through spatial search techniques, and enable changes in special area boundaries to be accommodated without disrupting the contents of the Parcel Polygon and Street Segment Files.

7.2.2 Integration of Data Structures

The *second* stage in the formulation of the DCDB file design is to formalise the mutual interrelationship between the point, segment and areal units in the DCDB files and to attempt to integrate these different data structures into a systematic design. BAXTER (1976) has stated that any attempt at integration, in a sense, is a fruitless task as any general design specification is likely to be suboptimal for a specific application. He concludes, however, that *compatibility* between different data systems is essential if disparate files of spatially referenced data are to be integrated in the future, and this suggests that it is worth attempting a simple schema for such an integration of files.

For the purpose of encoding spatial data, the interrelationship between points, lines and areas can be expressed in at least three basic forms - as *node, segment and area* oriented structures as depicted in figure 7.2. This classification will serve as a preliminary basis for the integration schema. BAXTER has also described several less obvious data structures for encoding polygons such as *unit length vectors, chain encoding* and *maximum neighbourhoods*. These alternative data structures are not considered in the DCDB file design, being more



Node-oriented data:

N1: P1 :(points)
: L1,L2,L4 :(segments)
: A1,A2,A4 :(areas)

Segment-oriented data:

L1: P1,P6,P5,P4 :(points)
: N1,N3 :(nodes)
: A1,A4 :(areas)

Area-oriented data:

A1: P1,P2,P3,P4,P5,P6 :(points)
: L1,L2,L3 :(segments)
: N1,N2,N3 :(nodes)

FIGURE 7.2 Basic data structures for the encoding of spatial data (after DUEKER, 1972; BAXTER, 1976; ZIEMANN, 1977b).

appropriate to the encoding of more complicated areal shapes (such as land use units) where they are used to optimize storage requirements and to simplify data structure for mapping.

Definition of Spatial Entities and Their Relationships

A preliminary step in the integration of these data structures is the *definition* of spatial entities and their relationships. The following definitions have adopted several well established conventions and terminology for the encoding of spatial data.

An established convention is to distinguish between those points (boundary corners or vertices) which describe the boundary *topology* (connectivity, direction and adjacency) and those points which are purely *descriptive* of the shape of the line between these former points. The former can be termed *nodes* and the latter *chain points*. A node or *junction point* (MACLEOD et al, 1973) can be more precisely defined as the junction of three or more area boundaries or, in the case of networks, as the intersection of three or more lines or as a terminal point of a network. A pair of consecutive nodes is referred to as a *segment* although British terminology favours the term *link* (BAXTER, 1976; COX & RHIND, 1977; THOMPSON, 1979b). Provision for the recording of chain points has been made in several overseas systems where they have been variously referred to as *strings* (COX & RHIND, 1977), *intermediary points* (SABATIER, 1977), *auxiliary points* (RÖNNBERG et al, 1974; SALMONSSON, 1977) and *contour points* (COOKE, 1977). The distinction between, and separation of nodes and chain points in the data structure permits the efficient processing of topological relationships which, by definition, does not require the descriptive (topographical) data supplied by the chain points.

Partitioning into Areal Domains

Since any file of spatially referenced data is likely to be large in extent, the next step in the integration of node, segment and area oriented data structures is to partition the spatial data into *areal domains*. Areal domains are chosen in anticipation of the need to retrieve data from the LIS subject to spatial criteria as opposed to, say, attribute criteria.

HUMPHRIES et al (1971) concluded that the optimum size of module or areal domain for the storage of survey plan data was one minute of latitude by one minute of longitude, necessitating the conversion of the search key to geographical coordinates. This areal domain not only provided a convenient search size of approximately one square mile but enabled the areal domain to be defined by a logical breakdown of the geographical grid, without the problems of multiple sets of map grid coordinates for those points lying in the overlap between adjacent projection zones. However, for digital data banks derived from large scale maps, areal domains formed by map grid lines appear to be more flexible. For example, the Ordnance Survey digital (topographic) data files are organised on a grid square basis in the National Grid with "basic grid units" of 40mm at map scales of 1:1250 (50m x 50m) and 1:2500 (100m x 100m) (ATKEY & GIBSON, 1975). For most urban areas, grid squares of 1km x 1km would appear to be a convenient size for the DCDB storage modules.

The spatial partitioning of DCDB records has the characteristic that if a large grid square size is chosen, spatial retrieval of point, segment and areal spatial units necessitates the processing of an excessive number of items. Response time to any inquiry therefore becomes a function of the size of the areal domain. Conversely, small grid square sizes leads to a very large number of grid square records that the DCDB has to maintain.

Experience with the LAMIS System suggests that this problem can be overcome to some degree by the method of grid square file organisation. By locating neighbouring grid squares on the ground, close to one another on the file, access times can be greatly minimized (HARRISON, 1976). *Spatial retrieval* can be further facilitated by the method of arrangement of records within the chosen grid square files. BRADY (1978) describes the sorting of point referenced records on an "implied grid" in which the sort key is generated from a point coordinate using an algorithm. When the file is sequentially sorted according to this sort key, the file has a grid structure (implied by the order) which permits the efficient sequential reading of point records. For example, the sorting of records into 100m grid cells within a 1km grid square in the DCDB areal domain be achieved by the stripping of 2 significant digits from each coordinate value. The sort key comprises the leading easting and northing coordinate values followed by a code formed by the alternating of the stripped digits. A similar subgrid technique has been reported by MITTELSTRAß (1979) in the derivation of a primary index for point records from their coordinate values.

The sequential ordering of DCDB records does however, create problems for the updating of these files. A requirement of the DCDB is that the updating of its files from the input of survey plan dimensions be performed efficiently without seriously disrupting the existing file contents. This requirement is more critical for Parcel Polygon Files than for Special Area Files which change less frequently. The addition of new entities to any ordered file involves the location of the new record, the insertion of the record and the shifting down of all records remaining in the file, with the resultant possibilities of errors in data transmission. The conflicting requirements of ease of updating and efficient searching of DCDB files can be overcome by the use of an indexed records system in which records can be stored in implied grid order and the desired records retrieved by a system of look-up tables and linked pointers (see ELFICK, 1979). However, a balance must be struck between the conflicting requirements of retrieval and maintenance of the DCDB. As RHIND (1977) states, with increasing complexity of retrieval demands, it is not difficult to get to the stage where the indexes rival the main data set in size and complexity. Indexes should therefore only be provided for those DCDB files which are most frequently accessed.

A Schema for the Integration of Data Structures

Adopting the notation of BAXTER (1976), the following schema for the integration of data structures is proposed for a DCDB file design in which the anticipated uses require cross referencing by location and in which:

x, y	are the grid coordinates of the spatial reference
a	is the value of an attribute
⟨ ⟩	encloses a data item
[ ]	denotes defined repetition
( )	denotes undefined repetition
ξ	is the partitioning of the file based on areal domains
Δ	is a terminator for trapping during processing, necessary for items of undefined repetition.

1. Point referenced spatial units are structured in the following manner:

$$(\{ (\langle x,y \rangle \ [\langle a \rangle] \ ) \langle \Delta \rangle)$$

in which the attribute list relates to the parcel, block or similar unit.

2. Network data is best described in terms of node, segment (link) and chain files:

The Node File has the following structure:

$$(\{ ([\langle a \rangle] \ \langle x,y \rangle \ ) \langle \Delta \rangle)$$

in which the attribute list includes the node number and other data about the node including the numbers of connected nodes.

The Segment (link) File structure is:

$$(\{ ([\langle a \rangle]) \langle \Delta \rangle)$$

in which the first attribute is the segment number, the second and third are the node numbers cross-referencing with the node file and the remainder are other attributes relating to the segment.

The Chain File has the following structure:

$$(\{ (\langle a \rangle \ (x,y) \ \langle \Delta \rangle \ ) \langle \Delta \rangle)$$

in which the attribute is the segment number or node pair for cross-referencing with the segment file.

3. Areal units are structured in at least three forms:

The Boundary Segment File:

$$(\{ ([\langle a \rangle \ \ \langle a \rangle] \ (x,y) \ \langle \Delta \rangle \ ) \ \langle \Delta \rangle \ )$$

in which the two attributes lists relate to zones on either side of the boundary section.

The Polygon Chain File (boundary referencing):

$$(\{ (\ [\langle a \rangle] \ (x,y) \ \langle \Delta \rangle \ ) \ \langle \Delta \rangle \ )$$

in which the attribute list relates to the enclosed polygon.

The Polygon Node File

$$(\xi \quad ([\langle a \rangle] \quad (a) \quad \langle \Delta \rangle) \quad \langle \Delta \rangle)$$

in which the coordinate chain is replaced by a string of node numbers, listed in clockwise order and cross referenced to the node file.

In order to ensure compatability between the DCDB files and between the DCDB and external files, these conventions should be adopted for the data structures employed in each of the three basic DCDB file series.

<u>Degree of Data Ambiguity and Redundancy</u>

The *final* stage in the integration of data structures into an efficient DCDB file design is to determine the degree of ambiguity and redundancy required for the encoding of the DCDB files.

> "The relationship between the files of data is the critical issue in the integration exercise. Individual files must be coded in a precise and unambiguous manner. The method of structuring the file will depend on its content but as few different structures as feasible should be the aim even if this implies certain redundancies" (BAXTER, 1976).

Ambiguities caused by non-unique identification were cited by DUEKER (1972) as one of the main criteria for choosing an appropriate data structure from the several possibilities previously outlined. The example of the encoding of areas as being contiguous to other areas is a case where ambiguities can arise. For example, areas A6 and A7 in figure 7.2 are wholly contained within the same larger area A2 and both would be identified by this same code. The identification of segments by their contiguous areas gives rise to similar ambiguities as for segments L4 and L7 in figure 7.2. MACLEOD et al (1973) describe how this frequent occurence was overcome in the encoding of census collector district boundaries by the incorporation of a special data field in each segment record, distinguishing each n of m segments with the same area codes. The identification of segments by the nodes at either end also creates ambiguity problems when more than one segment exists between two nodes, as is the case for segments L8 and L9 in figure 7.2. This problem can be overcome by the use of *pseudo nodes* which are nodes with only two connected nodes. For example, chainpoint P9 can be made a pseudo node in figure 7.2.

Pseudo nodes are frequently employed in network structures to break up long segments into more manageable and meaningful units (SABATIER, 1977), or to facilitate path and route operations (COX & RHIND, 1977). Their use in ensuring uniqueness of the node pair (where multiple paths exist between two consecutive nodes) has been reported by WALKER & DAVIS (1978), where dummy nodes are inserted on the extra paths in a street network. Alternatively, these problems can be overcome by the identification of each segment by a unique code. However, the identification of segments by segment codes in addition to node numbers introduces some degree of redundancy in the file design which may or may not be necessary depending on a number of factors as discussed below.

DUEKER (1972) stresses the desirability of some degree of *redundancy* in encoding spatial data to provide the means for editing to detect errors for quality control and completeness. Redundancy is achieved by the encoding of spatial entities by two independent methods. The redundant encoding of street segments by boundary (bounding node identifiers) and co-boundary (bounded area identifiers) assisted greatly in the editing of the manually encoded DIME files (see 6.4). Provision of redundant data in designing a file structure is also imperative so that the reliability of the data can be assessed and checks made on data reliability over time (DALE & HOLLWEY, 1978). The degree of data redundancy in the file structure will also be determined by the primary function of the particular file series and the analyses which are to be performed on them. For example, the redundant coding in the DIME files make them well suited to neighbourhood retrieval operations. Based on their study of the functional requirements of network information systems, COX & RHIND (1977) recommended the maintenance of separate files for nodes and segments for network referencing, because of the importance of topological applications in these systems. Similarly, in order to facilitate the processing of parcel boundary data, the Ordnance Survey restructured data base consists of

- *node files* with pointers to the segments that meet at this node
- *segment (link) files* that contain the coordinate data and feature codes of the segment between two nodes, and pointers to these nodes (THOMPSON, 1979b).

On the other hand, a high degree of redundancy may complicate updating procedures and increase the storage space required for the DCDB files.

Based on the preceding considerations, file structures and file interaction for the basic DCDB files are presented in 7.3 and 7.4. The characteristics of the file design are:

- the basic file series is partitioned on a map sheet basis, in most cases being the areal domain formed by the map grid lines of the 1:1000 map sheet series
- polygon, node and segment files within each series are indexed according to their centroid, node and node (origin) numbers respectively
- spatial manipulation of these files is facilitated by indexes in which the numbers (pointers to the corresponding records) are listed in "implied grid" order
- the node files are structured so that their coordinates are stored only once
- segments are not separately numbered but are identified by their node pair numbers. Pseudo nodes used to overcome the ensuing problems of ambiguity
- nodes and chain points are stored in separate files.

Finally, the structures proposed in the following sections (and depicted in figures 7.4 and 7.5) represent file content rather than actual storage structure in the computer. To a certain degree, the data structure dictates the form of storage structure, although some flexibility exists in this process (BAXTER, 1972). Storage structure will reflect operational constraints, notably storage space and CPU time (COX & RHIND, 1977) and is designed in anticipation of the patterns of access and updating (BAXTER, 1972).

7.3 Parcel Polygon and Centroid Files

There exist at least 3 file structures that can be used to encode land parcel boundaries and to link the parcel identifier to the polygon formed by the boundaries:

1. a *boundary segment file structure* with left and right parcel identifiers encoded to each segment
2. a *boundary segment file structure* in which parcel identifiers are linked to the parcel polygon by spatial data processing

3. a *polygon file structure* in which the parcel identifier is linked directly to the polygon strings, or to polygon nodes with an auxiliary chain file.

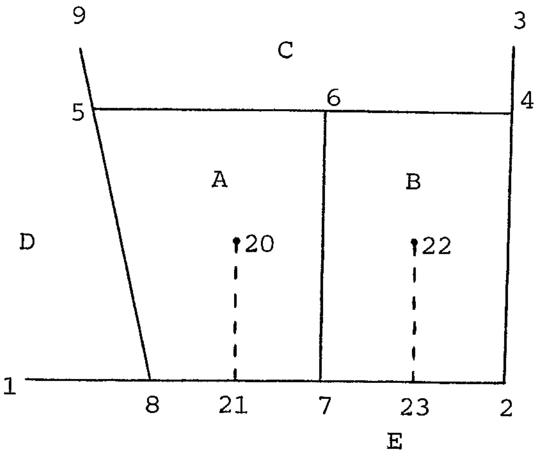
The definition of these structures are found in the schema presented in 7.2.

(1) The application of the DIME boundary/co-boundary method to the encoding of land parcel boundaries has been described by WHITE (1977) who argues that the parcel structure is similar to the geometry of the blocks for which the DIME file structure was originally devised, the major difference being one of resolution only. The file structures adopted are compatible with the ARITHMICON programme which can be used to process, retrieve and analyse the boundary data. The file design centres around the *segment file* which lists the node numbers (from and to) and parcel identifiers (left and right) for each boundary segment number (see figure 7.3). The content of the segment records is significantly reduced by the use of *node coordinate directories* and *parcel directories* with pointers to the segment file. Parcel boundary topology and the linking of the parcel identifier to the parcel polygon are implicitly established by the inspection of the boundary/co-boundary relationships. The advantages of this approach are:

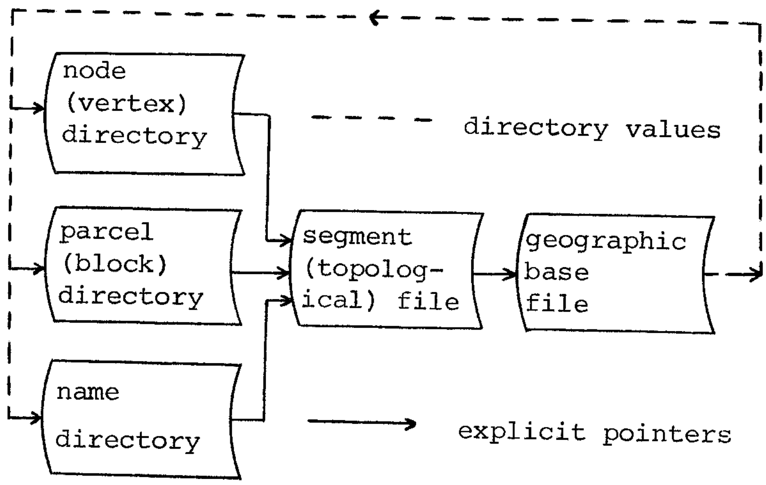
- automatic detection of errors which are not revealed by visual inspection of a plot of the segment network, usually in the form of small missing segments or overlapping segments
- automatic editing that guarantees completeness and consistency of data through topologically based verification.

The disadvantages of this data structure for encoding land parcel boundaries are manifold and are discussed in 7.5 in relation to the segment-oriented method of digitizing. This choice of file structure has been dictated almost entirely by the existence of appropriate software and on the premise of similarity of geometry with the DIME block/street segment structure.

(2) A boundary segment file structure in which parcel identifiers are linked to the parcel polygon by spatial data processing has been proposed by MITTELSTRAß (1979) and KELLY (1980). In both cases, this



6-7	B	A
5-6	C	A
7-8	E	A
8-5	D	A
6-4	C	B
4-2	E	B
2-7	E	B



1. Boundary segment file structure (left/right coding)

1-2
2-3
4-5
6-7
8-9

A	20-21
B	22-23

A	5,6,7,8
B	6,4,2,7

2. Boundary segment file structure (logical trace)

3. Polygon file structure

Figure 7.3 File structures for the encoding of land parcel boundaries and linkage of parcel identifier to the parcel polygon.

data structure has been chosen in anticipation of the major use of the DCDB (at least in its initial stages) as a mapping rather than spatial referencing tool. An auxiliary table links the parcel identifier to an arbitrary point within the parcel and provides a logical connection (or invisible line) to one of the parcel boundaries or corners. The parcel polygon is then formed by the processing of the coordinate data contained in the segment file. A "logical trace" or "sequence line" around the boundary is determined by computing the angles formed by segments leaving each node, and selecting the next segment in the sequence as the segment forming the smallest interior angle at that node. The principle deficiency of this method is that while the data is in a form amenable to direct plotting, logical relationships are not explicitly coded but must be derived by processing each time they are required.

(3) A polygon chain file structure (referred to as boundary referencing in 6.3) has been employed successfully for spatial referencing in the LAMIS system in Britain (HARRISON, 1979) and Australia (BRADY, 1978). Each record in this structure is of variable length and in both cases, this data structure has been specifically chosen to facilitate spatial referencing applications. The principal deficiency of the polygon file structure is that all coordinates are stored at least twice and in some cases up to 5 times for corners common to several parcels. That is, all segments are stored twice. MITTELSTRAß (1979) has reported that because of this redundancy, the segment oriented file structure requires approximately only 67% of the computer storage required for this area oriented structure. Apart from the problems of storage, the plotting of line detail from this file structure requires the continual elimination of repeated lines in order to minimize plotting time and to avoid the double plotting of lines. Procedures for the elimination of repeated lines were employed in the Bathurst project described in Appendix A.

The conflicting requirements of cartographic uses of the DCDB for line-oriented data structures, and spatial referencing uses for area-oriented data structures, suggest that a fully operational DCDB should provide separate segment (boundary) oriented and area (parcel) oriented files. This implies some degree of redundancy within this file series.
The proposed file structures and file interaction for the Parcel Polygon and Centroid Files are depicted in figure 7.4 and the files are

data structure has been chosen in anticipation of the major use of the DCDB (at least in its initial stages) as a mapping rather than spatial referencing tool. An auxiliary table links the parcel identifier to an arbitrary point within the parcel and provides a logical connection (or invisible line) to one of the parcel boundaries or corners. The parcel polygon is then formed by the processing of the coordinate data contained in the segment file. A "logical trace" or "sequence line" around the boundary is determined by computing the angles formed by segments leaving each node, and selecting the next segment in the sequence as the segment forming the smallest interior angle at that node. The principle deficiency of this method is that while the data is in a form amenable to direct plotting, logical relationships are not explicitly coded but must be derived by processing each time they are required.

(3) A polygon chain file structure (referred to as boundary referencing in 6.3) has been employed successfully for spatial referencing in the LAMIS system in Britain (HARRISON, 1979) and Australia (BRADY, 1978). Each record in this structure is of variable length and in both cases, this data structure has been specifically chosen to facilitate spatial referencing applications. The principal deficiency of the polygon file structure is that all coordinates are stored at least twice and in some cases up to 5 times for corners common to several parcels. That is, all segments are stored twice. MITTELSTRAß (1979) has reported that because of this redundancy, the segment oriented file structure requires approximately only 67% of the computer storage required for this area oriented structure. Apart from the problems of storage, the plotting of line detail from this file structure requires the continual elimination of repeated lines in order to minimize plotting time and to avoid the double plotting of lines. Procedures for the elimination of repeated lines were employed in the Bathurst project described in Appendix A.

The conflicting requirements of cartographic uses of the DCDB for line-oriented data structures, and spatial referencing uses for area-oriented data structures, suggest that a fully operational DCDB should provide separate segment (boundary) oriented and area (parcel) oriented files. This implies some degree of redundancy within this file series.
The proposed file structures and file interaction for the Parcel Polygon and Centroid Files are depicted in figure 7.4 and the files are

briefly described below:

1. *Central Index:* the inclusion of a centroid number and map sheet number in the *Central Index* provides a link between a property record in the LIS Base File and its corresponding record in the DCDB *Polygon and Centroid File* (2) located within the appropriate areal domain.

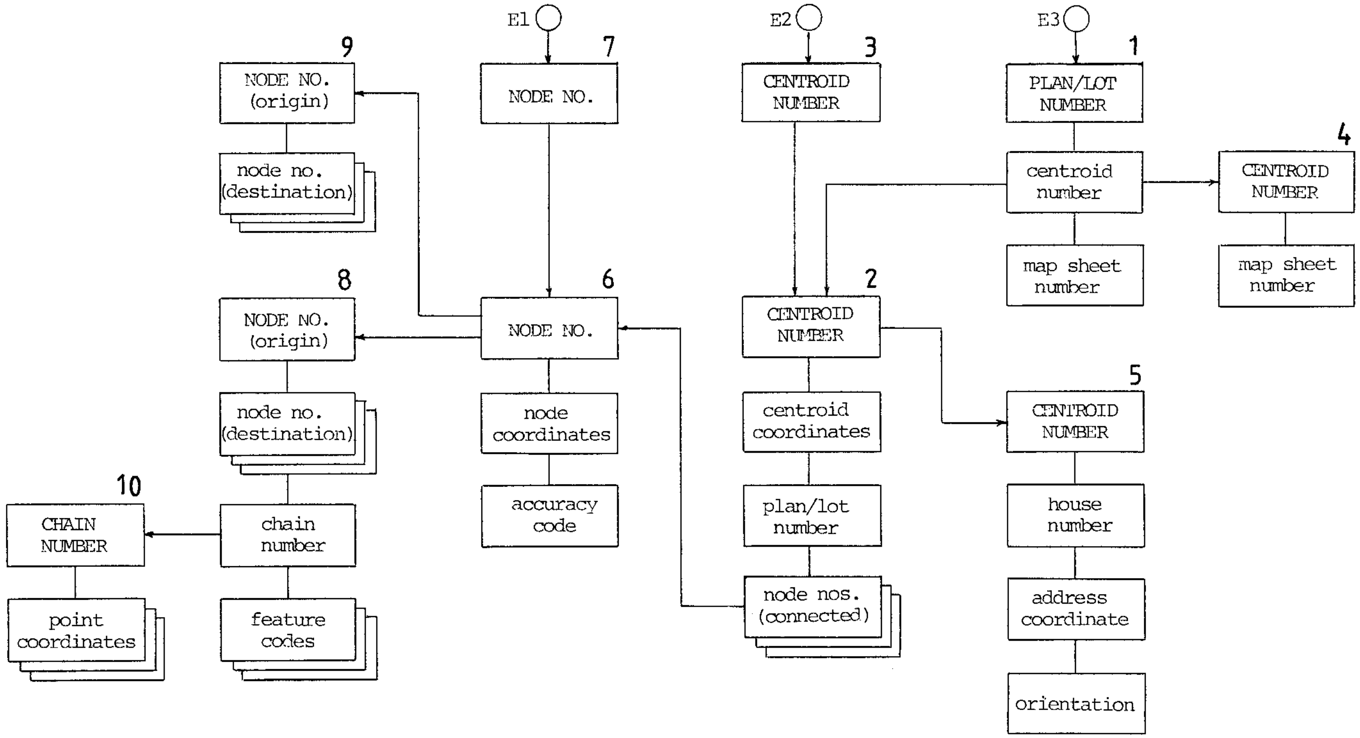
2. *Polygon and Centroid File:* a file of variable length records linking the parcel identifier and centroid coordinates to the nodes defining the parcel polygon, listed in clockwise order. The node number is a pointer to the node file (6).

3. *Centroid Coordinate Index:* a file in which pointers to the *Polygon and Centroid file* (2) are listed in "implied grid" order to facilitate the spatial searching and updating of the parcel file without disrupting the current contents of the *Central Index* (1) or *Polygon and Centroid File* (2). Based on the concept of the TRAMS *grid reference file* (see Appendix B).

4. *Supplementary Centroid File:* a file containing pointers to the records of those parcels whose boundaries lie partly inside, but whose centroids lie outside the map sheet. Designed to facilitate the spatial searching of parcels in those applications where centroids are not sufficiently accurate as search criteria. Based on the LAMIS *grid square file* for property reference numbers (HARRISON, 1976).

5. *Annotation File:* primarily designed for cadastral map annotation purposes.

6. *Node File:* a file listing the coordinate values for each node and attributes connected with the node including accuracy code. Sufficient redundancy exists in the *Polygon* (2) and *Segment Files* (8) to eliminate the need for listing connected nodes within the *Node File*. These linkages are not required to be explicitly recorded because boundary topology is only used for plotting and searching processes, in contrast to street, utility and other network systems in which directional and other attribute data are referenced to the nodes themselves. As well, the redundancy in the Ordnance Survey data base discussed in 7.2



1. Central Index
2. Polygon and Centroid File
3. Centroid Coordinate Index
4. Supplementary Centroid File
5. Annotation File
6. Node File
7. Node Coordinate Index
8. Segment File
9. Supplementary Segment File
10. Chain File

E1: Enquiry by spatial search on parcel boundaries
E2: Enquiry by spatial search on parcel centroids
E3: Enquiry by parcel identifier

FIGURE 7.4 File structures and file interaction for DCDB Parcel Polygon and Centroid Files.

is required for processing of parcel polygons, which the DCDB provides explicitly.

7. *Node Coordinate Index:* a file in which pointers to the *Node File* (6) are listed in "implied grid" in order to facilitate the spatial searching and updating of the *Node File* (6) without disrupting the contents of the *Polygon File (2) Segment File (8)* or *Node File (6)*. Based on the concept of the TRAMS *grid reference file* (see Appendix B).

8. *Segment File:* a file indexed on the origin node number, primarily designed to facilitate plotting and feature coding for cartographic purposes. Segment numbers are an unnecessary redundancy because each segment is uniquely identified by its pair of node numbers. Any ambiguity is eliminated by the use of pseudo nodes. The Segment File can be made internally non-redundant by recording only those segments whose direction from origin to destination node lies between 0° and 180° in the given coordinate system (MITTELSTRAß, 1978). Feature codes and pointers to the *Chain File (10)* are therefore only recorded once for each segment.

9. *Supplementary Segment File:* a file listing those destination nodes not recorded in the *Segment File* (8) which enables the DCDB to complete the boundary topology required for plotting purposes.

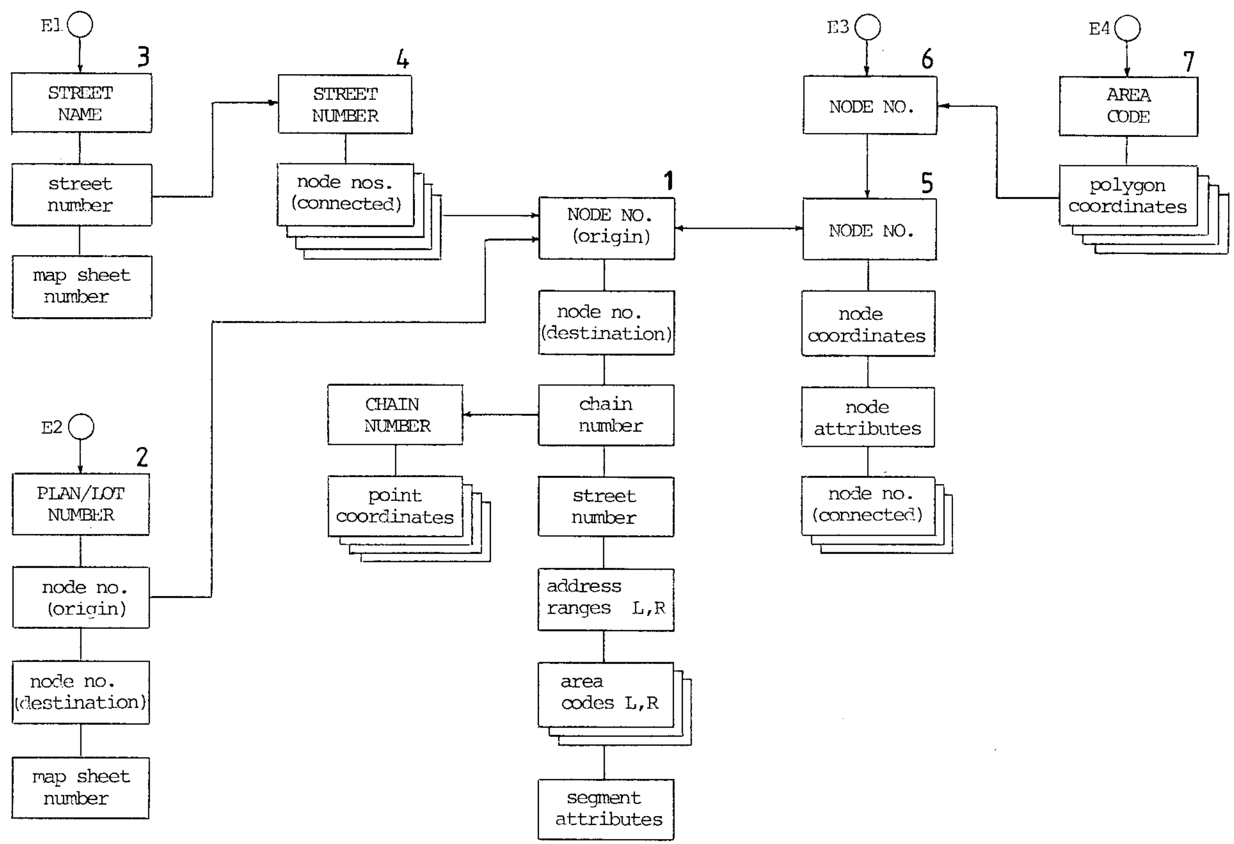
10. *Chain File:* a file of variable length records listing the coordinates defining the shape of each segment (if required) in the direction specified by the chain number, This avoids the need to include all points in the *Node File* (6) and *Segment Files* (8, 9). For data compaction purposes it may be possible to store coordinate increments relative to absolute coordinates held against the node rather than the coordinates themselves (see COOK & JOHNSON, 1973).

7.4 Street Segment and Special Area Files

Since the ownership of all public rights of way in Australia is automatically vested in Local government and partly because of the unsystematic nature of the compilation of cadastral maps and records in Australia, none of the State Land Titles Offices have adopted the principle of partitioning transportation space into legally defined parcels for title registration purposes (as is the practice in some European jurisdictions). Although street parcellation has been attempted as part of a general land parcellation programme in at least one State (RAINSFORD, 1976), the demand for this form of BSU in the DCDB is more likely to arise from developments in Local government and utility information systems which require that all urban space be partitioned into manageable units for the recording of utilities, street furniture and other assets. However, partitioning criteria will vary according to the function of the agency involved. For example, the requirements of Local government may give rise to alternative definitions for street intersection parcels (see BRADY, 1978, WILLIAMS, 1980) as depicted in figure 7.2. Block faces may also need to include part of the street space (see figure 7.2) to ensure that all assets (point referenced by coordinates) can be automatically given their correct street name by point-in-polygon techniques (see DARLINGTON, 1979). Because of these conflicting requirements, the DCDB may need to provide several forms of street parcels, utilising data structures compatible with the Parcel Polygon and Centroid Files.

In contrast to street parcellation, conventions for the representation of transportation space by street segments are relatively well established. Nodes are generally located at prominent positions in the street network, that is, whenever network systems cross one another. This crossing can occur *internally,* e.g. street intersections and cul de sacs, or *externally* e.g. rivers and railways (WELLS, 1976). Conventions for the definition of the street network used in the French Spatial Referencing System (RGU) can be found in MINISTERE DE L'EQUIPMENT (1976).

The proposed file structures and file interaction for the Street Segment and Special Area Files are depicted in figure 7.5, and the files are briefly described below:



1. Street Segment File
2. Central Index
3. Street Index
4. Street File
5. Street Node File
6. Street Node Index
7. Special Area Files

E1: Enquiry by street name
E2: Enquiry by parcel identifier
E3: Enquiry by spatial search on street network
E4: Enquiry by special area code or spatial search on area boundaries

FIGURE 7.5 File Structures and file interaction for DCDB street network and special area files.

1. *Street Segment File:* fulfills the role of the *route file* in the TRAMS system and the *topological file* in the NIMS system (see Appendix B). Segments are identified by the numbers of the nodes defining them. Segments are recorded only once in the direction implied by the order of the node pair as listed in the *Street File* (4). Segment sides are implied by left/right encoding of address ranges and area codes in the direction of the node pair. Segment shape is defined by coordinates obtained in a separate Chain File.

2. *Central Index:* land parcels are directly linked to their corresponding street segment by the inclusion of node numbers in the Central Index.

3. *Street Index:* one of the Peripheral Indexes designed to facilitate access to the LIS via street address (see figure 5.1) by identifying each street by a unique number.

4. *Street File:* to facilitate access to the DCDB by street name. Based on the *route file* in the TRAMS system. Order of nodes is a general east-west direction to facilitate its use for cartographic street name placement.

5. *Street Node File:* unlike the Parcel Boundary Node File (see 7.4), this file lists the numbers of connected nodes in order to provide the redundancy recommended for efficient network analysis.

6. *Street Node Index:* facilitates spatial retrieval of segment and node records in the *Street Segment File* (1) and *Street Node File (5)* respectively. Node numbers are ordered sequentially on an "implied grid" order. Based on the *grid reference file* in the TRAMS system (see Appendix B).

7. *Special Area Files:* permits parcel and street segment records to be more rapidly and automatically amended as changes are made to the boundaries of special areas through point (or segment) in polygon search techniques. Structured as a polygon chain file or polygon node file according to the proposed schema. The TRAMS and NIMS systems encode all

areas in this manner because it has been found a more efficient method for the production of shaded area maps, than building up areas from street segment sides. (WALKER & DAVIS, 1978). Spatial manipulation of records within special areas could be facilitated by a map sheet index listing the codes of the areas falling within a given map sheet (areal domain), in a similar manner to the *grid square files* used in the LAMIS system (HARRISON, 1976).

7.5 DCDB File Creation

7.5.1 Alternative File Creation Procedures

The Parcel Polygon and Centroid Files are the most costly and complicated of the three basic DCDB file series to create. This is due to:

- the large amount and high resolution of *spatial (coordinate) data* required to encode land parcel boundaries and centroids

- the large amount of *logical data* required to link this data within and between the files.

As discussed in 7.1, traditional cartographic digitizing methods do not capture these data linkages. If the DCDB files are to be created as a by-product of existing cadastral mapping processes, then provision of these linkages must not be permitted to complicate or retard the overall data input process. For the purposes of DCDB file creation, these logical data can be defined in terms of the topological relationships of connectivity, direction and adjacency, and can be divided into 3 types:

(1) linkages between the spatial elements (point coordinates) forming the basic spatial unit (parcel polygon and centroid)

(2) linkages between the basic spatial unit (parcel polygon and centroid) and its external index or nominal code (parcel identifier).

(3) linkages between basic spatial units (parcel polygon and centroid, street segment, block face, block, special areas).

Experience in file creation for spatial referencing systems has shown that the creation of these data linkages can be achieved in two ways:

1. the modification of the digitization process to *manually* capture these data linkages during or outside digitizing

2. the continuation of line oriented digitization processes and the restructuring of the resulting data bank to create these data linkages *automatically*.

1. Manual Encoding of Logical Data

(i) *Area-Oriented Digitizing*

In the area-oriented or "common-sense" approach (BRADY, 1979), points defining each parcel are digitized in a clockwise manner, creating a polygon chain file for each parcel which reflects the order of digitizing. This method of digitizing has been favoured because of its conceptual simplicity which provides a systematic framework for the input and storage of data. This simplicity is a particularly attractive feature for those systems which lack sophisticated software and hardware for the processing and editing of the digitized data. The method has been chosen for this reason for digital cadastral mapping purposes by ELFICK (1974) and for spatial referencing purposes in early developmental work with the LAMIS system in Britain (see BRADY, 1979). The obvious deficiency of the method is that each point is digitized at least twice and up to 4 or 5 times. That is, each boundary segment is captured twice. Data input time is therefore excessive because coordinate and logical data (linkages (1) and (2)) are captured during digitizing. A less serious problem is the appearance of "slivers" or misalignment of double-plotted lines caused by the existence of multiple sets of coordinates for the same point (BRADY,1979). These problems can be easily overcome by the automatic comparison of point coordinates and the elimination or meaning of these additional coordinates in a manner described by ELFICK (1974) and used in the Bathurst project (see Appendix A).

(ii) *Segment-Oriented Digitizing*

The encoding of individual boundary segments as a method of data *input* was developed to overcome the problems of excessive digitizing time involved in the area-oriented digitizing of complex areal units. In earlier applications of the method e.g. the DIME files (see 6.3) nodes were numbered manually, data linkages (1) and (2) encoded manually by the input of the areal code on either side of each segment, and node coordinates digitized (once only) at a later stage. More recent applications (MACLEOD et al, 1973) for digitizing census collector districts by-pass the manual encoding of nodes by accurately digitizing each node as a first stage, and then digitizing each segment individually. Coordinate matching techniques are then used to identify the node numbers at either end of the segment. Area coding during digitizing is also minimised in this application by exploiting the hierarchical nature of the census area codes. In both cases, data linkages (1) and (2) are subsequently created by the automatic detection of node numbers and nominal codes which also provide redundant data for validation purposes. The segment-oriented method is usually only considered for digitizing cadastral maps in the absence of sophisticated computer graphics equipment (see KEDGE, 1974) or where an opportunity is seen to minimise development costs by using available software and techniques and procedures which have proven successful in other applications (see WHITE, 1977). The principal deficiency of the method from the point of view of land parcel digitizing is the large amount of logical data required to encode data linkages (1) and (2). Segment-oriented methods were originally designed to encode relatively complex polygonal shapes where there are many chain points describing the shape of the segments. The comparatively simple shape of cadastral parcels (in which segments usually comprise only one straight line between consecutive nodes) give rise to a disproportionately high ratio of nominal codes to digitized coordinates. Any benefit which the left/right encoding of segments can offer data validation is therefore greatly outweighed by the tedious process of manual logical data encoding, irrespective of whether this encoding is done during or outside digitizing.

(iii) *Point-Oriented Digitizing*

In this method, every cadastral corner is digitized once, in any order, and numbered automatically. Data linkages (1) and (2) are then created manually after digitizing by listing in sequence, the numbers of the nodes defining each parcel. In principle, the method is similar to the area oriented method except that spatial data input and logical data input are separate processes. The main advantage of the method is that digitizing is kept to a minimum. This has proven a particularly attractive feature for the development of spatial referencing systems in Local government where digitizing is the major cost component in file creation (see BRADY, 1979, WILLIAMS, 1980). Its main disadvantage from a cartographic viewpoint is that logical data encoding is excessive and error-prone.

2. Automatic Processing of Logical Data

In each of the previous methods, logical data are encoded by considerable manual effort. For this reason, none are well suited for cartographic purposes. Of the three, the point oriented method is the most efficient because spatial data capture and logical data capture can be separated. The encoding of topology outside the digitizing process is now generally recognised as an essential characteristic of an efficient file creation procedure (COX & RHIND, 1977). The encoding of topology in these methods involves the manual inspection and recording of the relation between spatial data items. If all spatial data are captured during digitization, then it should be possible to detect topology by computer processing of this data and explicitly record these linkages in the restructured data, thereby considerably simplifying the file creation process.

The experience of the Ordnance Survey indicates that the automatic creation of topology is technically feasible. After studying the problem of restructuring their digital map data bank for spatial referencing purposes, the Ordnance Survey concluded that there were three possible solutions:

- *manual extraction* of the relevant information from computer printout followed by computer processing

- an *interactive system* to identify and extract nodal points with on-line computer processing
- the development of a *software system* to restructure the data automatically with minimal human intervention (ORDNANCE SURVEY, 1975).

It was decided that in the long term, the third solution would be the most economical one to pursue, particularly as digitizing procedures were already well established and a considerable amount of digital data had already been produced in line-oriented form. Details of the Ordnance Survey Restructuring Project, implemented in 1974, are outlined in ORDNANCE SURVEY (1975, 1977a), THOMPSON (1979a, 1979b). Restructuring involves two processes:

- the breaking up of individual line elements by identifying all line intersections
- the creation of a node file and link (segment) file from which parcel centroids, boundary polygons and, in the long term, street segments can be derived.

The latter process uses the feature codes in the data bank to assist in the formation and classification of land parcels. The software alone provides only a 60%-85% success rate in the definition of parcels (RHIND, 1979). This is because the parcel boundaries depicted on the Ordnance Survey maps represent the *physical* (topographical) rather than the *legal* delineation of ownership rights. Since not all cadastral boundaries are fenced, the processing of boundary line data does not always give rise to a closed entity (THOMPSON, 1979a). The processing of digitized cadastral map would therefore be expected to yield a higher success rate.

7.5.2 A Parcel Polygon File Creation Procedure

A digitizing procedure for the creation of the Parcel Polygon and Centroid Files (see figure 7.4) is presented in figure 7.6. The procedure has been specifically designed to minimise manual effort both in the digitizing of the map content (spatial data input) and in the encoding of logical data. The procedure separates spatial and logical data encoding in order to achieve the former aim, and restructures the spatial data by automatic processing in order to achieve the latter.

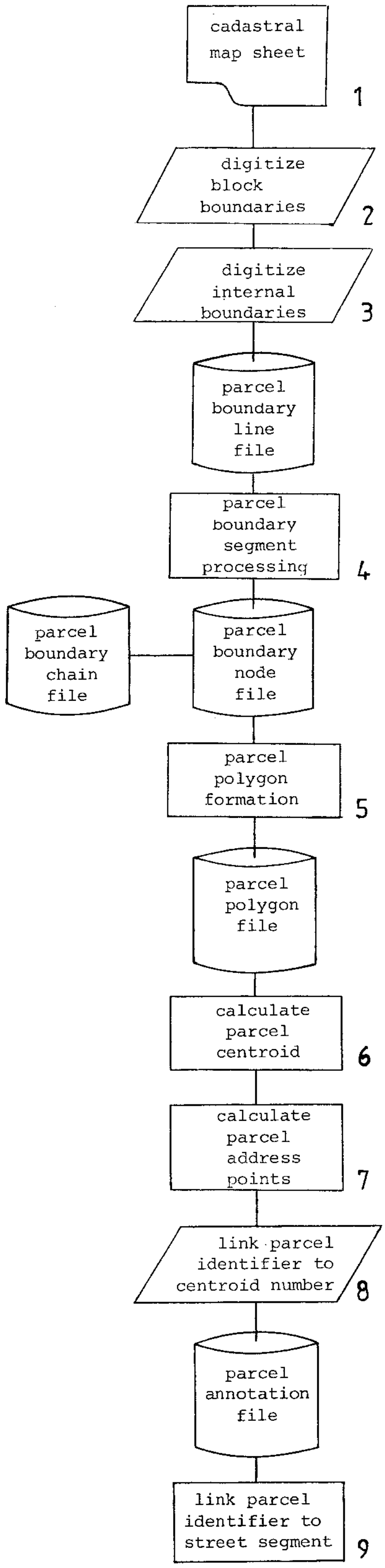


Figure 7.6 Digitization procedure for the creation of the Parcel Polygon and Centroid Files. Procedure is repeated for each block.

The procedure is described in detail below. The procedure has been partially tested in a project described in Appendix C, and statistics referred to in the following description are drawn from this experiment (referred to as the Peakhurst project).

1. *Selection and Initialisation of the Cadastral Map Sheet*. It is assumed that the coordinates for initial file creation will be derived from "the largest scale mapping available with due regard to accuracy" (BRIDGES, 1981). Sufficient map control must also be available to reference the coordinates to the Australian Map Grid.

2. *Digitization of Block Boundaries*. The block boundary (street frontage) lines are digitized clockwise as a series of continuous straight lines, ignoring the existence of nodes which lie on the line. The block boundary polygon is automatically closed by coordinate matching once the starting point is reached.

3. *Digitization of Internal Boundaries*. Internal boundaries are digitzed as continuous lines with the termination of each line (when the digitizer cursor must be moved from the line) being identified by the use of a special cursor button or menu code. It has been estimated (BELLAMY, 1976) that digitization of straight lines (as opposed to individual line segments) can reduce digitizing time by up to 70% for urban map sheets. In the Peakhurst test area 3% of the point coordinates needed to define parcel boundaries were digitized twice under this procedure. However 3% did not need to be digitized at all, being computed from line intersections in step 4. In fact, the total number of digitized coordinates was less than that required by the point-oriented method, with the added advantage that straight lines on the map remained straight after digitizing and plotting, thereby satisfying cartographic requirements.

4. *Automatic Creation of Parcel Boundary Node File*. For each block, the parcel boundary line file can be automatically processed to determine nodes created by:

   - lines *intersecting* other lines

- lines *terminating* at other lines.

The line terminator codes assist in the identification of these latter points. In effect, the line data is broken into segments, with each record in the node file listing the number and coordinates of the node and the numbers of the nodes connected to it. The ability to automatically create the node file already exists in modern cartographic bulk editor software which can detect and correct "overshoots" and "undershoots" to meet cartographic presentation standards (WALKER, 1979). The Ordnance Survey restructuring software also possesses such a capacity and the development of software for this purpose has been reported by BELLAMY (1976) and KELLY (1980). Those points which do not intersect or terminate at other lines are, by definition, chain points and can be stored in a separate file for processing purposes. Only 8% of the boundary segments in the test area required chain points to describe their shape, representing 16% of the total number of digitized coordinates. This confirms the conclusions made in 7.5.1 regarding the inappropriateness of segment-oriented methods for cadastral digitizing.

5. *Automatic Formation of Parcel Polygons*. The parcel boundary node file is processed to create a parcel polygon file for the block. Successful processing is dependent on several assumptions:

   - block boundaries are digitized in a clockwise direction
   - all parcels have at least one street frontage
   - there are no parcels lying totally within another parcel
   - boundary segment topology has been correctly encoded in the parcel boundary node file.

Processing can be confined to each block. Each parcel polygon is formed automatically by selecting the required nodes by computation and comparison of internal angles. This technique is described in Appendix C and appears similar to that reported by MITTELSTRAß (1979) and KELLY (1980). Unlike segment-oriented methods, the automatic spatial processing of topology does not generate redundant data for data validation purposes. However, sufficient scope exists for a non-rigorous data validation/error detection by:

- successful polygon closure within a predefined number of segments
- parcel area summation to block area
- visual validation of the processed data.

Apart from errors arising from incorrectly (manually) encoded parcel boundary node files (which were subsequently amended), parcel polygon formation in the test area was successful for all 622 parcels.

6. *Calculation of Centroid Coordinate*. The manual digitization of a "visual" centroid has long been an accepted method of acquiring a point reference in lieu of full boundary referencing (see 6.3). If boundary referencing is undertaken, then the possibility exists for the derivation of a point reference from the polygon boundaries. Computation of centroid coordinates offers the following advantages over manual digitization:

   - the centroid can be rapidly and unambiguously calculated from the relatively few boundary points defining each parcel polygon. Unlike land use, census collector district and other complex areal units, the parcel is a simple, contiguous unit with few chain points, and with few instances of areas within areas which would otherwise complicate this computation.

   - the manual digitization of a centroid may give rise to coordinates which may not be accurate enough to satisfy cartographic requirements for placement (position and orientation/alignment) of the parcel identifier for map annotation purposes. Computation of centroid (coordinates) using street frontage and internal boundaries not only provides an aesthetically acceptable placement of text, but also permits a dynamic approach to map annotation in which text can be placed according to any desired criteria.

A simple but non-rigorous algorithm based on the method of maximum and minimum bounds devised by MAGGS (1973) was used in the test area to compute the centroids. Only 2 of the 622 parcel centroids could not be satisfactorily computed by this process (see figure C.2). A rigorous algorithm for centroid computation, as reported by DAVEY (1976), would eliminate these failures.

7. *Calculation of Address Point.* The address point is a location within the parcel which indicates the street to which the house number applies. An algorithm was devised for the Peakhurst project which computed address point coordinates at the mid-point of, at a fixed distance from, and perpendicular to the frontage segment. Address points were unambiguously detected from the polygon data for 88% of the parcels in the test area. The remainder (corner lots, lots with no frontage and lots with more than one frontage) required manual identification of the required boundary segment. The address point algorithm also ensured that no symbol was written upside down (see Figure C.2).

8. *Linking of the Parcel Identifier to the Parcel Polygon Record.* In line with the principle of minimisation of digitizing time, the input of the parcel identifier and its linking to the appropriate parcel polygon record is separated from the digitizing process. Identifiers are linked manually to the nominal parcel number (a number generated automatically for each parcel and unique within each block) which is plotted on the digitized boundary pattern in the position defined by the parcel centroid coordinates. Separation of these processes is supported by British experience in gazetteer creation. For example, STEPHENSON & YOUNGER (1972) claim that digitized centroid coordinates and parcel identifiers are best linked by file matching after digitizing primarily because:

   - the danger of keying in the wrong parcel number is great and cannot be easily guarded against
   - the digitizer operators can work faster and more efficiently if keyboard working is kept to a minimum.

   The means by which the nominal codes and parcel identifiers are linked will depend on the identifier chosen for this purpose which will, in turn, depend on the nature of available cadastral mapping.

Experience has shown that the matching of identifiers to nominal codes can be simplified by exploiting the hierarchical structure of street name and house number, and the sequential numbering of houses along the street (see RHIND & TREWMAN, 1975). However, most standard cadastral mapping in Australia depicts the plan/lot number. Under these circumstances, linking can still be carried out efficiently on a block by block basis by exploiting the hierarchical structure of the plan/lot number within each block.

9. *Linking of Parcels to Street Segment Sides*. Once parcel boundary coordinates are captured, data linkages (3) (the linking of parcels to blocks, block faces and some special areas) can also be encoded automatically. Parcels are explicitly linked to blocks by the order of digitizing and these linkages can be re-established by the point-in-polygon retrieval of centroids within block boundaries. Other linkages are expressions of the relationship between the parcel and the side of the street on which it fronts. These linkages have traditionally been supplied by the manual encoding of street address ranges to street segments. In the Peakhurst project, a street segment network was digitized to serve as the basis for the Street Segment Files for the test area. A path search (using each street segment as the path centreline) detected those address points lying within 15m of each side of the segment. The identifiers for these parcels were then automatically allocated to and arranged in sequence along each segment side in preparation for address range coding. 88% of the parcels were directly allocated to the correct segment side by this process. 11% were allocated to more than one segment, these being parcels on street corners. However, this ambiguity can be subsequently removed by reference to the street name contained in the Central Index. Only 1% could not be allocated to a segment side by this path search method.

7.6 Summary and Conclusions

The creation of the Digital Cadastral Data Base (DCDB) as a by-product of existing cartographic digitization processes involves a rationalisation of data structures in the digital cadastral mapping system. The successful implementation of the DCDB must therefore resolve the conflict between cartographic and spatial referencing data structure and file creation requirements.

The basic DCDB file series presented in this chapter have been designed primarily to satisfy the spatial referencing requirements of the LIS. Spatial references for basic spatial units may be retrieved from the DCDB via their nominal codes (such as parcel identifiers, street network node numbers and special area codes). Alternatively, the nominal codes for the basic spatial units may be retrieved from the DCDB via spatial search techniques, thereby enhancing the ability of the Spatial Referencing System to correlate all land-related data.

The DCDB file creation procedure described in 7.5 has been designed to be acceptable for adoption by the cartographic agencies who are to be the initial sources of data acquisition. The appropriateness of any digitizing procedure to the data input phase of a digital mapping system and its acceptance by the map producing agency for this purpose, will depend on several factors:

- *available computer and manpower resources:* Local government and other non-cartographic agencies will find manually intensive procedures more acceptable than those methods depending on sophisticated computer graphics hardware and software
- *scale and quality of existing maps:* Considerable manual effort may be required to upgrade the map series prior to digitization
- *demand for structured cadastral map data:* Initially, the user demand for digital cadastral data will be for standard map production and some special purpose mapping
- *desire to persist with existing procedures:* Experience of the Ordnance Survey restructuring programme indicates that it is seldom cost effective to modify an existing digitizing procedure which is functioning smoothly
- *operator performance:* A desirable procedure should eliminate repetitive and time consuming tasks but allow operators sufficient scope for exercising their individual judgement.

However, it is the degree to which logical data encoding complicates the digitizing procedure which will be the greatest determinant of the acceptability of any method for cartographic purposes. The special features of the proposed procedure which minimise manual logical data encoding are:

- *the separation of spatial and logical data input to minimise digitizing time*
- *the automatic creation of data linkages to further minimise manual effort:* Very little topology is entered by the operator but is implied by the structure of the data input stream. The procedure combines line-oriented digitizing procedures with automatic processing of the digitized data
- *the modular design of the procedure:* This permits the staged digitization of blocks, parcel boundaries and street segments and the separate input of parcel identifiers for map annotation purposes. These processes can be carried out independently of one another and as required, while remaining part of the total data input system
- *the exploitation of the unique features of the cadastral map:* In contrast to the digitizing of land resource, administrative and other interlocking areal units, the digitizing and subsequent processing of cadastral parcels can be restricted to individual blocks which constitute manageable units for these processes. As well, the large number of straight line boundaries (that is, a small number of chain points) permits the use of line-oriented digitizing methods which have been shown to be the most rapid means of spatial data input.

Ultimately, acceptance by map producing agencies of the need to encode logical data as part of the cadastral digitization process will depend on whether these agencies view digital cadastral mapping only as a means to assist in the production of the traditional graphical product, or whether they recognise the need to produce digital cadastral map data in a form required by their traditional users. In earlier experimental work, the cost effectiveness of digital cadastral mapping depended on this recognition. For example, GLENDINNING et al (1971) concluded their report on their experimental cadastral data bank by stating that:

> "....its economy is apparently bound by whether or not the system is to be accepted as a total system of Land Data reference, or whether it is to remain a map compilation tool only.
>
> If restricted to map compilation only, the unit cost of plotting a single surveyed lot.... will be approximately twice the cost of the present compilation practices".

THOMPSON (1979a) has also reported that the restructuring of the Ordnance Survey digital data bank for use in information systems was prompted by the fact that the production of maps using the Digital Mapping System was between 1.3 and 1.6 times as expensive as doing it by hand and took longer.

The fact that digital cadastral mapping is now cost effective for cartographic purposes alone (BRIDGES, 1981) does not lessen the importance of the need for structured digital cadastral data for standard cartographic processes. In this regard, it is proposed that the structured DCDB files presented in 7.3 and 7.4 can offer several benefits in the following aspects of standard and specialised map production:

- *map format:* Spatial partitioning of the DCDB files on a map sheet basis provides a convenient storage module for map editing and plotting purposes.
- *map annotation:* The traditional "data bank" approach to inputting parcel identifiers and other map annotation is a static process which locates these labels where they appear on the original map. The creation of a Parcel Polygon File enables the location and orientation of parcel identifiers to be selected and computed according to user defined criteria. The satisfactory results obtained in the Peakhurst project (see figure C.2) are evidence of the potential of automatic identifier placement. A similar dynamic approach to map annotation applies to street name placement. Figure C.4 depicts the results of automatic street name placement using a digitized street network (see figure C.3). As well, the "data bank" approach to street name placement digitizes the names of streets in the positions where

they have been placed on the original map sheet. If any section of the map sheet is to be retrieved from the data bank for specialised cartographic products, then the DCDB Street Segment Files can be processed to place street names within the new map format. For example, a comparison of figures C.1 and C.4 shows that 3 of the street names which do not appear on the section of the standard map sheet have been automatically placed in the test area.

- *special purpose mapping:* The production of specialised cartographic products often involves the extraction of map detail from the data bank according to spatial or feature code criteria. In the former case, the street segment file can be used to produce cadastral map products on a street alignment basis by a spatial search around each segment within a user defined path width.
- *derived mapping:* The DCDB Parcel Centroid and Street Segment Files can assist in the production of smaller scale cadastral and topographic maps. For example, centroids can be used to depict schools, factories and other special purpose buildings on small scale topographic maps. Also, it is the practice of the Ordnance Survey to digitize street centrelines on their 1:1250 and 1:2500 large scale series (even though they are not shown on these maps) in order to produce a generalised road network for the derivation of the 1:25000 series from the large scale data bank (ATKEY & GIBSON, 1975). The Street Segment Files can be used in a similar manner.
- *feature coding:* The traditional approach to feature coding in the creation of cartographic data banks is a tedious and time consuming process with each line usually being coded as it is digitized. WILLIAMS (1974) was one of the first authors to recognise the implications of area-oriented data structures for traditional feature coding practices:

> "It is, of course, possible to code line segments both in terms of the physical features which they represent and in terms of the areas which they separate. Cartographic systems have been developed which

> incorporate such coding. However, in setting up the [data base] format, it will ultimately be necessary to decide whether to adopt a feature coding base or an area reference coding base".

The nature of cadastral maps is such that the majority of codes required in digital cadastral mapping fall into the latter category (for example, land use, administrative/statistical district). The appropriate line segments can therefore be rapidly coded by the attachment of the code to the parcel or group of parcels to which the code applies (via the centroid or centroids contained in the DCDB Parcel Polygon and Centroid Files). This can also be efficiently carried out after digitization. Further, since many of these features will be recorded as parcel attributes in the LIS Base File, it also follows that much of this feature coding will eventually be removed from the responsibility of the map producing agency and selected as required by the DCDB user by linking with the LIS.

In conclusion, RHIND & TREWMAN (1975) succinctly expressed this interdependence of traditional cartographic processes and the derivation of spatial references for information systems (and the implications of this relationship for cartographic data structure) when they wrote:

> "In our experience, automated cartography cannot be seen as distinct from the available data base and its organisation..... unless the scope of cartography is to be greatly diminished".

8. LAND-RELATED SUBSYSTEMS

8.1 Introduction

The conceptual model depicted in figure 4.1 recognised the existence of various subsystems containing data which cannot be explicitly related to individual parcels of land. It was proposed that data in these subsystems could be integrated with property-based data through the Spatial Referencing System. This capability reflects the ability of the large scale cadastral map to serve as a framework for referencing other data types.

This chapter briefly describes design principles for the following subsystems:

- utility and services networks
- road and transportation data banks
- census and statistical data files
- land resources data banks.

Since the first three subsystems are likely to utilise the digital cadastral map data contained in the Digital Cadastral Data Base (DCDB), developments in these subsystems must also be subject to the control of the LIS coordinating agency proposed in 4.3.1. This will ensure that the basic spatial units contained in the DCDB will be compatible with those in all subsystems. On the other hand, land resources data banks are generally independent of cadastral boundaries. However, a brief review of the spatial referencing methods likely to be used in this area is also made in order to identify future enhancements of the Spatial Referencing System.

Many of the referencing techniques described in this chapter have been described in detail in chapter 6.

8.2 Utility and Services Networks

The provision of telephone, electricity, gas, water, sewerage and drainage services is an important function of urban administration. In Australia, these functions are the responsibility of a variety of local government and statutory authorities (Federal and State) (see 2.1). Each authority separately maintains records of its own installations (ducts, cables, pipes etc) and associated elements (manholes, hydrants etc) usually in the form of large scale maps and plans. Plans are used to relocate installations by referencing them to fence lines and fence intersections by direct measurements. These measurements are used to position the services on a large scale cadastral map which is used for indexing purposes. Elevations are usually quoted in terms of depth below surface.

As the competition for road space intensifies, the often inaccurate and unreliable information contained in these records, together with the lack of coordination between agencies, have added to the costs of maintaining these services and planning for future expansion. In recent times, there has been an increased awareness of the need to establish a central, up-to-date register, locating by AMG coordinates the position, depth, purpose, size and capacity of all underground utilities (SOUTH AUSTRALIA, 1977).

Initially, the register would be in the form of a large scale map based on the system proposed in 3.4. Ultimately, the register and maps would be automated and (through the application of data base technology) form the basis of a utilities information system providing the following benefits:

- shortening time for planning and design of new utilities
- minimisation of damage to existing utilities caused by excavations during construction works
- easier maintenance and faster repairs of the utility services (HAMILTON et al, 1976).

The main obstacles to the creation of such a system in Australia have been identified as:

- the fragmented control of public road space for service conduits
- the lack of formal responsibility to record and chart underground services
- the lack of uniform standards for the placement and recording of underground services
- the inaccuracy and incompleteness of existing records (INSTITUTION OF SURVEYORS, N.S.W., 1977a; SOUTH AUSTRALIA, 1977).

To ensure that all new installations are recorded and information made available to all potential users, a centralised registry can be established through cooperative action between the various authorities (see ANDRECHECK, 1972). To ensure that they are placed according to uniform standards, it would appear that some statutory measures are required. Codes of practice for placing services in roads and footpaths have proven ineffective in improving recording and placement, since these recommendations are not obligatory (SOUTH AUSTRALIA, 1977). Legislation requiring the preparation and submission of "identification surveys" to be issued as certification of the location of new underground facilities, and adopting common standards in this task (INSTITUTION OF SURVEYORS, N.S.W., 1977a).

The production of large scale maps accurately depicting existing services in plan and elevation is the major cost in establishing the new system. SHERWOOD (1976) has stated that there are only two alternatives for this task:

- to obtain information physically by investigation of the area
- to obtain information from existing sources.

Due to the high cost of the former method, and the inaccuracies of the latter, the solution will necessarily be a judicious combination of both data sources.

Positional accuracies of ±10cm to ±20 cm in plan and elevation are generally accepted as sufficient for location and engineering design for underground services, except for gravity conduits where ±1cm to ±2cm is quoted for vertical (HAMILTON et al, 1976). Photogrammetry can supply from 20% to 40% of this information (BLACHUT et al, 1979). However, field survey will always be necessary to detect and locate services not visible above ground. Existing records can be used to supplement this data. Electronic detectors can be used to locate unrecorded services (KATONA, 1974). Such a survey would become more cost effective if incorporated with the large scale mapping and control densification programme proposed in 3.4.

In the absense of accurate utility mapping, authorities in Australia have digitized existing cadastral maps and referenced their services to this digital base via connecting measurements (see KELLY,1980). This is in recognition of the fact that the cadastral framework will eventually be upgraded and the location of the utility network change accordingly. Such a product may serve as an indexing base for utilities until accurate coordinates become available.

The DCDB can provide the same cadastral data for the initial stage of the utilities information system, with the following advantages:

- providing a common cadastral base for the referencing of all utilities
- eliminating the present duplication of mapping in the compilation of selected utility map products
- linking of network capacity and other utility data with external data files to estimate demand for services for forward planning purposes.

8.3 Road and Transportation Data Banks

The responsibility for construction and maintenance of major roads in Australia is vested in State government. Minor roads and streets are vested in local government. From the early 1970s the National Association of Australian State Road Authorities (NAASRA) has been planning a nationally integrated road data bank recording such data as road surface and width characteristics, traffic volumes and road related structures (BRIDGE, 1980).

Construction of the data bank involves the breakdown of the major road system into manageable units for the storage of data. These network segments are identified in terms of their nodes. Coordinates for each node will eventually be digitized from 1:100000 topographic mapping to provide for the spatial retrieval, analysis and automatic plotting of the network data (HILL, 1977).

In order to ensure future compatibility of road data bank systems and other transportation data, the DCDB should be designed so as to ensure that the segments contained in the street segment file (see 7.4) are acceptable for use in the road data banks. The DCDB files have the advantage that they are up-to-date and are of sufficient accuracy to permit their use for updating topographic mapping (see BÖHME, 1972). The address ranges contained the DCDB files should permit integration of road data with real estate, motor vehicle, business and other property-based data in a similar manner to the Swedish Road Data Bank (BYLANDER & NILSSON, 1977). The breakdown of the transportation network to the street level will enable the referencing of traffic accidents as proposed in a future enhancement of the NAASRA project (HILL, 1977).

8.4 Census and Statistical Data Files

HART (1973) described the Australian Population Census as the "most important single source of planning data which is uniform over the whole country". The following review will therefore concentrate on this data source.

Census data possess certain characteristics which restrict their ability to supply timely, accurate and useful information:

- data timliness: since Census data is collected only once every six years (that is, it is not continually updated) the data needs to be processed quickly before it becomes out of date. However, the huge volume of collected data requiring processing means that derived information is often out of date before it is made available

- data sensitivity: since the data is acquired on the undertaking that it will not be stored or disseminated on an individual basis, the data must be aggregated so that no one individual can be identified by their location or attribute. Census data in Australia are collected and stored by "collector's districts" (CD) each averaging between 200 to 250 dwellings or households (HART, 1972).

- data compatibility: since they are based on a fixed population basis, CDs vary greatly in size between urban and rural areas. As well, CD boundaries change between Censuses due to population increases and changes in electoral and local government boundaries. Consequently, compatibility with other data sources and over time, is difficult to achieve

- data assimilation: the variety of data collected makes comprehension and assimilation of information difficult unless displayed in graphical form. Manual production of Census atlases however, is a costly and time consuming process.

Problems with managing Census data efficiently,have become more acute in recent times. HART (1973) has commented that:

> "It can be argued that the Population Census has reached the stage where no longer is the collection of information the major problem....but the real difficulty lies in accessing the mass of collected data quickly and efficiently .... We are acutely aware of the need for more timely statistics particularly for small areas."

The use of spatially referenced small area statistics has been seen as a means of overcoming many of the above problems. Address coding guides (ACG) were originally introduced in the United States Census to automatically allocate census tract numbers to street addresses for the mail-in, mail-out census. The ACG research eventually lead to the development of the DIME file system in which street segments constitute the smallest basic spatial units (see 6.3). Through the DIME files, census data can be readily allocated to blocks and can be spatially referenced by the coordinates allocated to each street node. The British 1971 Census was collected on a 100m grid cell basis. The grid cell code was allocated by collectors in the field. The addition of this spatial reference was expected to improve areal compatibility, computational methods and display of the data (GREAT BRITAIN, 1970).

Experimentation with spatial referencing methods in Australia has not yielded an acceptable system for Census data (BYATT, 1976). Grid cell methods are unsatisfactory because they cut across established administrative boundaries, while street segment methods have proven highly error prone in the allocation of parcels to their appropriate segment.

In this environment, it would appear that the Spatial Referencing System can offer only limited application to Census data. The System can automatically allocate parcels to CDs by a spatial retrieval of parcel centroids on the Special Area Files. Smaller CDs may be one future option in this regard. Similarly, parcels can be readily allocated to grid cells by spatial search techniques, and to street segments via address ranges in the Street Segment File. If problems of data sensitivity prevent the storage of data for smaller basic spatial units, then the Spatial Referencing System can be used to automatically produce lists of properties for each CD in preparation for each Census through parcel centroid retrieval on the already digitized CD boundaries (see MACLEOD et al, 1973). Eventually, CD boundaries must be provided by the DCDB.

8.5 Land Resource Data Banks

Land resource data was defined in 4.3.3 as such environmental parameters as slope, terrain, soils, geology, land use, vegetation, erosion etc. A land resource data bank is a computerised collection of these parameters for a given area. The parameters have been traditionally collected from existing resource maps and aerial photography.

From the viewpoint of spatial referencing, land resource data banks differ from the preceding subsystems in the following ways:

- they are generally restricted to non-urban areas
- their coverage is rarely comprehensive
- their contents are seldom updated.

Spatial referencing methods used to encode land resource data are usually confined to grid cell or polygon techniques. HSU et al (1975) report the use of land parcels to reference resource data in Minnesota. However, the system owes its success to the regular grid pattern of the United States Public Land Survey and would be inappropriate outside this framework.

Polygon methods offer the most accurate spatial representation of land resource units since each boundary is digitized directly from the map or delineated aerial photograph. However, grid cell methods were extremely popular during the early 1970s for several reasons. Their main advantage is their relatively simple data structure which permits modification and processing of the data with simple algorithms. Data input is achieved without the aid of a digitizer by overlaying a grid on the source document. Output can be readily and cheaply obtained through line printer mapping. Their main disadvantage is that the appearance of the output is unacceptable to many users, being unable to recreate the original "smoothness" of the resource unit boundaries. In addition, the grid may not be fine enough to encode small but important resource units. However, HOSCHKE (1974, 1976) argues that these problems are not serious since land resource boundaries are, in reality, not the well defined limits that are traditionally delineated on maps and aerial photographs, while isolated data not detected by the grid can be accommodated by supplementary coding.

Proportional grid cell methods have also been employed to capture these small but significant areas (LYNCH, 1976). Such methods encode resource types according to the percentage area of the grid cell they occupy, rather than reducing the size of the grid to capture this data. The main deficiency of this method is that the cell size is too coarse to permit the integration of other data sources such as land parcel attributes. This problem can be overcome by the use of small cell referencing techniques devised by BULLOCK (1978c, 1979b) which decrease cell size but do not significantly increase coding time and the size of the data bank.

In the light of recent advances in digitizing and computer graphics technology, it is recommended that polygon methods be used to encode existing resource maps. The advantages of grid cell manipulation and output of data can be achieved by automatically converting the polygon structure to a raster form for these operations (see CRAM, 1974). If computer-based land resource inventories are to involve the simultaneous interpretation and coding of a number of parameters from aerial photographs, then small cell techniques may prove more economical in the long run, than delineation of multi-parameter units and their subsequent digitization.

These recommendations are necessarily subject to future technological developments in the land resource field. The promise of comprehensive and up-to-date data from digital topographic data bases (PENNY, 1975,

1977) and the Landsat satellite (WARNE et al, 1975) may see the eventual disappearance of grid cell and polygon encoding methods. In any case, the Spatial Referencing System must provide for the analysis, retrieval and output of grid based and polygon based data, including facility for raster/vector conversion.

8.6 Conclusions

The preceding review of the spatial referencing requirements of the major land-related subsystems has attempted to identify the unique features of these subsystems with a view to indicating those areas requiring further investigation. It has necessarily been a brief account and its brevity should not be taken to imply that these subsystems are any less important than the LIS. However, it is readily apparent that the utility and services,road and transportation, and census and statistics subsystems are highly dependent on developments in DCDB file creation and operation, and these developments will naturally influence system design in these cases.

9. FINAL CONCLUSIONS

Since LIS theory and practice are still in their infancy in Australia and no truly successful system has yet been developed, this study has necessarily had to rely on reports of Australian and overseas LIS proposals and on an appreciation of existing cadastral arrangements, upon which to base many of its conclusions and recommendations. Nevertheless, within the framework of the conceptual model formulated in chapter 4, several significant conclusions can be made concerning future LIS development in Australia. Specific recommendations and conclusions can be found at the end of each chapter. The most important of these are now reiterated, together with some comments on LIS development generally, and on the role of the surveyor as a land information manager in particular.

The character and function of any cadastral system are a product of geographic, economic, technical, cultural and other factors. This implies that present practices may often result from past needs and environment, and are no longer appropriate to contemporary requirements. It also implies that practices in other countries, irrespective of their success within their own jurisdictions, may not be appropriate to other cadastral systems. Evidence of both of these phenomena has been found in this study.

A corollary to the above is that cadastral systems are dynamic and that they must change to meet the changing needs of society. Cadastral reform should therefore be an ongoing process.

Present cadastral reform measures, designed to improve the efficiency of the existing system, can be made to form the basis of an integrated LIS designed to serve a wide variety of administrative and planning functions of government.

The Torrens Title System provides a sound basis for the introduction of such system in Australia. However, the cadastral survey system does not presently exhibit many of the essential features of an efficient survey system. Reform of the system is a prerequisite for successful LIS development in the long term.

A relaxation of cadastral accuracy standards in proclaimed survey areas, and a greater reliance on existing, visible monumentation can greatly simplify survey practice while still providing boundary security and imparting a degree of finality to the system. A formal recognition of the role of identification surveys is an implicit feature of the proposed reforms.

Similar principles are applied to control network densification, thereby permitting the rapid introduction of proclaimed survey areas.

Large scale (1:5000) cadastral/topographic maps are a sufficient base on which to build a LIS in its early stages. Large scale (1:1000) line mapping will eventually be required if the LIS is to serve all user requirements. These maps will be updated by connection of surveys to control in proclaimed areas.

Problems associated with existing land data systems have stemmed from the functionally oriented data organisation, which has resulted in considerable data duplication and incompatibility. Data base technology has the potential to overcome many of these problems.

The LIS proposed in this study is not an end in itself. It is put forward as one part of the widespread trend towards improved land information management, and is created by integrating existing data sources into a central, readily accessible, non-redundant data source. It is developed as a separate entity within cadastral operations and draws upon that system for its basic data and update mechanisms.

Activities associated with LIS development should be coordinated by a central agency which must be able to enforce conformity within the LIS framework.

Integration is best achieved in stages commencing with the Base File and Central and Peripheral Indexes. The Valuation File, Register of Restrictions and Unregistered Documents File are later enhancements.

The Central and Peripheral Indexes provide access to the LIS via the main reference keys, without disrupting existing systems by imposing a standard identifier. The legal description (plan/lot number) is the most desirable choice of existing identifiers to serve as the primary identifier.

The Spatial Referencing System is designed as an adjunct to the LIS through which all land-related data can be integrated with property-based data contained in the LIS. The System comprises a geographic base file of basic spatial units, and procedures for the retrieval, linkage,analysis, display and updating of these units and the data referenced to them. Boundary, centroid and street segment references must be provided by the System since each basic spatial unit possesses unique characteristics which a flexible system must provide.

The Digital Cadastral Data Base (DCDB) is the best choice for the geographic base file of the Spatial Referencing System, being created as a by-product of an existing process, continually updated through an existing process, eliminating duplication of digitizing effort, and ensuring compatibility of basic spatial units.

It is technically possible to minimise manual effort in the creation of the DCDB files through the separation of spatial and logical data input, and the automatic creation of data linkages by spatial data processing. The structured DCDB files also offer benefits to standard and special purpose cadastral mapping in the areas of map annotation, derived mapping and feature coding.

Due to their dependence on the Spatial Referencing System, the land-related subsystems should be developed under the control of the LIS coordinating agency.

A fully integrated LIS is technically feasible to implement provided existing data sources and administrative procedures are incorporated in the system design. However, the integrated model requires the the sharing of data between different agencies. Loss of control over their data will mean that agencies may be reluctant to participate in LIS development. Institutional problems are likely to be the major inhibiting factors to system development.

The response of the surveying profession to LIS development may determine the future role of the profession and its standing in the community. If surveying is viewed as an information science rather than one of measurement only, then there is considerable scope for the surveyor to be responsible for the analysis and dissemination of the environmental information he collects (McLAUGHLIN, 1975a). Expanding this concept to the LIS proposals, BLACHUT (1976a) has stated:

> "It is the surveyor who is best prepared, by his training and traditional preoccupation with the earth, to assume the responsibility for the coordination of various phases of the project and the molding of it into one operational entity."

The future role of the surveyor as an information manager has been addressed by DALE (1977a) in the following terms:

> "It is suggested that the dilemma facing the land surveyor today is to determine what information he should record for whom, and how he should record and display it. If this diagnosis is correct, the land surveyor is already thinking as a land information manager."

The role of the surveyor as initiator and custodian of the LIS is a challenge which the surveying profession must accept if it is to maintain its professional standing in the community.

APPENDIX A

THE BATHURST DIGITAL CADASTRAL MAPPING PROJECT

A.1 Background

The origins of the Parish map series in New South Wales (N.S.W.) are described in detail in SMAILES (1966). Each map was compiled from individual portion plans without the aid of a control network. Consequently, each map not only contained large scale errors but adjacent Parish maps could seldom be accurately joined (see 2.3). In recent times, considerable effort has been expended in the stabilisation of the cadastral pattern in N.S.W. to form an overlay to the 1:25000 rural topographic series. The difficulty in joining adjacent parish maps (at scales of approximately 1:30000) was eventually overcome by tracing and fitting the existing parish maps to the topographic base map by what has become known as the "let-in" process (URBAN, 1977).

In the early 1970s research was conducted into the digitization and adjustment of the parish series as an alternative means of compiling the standard overlay (ELFICK, 1974). By using one control point per Parish and 2 to 4 pass points (points such as boundary intersections which adjoin adjacent parish maps) and using a least squares transformation technique, accuracies of $\pm$ 15m for cadastral corners were obtained. This accuracy was considered adequate for 1:25000 mapping and was as good as could be obtained by manual plotting methods. However, problems with close parallel lines meant that the plot obtained from the transformed coordinates failed to conform to cartographic standards. Although these problems could have been overcome by smoothing algorithms the new map series so produced would (like the manually produced series) contain any gross errors which may have existed in the Parish map series.

In order to achieve a more rigorous solution to Parish stabilisation, it was decided to use the basic source dimensions from the survey plans in the adjustment process. The survey plan dimensions were input and automatically merged with the digitized coordinates which were used as approximate coordinates for the adjustment. Preliminary results for the Parish of Gill revealed that 80% of the distances (computed from adjusted coordinates) were less than $\pm$ 10cms from the dimensions shown on the survey plans.

Although this research estimated that production times using dimension methods would be significantly less than existing manual methods, later research (CENTRAL MAPPING AUTHORITY, 1977) failed to repeat these promising results. The 1:25000 series was therefore eventually completed by manual methods. URBAN (1977) claims that the main problems with the dimension adjustment approach were:

- the existence of errors in older survey plans
- a lack of connections across rivers and roads
- the sparsity of coordinated cadastral corners as control for dimension adjustment.

A.2 Aims and Results of the Original Project

The original Bathurst project (see BULLOCK, 1978) was begun in 1977 with the primary objective of familiarising the writer with the problems involved in digital cadastral mapping for rural areas. Part of the original Parish map of Bathurst is shown in figure A.1. A data bank of over 200 parcels was created for a test area by digitizing portion of the standard 1:25000 sheet Bathurst 8831-III-S. The project had three main aims:

1. to develop techniques for digitizing rural cadastral maps having regard to the future incorporation of survey plan dimensions
2. to investigate the quality of survey plan dimensions in rural N.S.W. in order to establish criteria for the acceptance of this data for possible dimension adjustment purposes
3. to test assess the feasibility of using plan dimensions in order to produce large scale (1:10000) rural cadastral mapping.

The digitizing procedure (which was area-oriented) was suitable for the hardware used in the project, but would be inefficient if used with modern interactive graphics systems. A superior digitizing method (specifically designed for urban maps) was subsequently developed in the Peakhurst project (see Appendix C). The analysis of survey dimension quality confirmed the generally accepted principle that linear and angular measurements made prior to 1875 were less accurate than those made with the theodolite and band subsequent to that date. However, intermediate data (1850-1875) proved useful for dimension adjustment in small blocks. The results of the dimension adjustment for large scale mapping showed that 80% of the adjusted points were less than 8m different from the true cadastral corners as determined by field survey. The achievable accuracy, however, was almost entirely dependent on the density of cadastral control points. The experiment proved that this technique was feasible and pointed to the

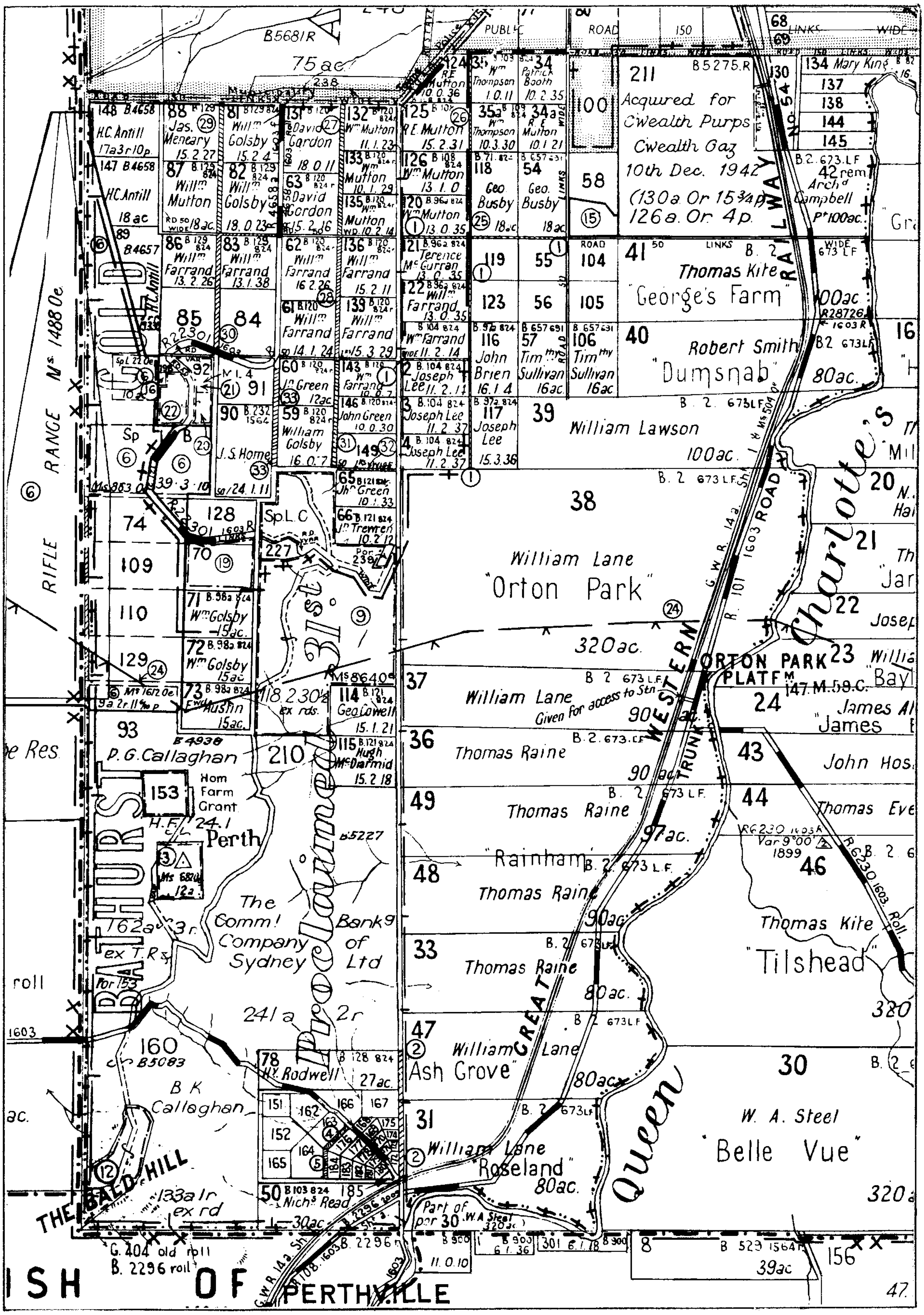


Figure A.1 Section of the original Parish map of Bathurst, New South Wales. Scale 1:25000.

potential of further refinement of the data bank as more and better control became available.

A.3 Aims of the Present Project

The poor quality survey plan data which dominated the original project area meant that it was not possible to verify the earlier work of ELFICK (1974) regarding the comparative cost effectiveness of dimension adjustment for map compilation purposes. A random sample of 10 Parish maps in the eastern division of the State revealed that most of the Parish maps in this region have been compiled from post 1875 surveys, including the Parish of Gill chosen for ELFICK's project. Consequently, a block comprising over half the 200 parcels in the original project area, (and comprising predominantly post 1850 survey data) was chosen for a second experiment designed to determine whether dimension adjustment could produce a significantly better cadastral overlay compared to the "let-in" method for most Parish maps in Eastern Australia. The new project does not attempt to compare the costs and benefits of either method on a production basis. Terminology used in the following definitions of segments, nodes, chain points etc. are defined in chapter 7. As the data bank for the second project was derived from the original data bank, the descriptions of the digitizing, and dimension incorporation procedures are the same for both.

A.4 Digitizing Method

The standard 1:25000 sheet was digitized using the "area-oriented" method (see 7.5). The parcel identifier was input. The corners of each parcel were then digitized in a clockwise direction commencing at the north-west corner. The system automatically determined when each parcel was completed, calculated the number of points comprising the boundary polygon and numbered each point sequentially. Two files were produced:

- a logical or polygon file listing the parcel identifier, number of boundary points and point numbers
- a point file listing the coordinates against each point number.

All coordinate strings comprising complex boundary shapes such as road and river boundaries were automatically identified as chain points and their coordinates stored (unnumbered) in a separate chain file under a unique chain number linked to the appropriate parcel. The file structures used in the original Bathurst project are described in more detail in BULLOCK (1979a). The separation of the chain file from the point file proved to be an essential requirement for efficient processing of the data bank contents.

Once the sheet was digitized, the initial point file was processed to determine those points which had been digitized more than once. Coordinate values were compared and when they agreed to within a specified tolerance, the second value was deleted from the initial point file and the corresponding records in the initial logical file were renumbered accordingly. This process reduced the initial point file from 1453 to 486 point records in the original project. The automatic elimination of redundant points not only reduced the size of the data bank, but also meant that problems with "slivering" (which occur when each parcel is plotted individually to produce a complete cadastral pattern) were eliminated.

The files were then amended in order to correct the obvious digitizing errors. However, visual validation of the plotted data bank contents did not reveal all errors in the parcel/point relationships. A more rigorous solution was achieved by converting the logical polygon file to a segment file and by verifying that each segment (node pair) had a corresponding segment elsewhere in the data bank. Five of the approximately 700 segments in the original project could not be matched in this manner. After manual inspection of the logical file, these errors were detected and the data bank amended. The use of segment-oriented technology for quality control of parcel boundary digitizing has been suggested elsewhere (WHITE, 1977).

In order to satisfy cartographic production requirements for minimising plotting time, the logical file was again converted to a segment structure and processed in order to automatically implant the pen commands needed to correctly plot the pattern in the most efficient manner. Segments were again systematically matched and redundant segments eliminated to avoid replotting of the same segment. The resulting plot file was then automatically compacted to minimise the number of pen-up commands.

A.5 Incorporation of Dimensions

Bearings and distances for each parcel were entered clockwise for each parcel commencing from the north western corner of the parcel (as in the digitizing phase). Selection of the same starting point proved straight forward to all but two of the 200 cases in the original data bank. The boundary misclose was used as a check on the data input. A comparison of the calculated area with the grant area stated on the survey plan provided an additional check on the older survey plans whose dimensions were difficult to read.

Since dimension input mirrored the digitizing procedure, the logical file provided a framework for the automatic matching of dimensions to node numbers. In order for the polygon and dimension files to be merged, it was necessary to determine whether each node pair in the polygon file comprised one dimension only, or whether they comprised only part of the dimension segment for that parcel. Figure A.2 shows this case more clearly where (because the adjacent parcels have been separately surveyed) point 206 does not form part of a dimension segment for parcel 54. These nodes were detected automatically by comparing each distance with an approximate distance computed from the digitized coordinates. River traverses, road boundaries and other complex coordinate strings in the chain file were replaced by a single bearing and distance for adjustment purposes. The logical file and dimension files were automatically merged to produce a dimension/segment file. This file was then processed to create a file of angles and a file of distances. Angles were chosen in preference to directions because each survey was based on a different orientation. These files were then formatted for input to a standard geodetic least squares survey adjustment program.

Prior to the adjustment, distance segments for adjacent parcels were automatically matched as a check on the consistency of the dimension data. Differences in distances for the same segment arose as a result of different dates of survey for adjacent parcels. The older survey dimension was automatically deleted. However, in 2 cases in the new test area, significant differences were found for adjacent parcels with the same date of survey. Inspection of the original survey plans revealed that the common node of these two connected segments (represented as the same point on the standard 1:25000 sheet) was in fact two separate corners. Points 306 and 307 in figure A.2 display this case more clearly. The data bank was amended for both cases.

A.6 The Adjustment

For the purposes of adjustment, roads were treated as parcels in order to:

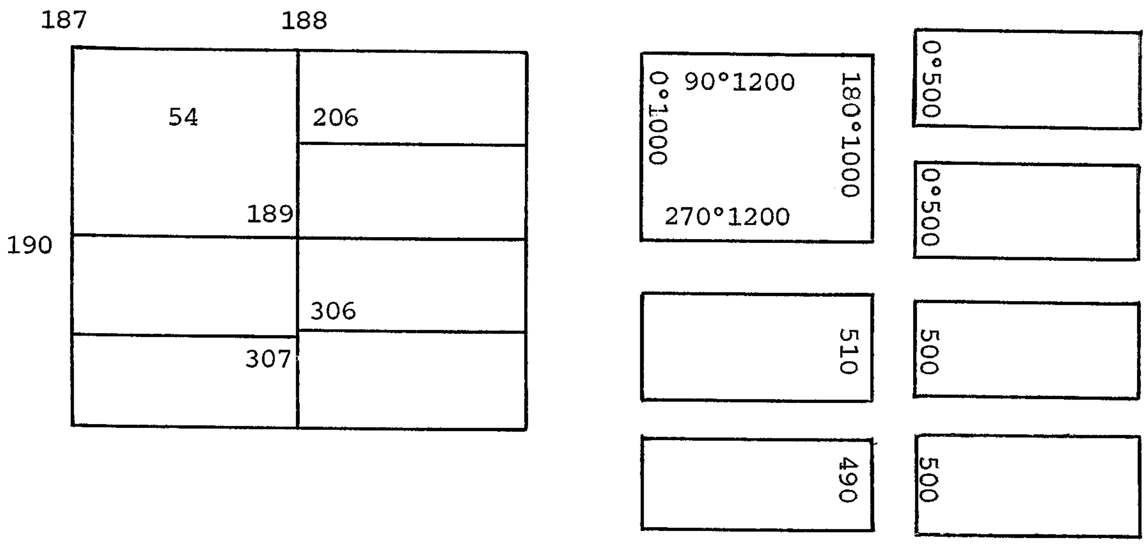


Figure A.2 Anomalies in logical file revealed by dimension incorporation.

- efficiently enter road widths into the data bank in the same manner as land parcels
- to ensure that road boundaries would be kept parallel after adjustment by entering the internal angles of the road parcel.

In order to minimise the effect of short distances in the adjustment, 10m width lanes were incorporated into adjoining parcels prior to adjustment, and reconstituted after adjustment.

Attaching variances to each measurement required a subjective assessment as to the quality of the measurements. A considerable portion of the second test area comprised survey plan data of the 1850-1875 era (see figure A.3). In the original Bathurst experiment, tests were conducted to determine the quality of this intermediate data. Angles and distances from three separate blocks of these older parcels were adjusted to control corners (whose coordinates were determined by field survey to $\pm$ 0.2m) using least squares techniques. The results of the adjustment showed that 80% of the angle corrections were less than 5 minutes of arc, while 80% of the distances were understated by a factor of 0.25%. The size of the angle corrections are consistent with the instrumentation in use prior to the introduction of the theodolite around 1875. The understating of distances was common practice in many early surveys in New South Wales in order that the calculated area of the parcel as surveyed would not exceed the acreage authorised by the grant order (HALLMANN, 1973). A direct comparison of 60 boundary distances extracted from recent subdivision plans with their corresponding grant distances yielded a similar result. Distances from the pre 1875 surveys were therefore scaled by a factor of 1.0025. The angles and distances were then allocated variances derived automatically from the dates of survey which were also input to the dimension file. To preserve the quality of the post 1875 dimensions, their variances were set at approximately zero.

For the purposes of adjustment the new test area was divided into two blocks as depicted in figure A.3. Control for the adjustment was obtained by digitizing fence intersections depicted on the standard 1:10000 orthophotomaps covering the area (Bathurst P-4597 and Perthville P-4590). In order to obtain a close approximation to the true cadastral corner, the criteria for selection of fence intersections were that they be:

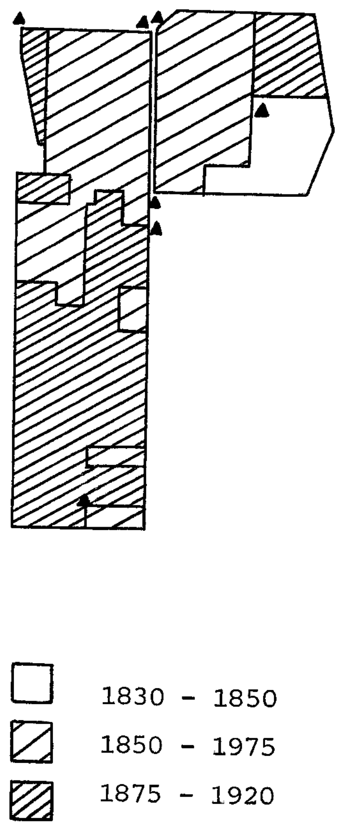


Figure A.3 Age distribution of survey plan data over the test area and control used for the adjustment of the two blocks of survey data.

- high contrast points on the orthophotomap
- on public road boundaries
- on or near the boundary of the block.

As figure A.3 shows, the last two requirements have been met. Comparison of these control points with fence corner coordinates derived from field survey indicated that the accuracy of this control was approximately ± 6m. The control was therefore comparable to that which would be derived by digitizing fence intersections from the stereo model used to produce the 1:25000 topographic map. Additional field survey would therefore not be required to establish this control.

A.7 Results

The relative merits of the methods of digitizing and dimension incorporation used in the experiment are discussed in BULLOCK (1979a). The most significant results of the original Bathurst experiment were the development of techniques for:

- the automatic validation of data bank structure and content by segment processing of digitized data
- the automatic derivation of plotting commands to avoid over-drawing, gaps and overlaps, and to minimise plotting time
- the automatic comparison of distances to detect misinterpreted points on the Parish or standard map.

A comparison of the accuracies of the manual/graphical and dimension adjustment methods follows.

Figure A.4 shows the cadastral pattern produced by the "let-in" process overlayed on the true cadastral boundaries as determined by field survey. Both are referenced to the Australian Map Grid. Only recent subdivision plan data was used to accurately coordinate the original Crown grant (portion) boundaries depicted on the Parish and standard map. The accuracy of these true corners is estimated to be ± 1m.

The "let-in" pattern clearly does not satisfy National Mapping Accuracy Standards which demand that 90% of all points tested should not be in error by more than 0.5mm at map scale. In addition to a general displacement of 25m in the eastings, the manually compiled overlay contains:

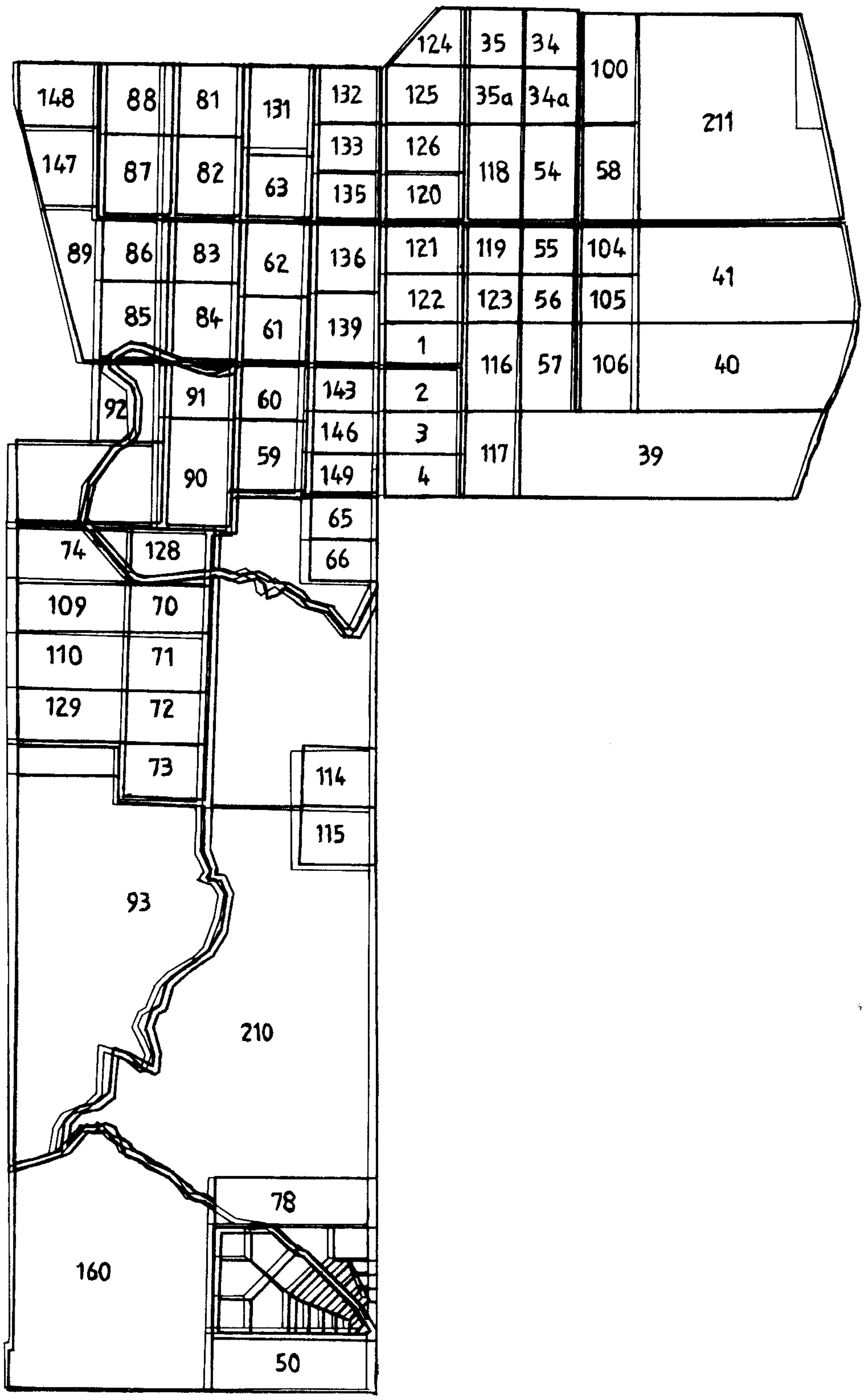


Figure A.4 Cadastral pattern produced from the "let-in" process (heavy) overlayed on the true cadastral boundaries as determined by field survey and recent subdivision plan information.

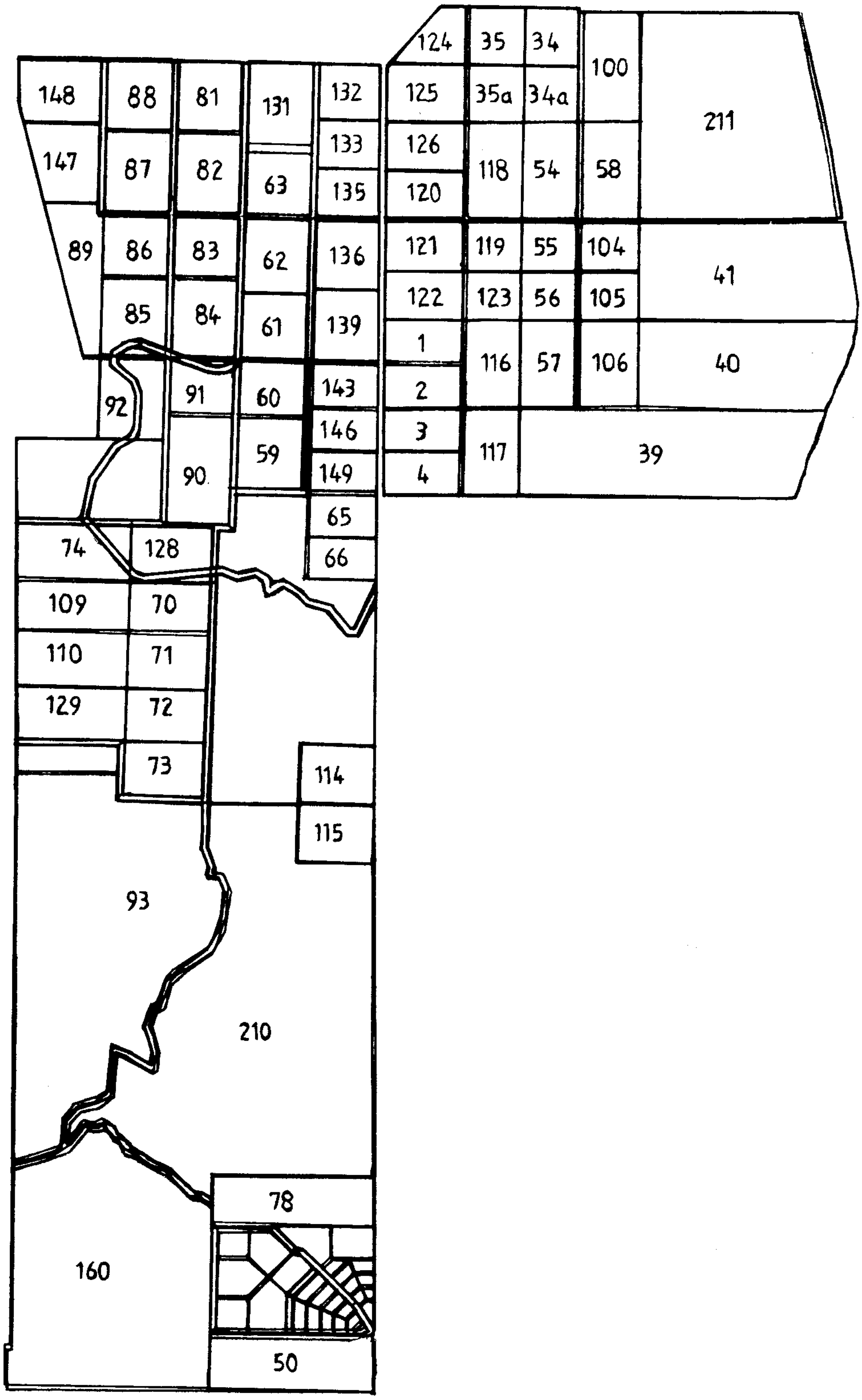


Figure A.5 Cadastral pattern plotted from the adjusted coordinates (heavy) overlayed on the true cadastral boundaries as determined by field survey and recent subdivision plan information.

- 50m errors in the eastings of the road separating portions 88 and 81 which has apparently been incorrectly plotted from the original Parish map
- 50m errors in the eastings of several boundaries in the central region of the western block which the orthophoto reveals is probably due to a lack of clear fence corners to serve as control for the "let-in" process.

Figure A.5 shows the cadastral pattern plotted from the adjusted coordinates overlayed with the true cadastral boundaries as determined by field survey. The almost perfect agreement between the two cadastral patterns at this scale would seem to indicate that the incorporation of survey plan dimensions (including selected pre 1875 dimensions) and their adjustment to judiciously selected cadastral fence corners, can be used to overcome the inherent deficiencies of the manual "let-in" process, namely:

- plotting errors in transferring Parish map detail to the topographic base
- plotting errors caused by the lack of visible fence lines for control in certain areas.

The use of selected fence corners as control for the adjustment method can therefore overcome the main objections to the earlier attempts at dimension adjustment, namely, the lack of sufficient cadastral control and the lack of connections across rivers and roads. Procedures employed in the Bathurst project can also detect and eliminate errors in the older survey plans. These factors (together with the dynamic nature of a data bank which includes dimensions) suggest that the use of dimensions in a digitized data bank to produce rural cadastral overlays, should be investigated further as to its cost-effectiveness compared to current manual methods.

APPENDIX B

SPATIAL REFERENCING SYSTEMS

Figures B.1 and B.2 depict the file structures and file interaction of two of the most successful segment-oriented referencing systems:

TRAMS : Transportation Referencing and Mapping System of the Transport and Road Research Laboratory, Crowthorne.

NIMS : Network based referencing of the Nordic Institute of Municipal Planning.

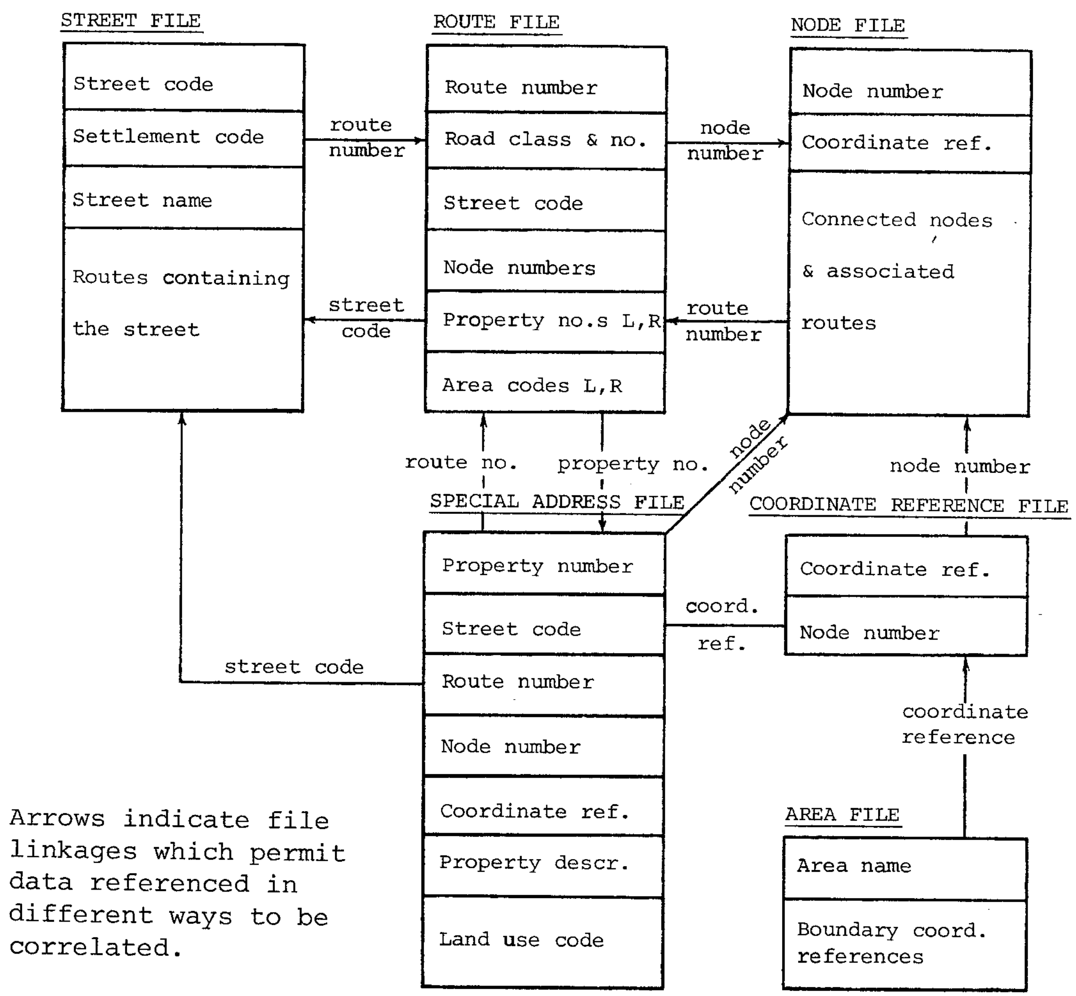


FIGURE B.1 Relationship of TRAMS (Transportation Referencing and Mapping System) files (after BURR, 1977 and WILLIS, 1978).

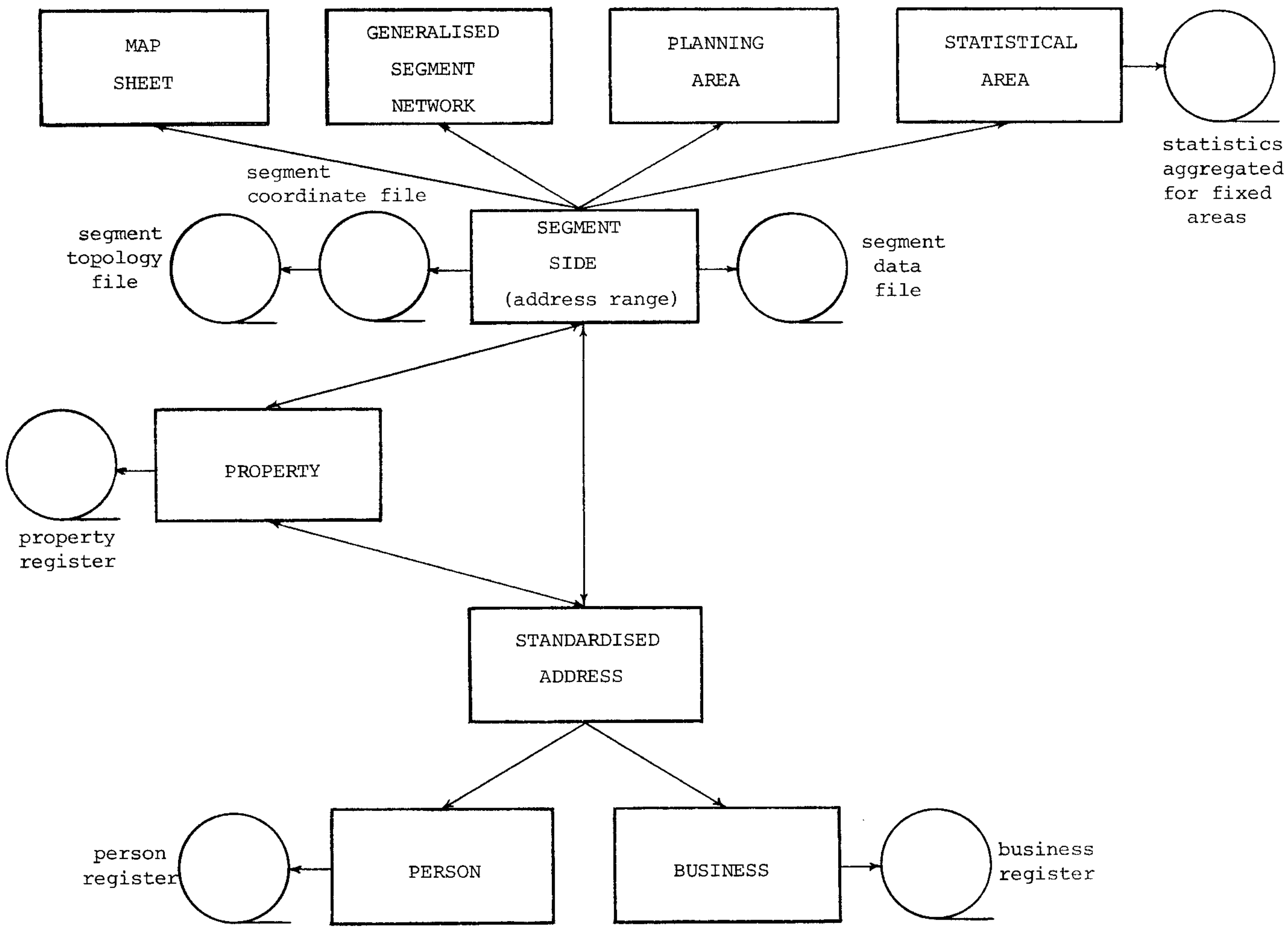


FIGURE B.2 Conceptual model of NIMS (network based referencing system of the Nordic Institute of Municipal Planning) showing linkages between the basic spatial unit (street segment side) and the basic data units and their associated data files (after SALOMONSSON, 1977).

APPENDIX C

THE PEAKHURST DIGITAL CADASTRAL DATA BASE PROJECT

C.1 Aims

The Peakhurst project was begun in late 1981 to partially test the digitising procedure developed in 7.5.2 for the creation of the Parcel Polygon and Centroid file of the proposed Digital Cadastral Data Base (see figure 7.4). The digitizing procedure is described in detail in 7.5.2 and comprises 9 main stages (see figure 7.6):

1. selection and initialisation of the cadastral map sheet
2. digitization of block boundaries
3. digitization of internal boundaries
4. automatic creation of parcel boundary node file
5. automatic formation of parcel polygons
6. calculation of centroid coordinate
7. calculation of address point
8. linking of the parcel identifier to the parcel polygon record
9. automatic linking of parcels to street segment sides.

The digitizing procedure has several special features which were designed to minimise manual effort in data capture and make the method more acceptable to cartographic agencies. Firstly, the method was line-oriented in order to minimise digitizing time. Secondly, the data linkages between

- the coordinates forming the parcel
- the parcel and its identifier
- the parcel and other basic spatial units

were created automatically by the processing of the spatial data and of the topology implicit in the digitizing procedure. Thirdly, the data files created by the procedure can be processed to perform several traditionally manual tasks, for example, the placement of a parcel and street name annotation.

The following sections describe several of the automatic processing techniques used to perform these tasks. The success of these techniques is discussed in 7.5.2. A section of the standard 1:4000 urban map sheet Peakhurst N.S.W. UO037-3 (see figure C.1) was chosen to partially test the digitizing procedure and the processing techniques. A total of 622 parcels were digitized. The area was selected as being typical of the urban cadastral pattern in most Australia cities but does not contain the characteristic cul-de-sacs and curved street alignments

FIGURE C.1 Test area for cadastral digitization experiment:
Section of the PEAKHURST N.S.W. U0037-3 1:4000 map sheet.

of more recent subdivision designs. Such features tend to lower the efficiency of the procedure and complicate some processes but it is considered that the techniques are also valid for these cases as well.

C.2 Creation of the parcel boundary node file

Although 7.5.2 suggests how digitized boundary line data may be automatically broken into segments, the parcel boundary node file was formed manually in the Peakhurst project.

The node file lists (for each node) the nodes connected to it. Psuedo nodes were introduced in the project to ensure that all boundary segments (including chain point strings) could be uniquely identified. The relatively small number of these cases (only 3 of the almost 1900 boundary segments required pseudonodes to remove this ambiguity, excluding those cases at the border of the test area) indicates the suitability of this technique for DCDB creation in preference to allocating a unique identifier to each segment in addition to the node pair it contains.

C.3 Formation of parcel polygons

The node file was processed to determine the nodes defining each parcel polygon which are then listed in clockwise order in the Polygon File. The procedure used was as follows. Each street frontage segment on the block boundary was selected as the first two nodes of the parcel polygon. Subsequent segments were selected by computation of the anti-clockwise angle from the preceeding segment to all other segments emanating from the node as listed in the node file. The smallest of these angles indicates the required segment (see figure (i)). The process is continued until the commencing node is reached. This procedure was successful for all parcels in the test area.

C.4 Calculation of centroid and address point coordinates

Centroid coordinates were computed for each parcel using a non-rigorous algorithm based on a routine devised by MAGGS (1973). The Parcel Polygon file was processed to determine the extremities of the parcel in the easting (see figure (ii)). The mean easting was taken as the easting coordinate of the "para-centroid". The northing of the para-centroid was computed as the mid-point of the segment formed by the intersection of the mean easting line with the parcel boundaries. No provision was made in the algorithm for this mean line cutting the

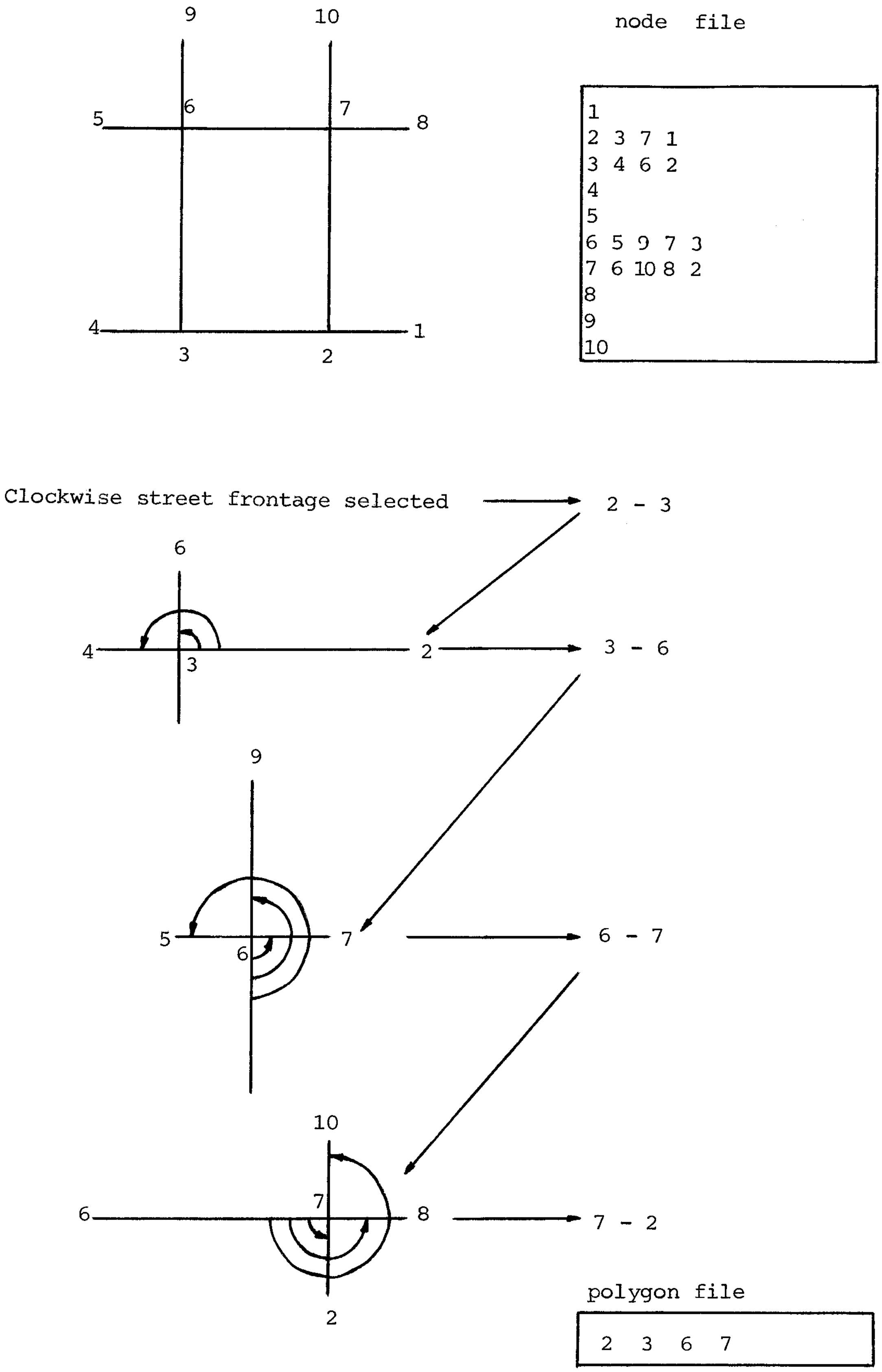
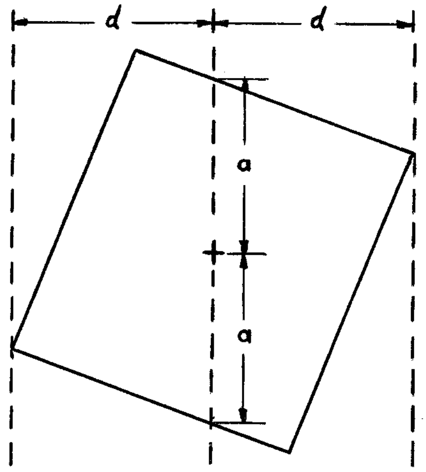
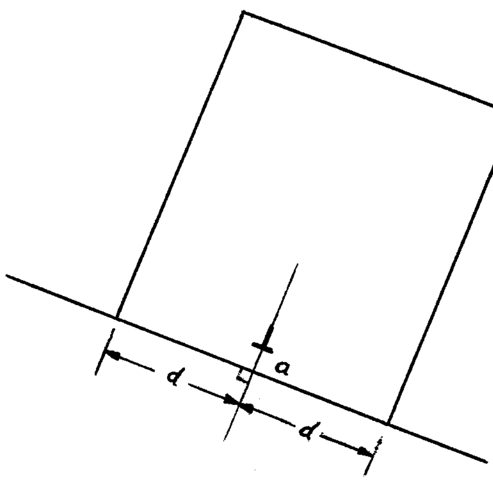


FIGURE (i) Automatic formation of parcel polygon by the computation of internal angles.



centroid



address point

FIGURE (ii) Geometry of algorithms used to compute centroid and address point coordinates for each parcel.

parcel in more than two places. As most parcels were rectangular or near-rectangular in shape, this assumption did not seriously detract from the performance of this technique, and only 4 of the 622 parcels could not be given a satisfactory centroid coordinate by this method. Figure C.2 displays the excellent results obtained by this method, particularly from the point of view of automatic placement of parcel annotation. A coordinate for the placement of the house number was also computed by taking the mid-point of the street frontage segment and off setting the position a fixed distance (4 m) from, and at right angles to, the frontage (see figure (ii)). The orientation of each computed position was checked to ensure that annotation was not written upside down. The results of these computations are shown by the (⊥) symbol in figure C.2 which also indicates the orientation of the text. Satisfactory results were obtained for 88% of all parcels.

C.5 Linking of parcels to street segment sides

Parcels were linked to the street segment by processing of spatial data.

A path search was conducted around each street segment with a width of 15m either side of the segment. Those parcels whose frontage mid point lay within each side of the path section were allocated to that segment side (see figure (iii)). 88% of all parcels were uniquely allocated to one segment side. If processed in conjunction with a street address/ parcel identifier file, automatic allocation would have been successful for 99% of cases. For each segment side, parcel identifiers were automatically arranged in sequence along each segment in the direction implied by the street segment file by computing distances from the starting node to the frontage mid point (see figure (iii)). All parcels which could be allocated to a unique segment side were correctly arranged by this technique.

C.6 Automatic street name placement

A digitized street segment file was created in the project (see figure C.3) to test the applications of such a file for the automatic placement of street names. Processing of the street segment file for this purpose was based on the assumption that the node string listed in the file was digitized in the general left to right direction of the street names depicted on the original map sheet (see figure C.1). This order is recommended for the DCDB street file (see figure 7.5).

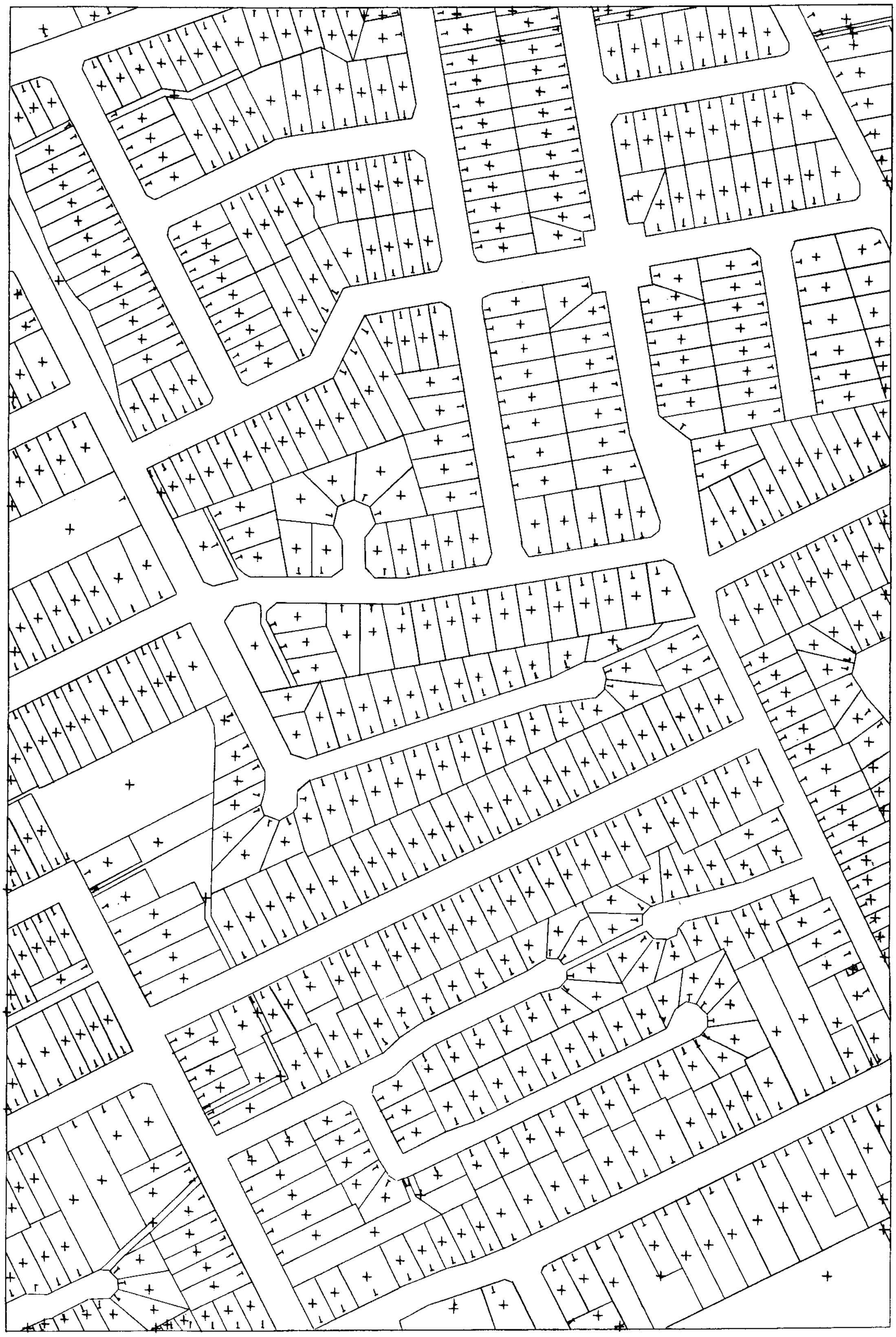
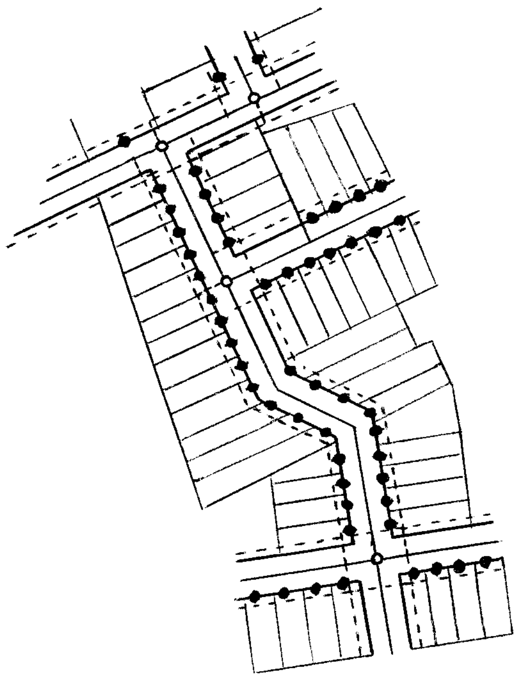


FIGURE C.2 Automatic placement of parcel identifier annotation computed from the parcel polygon file. Parcel centroid (+) parcel address point (⊥).



- ● street frontage mid point
- o street segment node
- \- - - - limit of path search

FIGURE (iii) Automatic linking and arrangement of parcels to street segment sides by path search of frontage mid points.

FIGURE C.3 Street segment network digitized for automatic street name placement.

The main criteria for the placement of the name and type of street was that neither should straddle a street intersection. As well, names and/ or type were to be written between consecutive nodes or along straight lines only. Therefore, the placement algorithm was not designed to annotate curved streets or sections of streets, although all chain points were processed in the allocation procedure. The procedure involved the following steps:

- calculation of total street length from street node coordinates
- calculation of length of street name and type from the number of letters in each
- determination of whether the street name and type could be written within the total length (including abbreviation of street type if necessary)
- single segment streets were annotated by placing street name and street type a fixed distance from either end
- streets with more than one segment were processed segment by segment from either end to determine whether the required text could be placed within the segment (including abbreviation of street type if necessary).

Selection of segments was dependent upon the orientation of each segment as well as their length. The only streets which failed all placement criteria were those comprising short segments only (e.g. Price Avenue in Figure C.1) and those truncated streets at the edge of the test area. The results of this process are depicted in figure C.4.

C.7 Conclusions

The Peakurst project has proven, for a selected area, the feasibility of the automatic processing of logical data in DCDB file creation (with the exception of the automatic creation of parcel boundary segments). Success rates for each process are described in detail in 7.5.2. It is readily apparent from the results of the project that the generally uniform shape and size of the cadastral parcel in urban areas permits the use of relatively simple algorithms to create necessary data linkages. The uniformity of the cadastral pattern is also partly responsible for the cartographically acceptable results for the automatic placement of map annotation.

FIGURE C.4 Automatic placement of street name annotation computed from the digitized street segment network.

It would be expected that similar satisfactory results would also be achieved for more complex patterns through the use of more sophisticated algorithms. Finally, the fact that no procedure yielded perfect results does not detract from the superiority of automatic processing over current manual methods. Data linkage processing is self checking and identifies those linkages not successfully established; while automatic text placement will always require some form of human intervention to amend the few cases which are not visually satisfactory. The fact that annotation in future digital mapping systems will need to be a dynamic process (particularly in derived and special purpose mapping) makes automatic methods even more attractive.

REFERENCES AND BIBLIOGRAPHY

AANGEENBRUG, R.T. 1973. "Theoretical and Practical Constraints of a Geographic Base File", in MOYER, D.D. and FISHER, K.P. Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

AANGEENBRUG, R.T. 1980. Review and Panel Session. 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

ALLAN, A.L. 1975. "Integrated Surveys in an Urban Area with Special Reference to London", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

ALLRED, C.K. 1975. "Notes from Alberta", Canadian Surveyor, Vol. 29, No. 3, 350-351.

ALMY, R.R. 1977. "Cadastres in Property Tax Administration", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

ANDERSSON, A. 1971. "Maps and Map-Information in a New Computer System for Real Estate Data", International Yearbook of Cartography, 11, 264-273.

ANDERSSON, S. 1974. "The Swedish Land Data Bank", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

ANDERSSON, S. 1975. "Main Characteristics of the Land Records System in Sweden", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

ANDERSSON, S. 1977. "Land Information System in Sweden", Proceedings of the 15th International Congress of Surveyors, Stockholm.

ANDRECHECK, B.T. 1972. "City of Ottawa Underground Public Utilities Central Registry", Canadian Surveyor Vol. 26, 541-544.

ANDREWS, G.S. 1966. "Integrated Surveys in British Columbia", Canadian Surveyor, Vol. 20, No. 2, 73-83.

ANGUS-LEPPAN, P.V. 1967. "Land System Reforms in Canada and Their Possible Application in Australia", Australian Surveyor, Vol. 21, No. 7, 213-220.

ANGUS-LEPPAN, P.V. 1968. "Plane Coordinate Systems in Surveying", Australian Surveyor, Vol. 22, No. 3, 185-197.

ATKEY, R.G. and GIBSON, R.J. 1975. "Progress in Automated Cartography", Proceedings of the Commonwealth Survey Officers Conference, Cambridge.

AUDRIAC, H. 1976. "Photogrammetry as Applied to Large Scale Mapping", Paper presented at the Pan American Meeting of Integrated Surveys & Development of Countries, Bogota.

AUSTRALIAN BUREAU OF STATISTICS, 1969. "Australian Standard Industrial Classification", Volumes I and II, Australian Bureau of Statistics.

AUSTRALIAN GOVERNMENT, 1978. "The Cost of Housing", Report of the Committee of Inquiry into Housing Costs, Volume 3, Australian Government Publishing Service, Canberra.

AUSTRALIAN LAW REFORM COMMISSION, 1979. "Privacy and the Census", Australian Law Reform Commission, ALRC 12.

AYERS, E.H. 1975. "Where Do We Go From Here?", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

BACKER, J.M. 1967. "Regional Planning", Paper presented at the Tri-State Conference on a Comprehensive, Unified Land Data System (CULDATA), University of Cincinnati.

BARB, C.E. 1971. "Rocky Road to 1980; A Scenario of the Future of Automated Geocoding Technology to 1980", Paper presented at the 9th Annual Conference of the Urban and Regional Information Systems Association (URISA).

BARB, C.E. 1974. "Task of Institutionalizing Local Geocoding Systems", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

BARNES, S.R. 1980. "The Current Situation in the Development of Management Information Systems in the United Kingdon Local Authorities with Reference to the Co-ordination between Different Levels of Government", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

BARRETT, M.M. 1971. "Boundary Surveys on Registered Land in England and Wales", South African Survey Journal No. 78, Vol. 13, Part 3, 36-44.

BARRETT, M.M. 1973. "Correspondence: Cadastral Boundary Disputes", Survey Review, Vol. 22, No. 170, 183-184.

BARRETT, S.M. 1972. "Department of Environment Manual on Point Referencing", Proceedings of the 2nd Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, London.

BARRIE, J.K. 1976. "The Surveying Profession in Australia - A Personal Interpretation of its Historical Development, Current and Future Trends:, Australian Surveyor, Vol. 28, No. 1, 6-56.

BARRIE, J.K. 1977. "Land Registration and Boundary Surveys", Australian Surveyor, Vol. 28, No. 5, 256-262.

BARRIE, J.K. 1978. "Letter to the Editor, Land Registration and Boundary Surveys", Australian Surveyor, Vol. 29, No. 2, 129.

BARWINSKI, K. 1975. "Modern Cadastre in a Highly Developed Country", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

BASSIAKOU, P. 1977. "An Integral Cadastral Information System, as Tool for Planning and Administration", Proceedings of the 15th International Congress of Surveyors, Stockholm.

BASTIAN, K. 1980. "Development of a Real Estate-Oriented Information System in Rural and Urban Regions", Proceedings of the 9th United National Regional Cartographic Conference for Asia and the Pacific.

BATHKE, W.L. and CARTER, R.S. 1973. "Geocoding and the Urban Environment, New Approaches", in MOYER, D.D. and FISHER, K.P. Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

BATHKE, W.L. 1975. "Basic Elements in the Planning of a New Land Record System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

BAXTER, R.S. 1972. "The Management of Data and the Presentation of Results from a Compterised Information System", in PERRATON, J. and BAXTER, R.S. (Eds) Models, Evaluations and Information Systems for Planners, MTP Construction, Lancaster.

BAXTER, R.S. 1976. "Computer and Statistical Techniques for Planners", Methuen, London.

BAYLISS, R.V. 1958. "The Coordination of Cadastral Surveys in the State of N.S.W.", Australian Surveyor, Vol. 17, 112-113.

BEAMAN, J. 1969. "A Data Bank for Use in the Social Sciences", Canadian Surveyor, Vol. 23, No. 2, 104-110.

BECKER, P.C. 1974. "The Rise and Fall of the Master Parcel File", Paper presented at the 12th Annual Conference of the Urban and Regional Information Systems Association, Montreal.

BELL, S.G.M. and BICKMORE, D.P. 1975. "Interactive Cartography at the Experimental Cartography Unit - Regional Geography A La Mode", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

BELLAMY, J. 1976. "A Computer-Controlled Plan Plotting System: SPAD", Metropolitan Water Sewerage & Drainage Board, Sydney.

BICKMORE, D.P. 1967. "The Oxford Cartographic Data Bank", Proceedings of the Conference of Commonwealth Survey Officers, Cambrdige.

BICKMORE, D.P . 1968. "Cartographic Data Banks", Proceedings of the 12th International Congress of Surveyors, London.

BICKMORE, D.P. 1971. "Experimental Maps of the Bideford Area", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

BINNS, B.O. 1953. "Cadastral Surveys and Records of Rights in Land", F.A.O. Agricultural Series No. 18, 14, Rome.

BLACHUT, T.J. 1969. "Technical and Organizational Problems in Urban Surveying and Mapping", Canadian Surveyor, Vol. 23, No. 4, 409-419.

BLACHUT, T.J. 1971 a. "Mapping and Photointerpretation System Based on Stereo-orthophotos", NRC 12281, National Research Council of Canada, Ottawa.

BLACHUT, T.J. 1971 b. "Role of Urban Surveying and Mapping", Plan Canada, Special Issue, 25-32.

BLACHUT, T.J. 1973. "Cadastre as a Basis of an Integrated, General Land Survey of the Country", National Research Council of Canada, Ottawa.

BLACHUT, T.J. 1975 a. "Introduction to the Conference on the Concepts of a Modern Cadastre", Canadian Surveyor, Vol 29, No. 1, 5-8.

BLACHUT, T.J. 1975 b. "What Constitutes a Land Records System - a Cadastre?",Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

BLACHUT, T.J. 1976 a. "Some Reflections on Survey Disciplines in the Context of the Present Development and Requirements of Society", Canadian Surveyor, Vol 30, No. 1, 3-10.

BLACHUT, T.J. 1976 b. "Stereo-orthophoto Technique in Cadastral and General Integrated Large Scale Mapping", Paper presented at the Pan American Meeting of Integrated Surveys and Development of Countries, Bogota.

BLACHUT, T.J., CHRZANOWSKI, A. and SAASTOMOINEN, J.H. 1979. "Urban Surveying and Mapping", Springer-Verlag, New York.

BLACK, S.M. 1972 a. "Overview Sweden", BURISA Newsletter, December Issue.

BLACK, S.M. 1972 b. "Urban Data Management: A Danish Feasibility Test", Proceedings of the 2nd Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, London.

BLACK, S.M. 1974. "Comparative Review of Geocoding Methods", Proceedings of the 4th Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, Madrid.

BLACKIE, W.V. 1975. "The Ottawa Conference on Concepts of Modern Cadastre", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

BLEANEY, J.H. 1975. "Geographic Data for Engineering Purposes", Canadian Surveyor, Vol. 29, No. 1, 104-113.

BOGAERTS, M.J.M. 1977 "Land Data Systems", Proceedings of the 15th International Congress of Surveyors, Stockholm.

BOGDAN, W.H. 1972. "Large-scale Urban Mapping Techniques Within Survey Control Areas in Alberta", Canadian Surveyor, Vol. 26, No. 5, 510-530.

BÖHME, R. 1972. "Automatic Processing of Road Data for Map Revision", International Yearbook of Cartography, 12, 112-123.

BOYLE, A.R. 1981. "Digitizing and Encoding of Spatial Data", in MARBLE, D.F. (Ed) Background Materials for Workshop on Specification and Design of Geographic Information Systems, University of New South Wales, Sydney.

BRAASCH, H.W. 1975. "The Arrangement of Numerical Cadastral Data in a Modern Cadastre of Land Holdings", Canadian Surveyor, Vol. 29, No. 1, 39-48.

BRADY, R. 1974. "Computers in Planning and Management: A Demonstration", Proceedings of the 4th Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, Madrid.

BRADY, R. 1978. "The Development and Implementation of a Data Base for Management at the City of Sydney", Proceedings of the 6th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

BRADY, R. 1979. "Data Management Systems for Government with Particular Reference to the MAPS Element", Paper presented at the Seminar/Workshop on Geographical Information Systems, Canberra.

BRIDGE, R. 1980. "Computer Graphics in Spatial Analysis : A Transportation Planning Viewpoint", Proceedings of the 6th Australian Cartographic Conference, Hobart.

BRIDGES, B. (Chmn) 1981. "Report of the Enqiury into the Development of a Digital Cadastral Data Base for South Australia", Digital Cadastral Data Base Steering Committee, Department of Lands, South Australia.

BROCKLEBANK, R.A. 1966. "The Use of Photogrammetry in Integrated Surveys", Canadian Surveyor, Vol. 20, No. 2, 66-72.

BROCKLEBANK, R.A. 1971. "Urban Maps", Plan Canada, Special Issue, 51-56.

BUCHLER, S. 1974. "Automation of Land Inventory in Israel", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

BUTLER, C.A. 1971. "Cadastral Surveys by Photogrammetry", Proceedings of the 14th Australian Survey Congress, Hobart.

BULLOCK, K.R. 1978 a. "An Introduction to the 'Land Information System' Concept in Australia", UNISURV G28, 59-75, 1978.

BULLOCK, K.R. 1978 b. "Cadastral Data Bases: Some Suggestions As To Their Future Role in Mapping and Spatial Referencing in Australia", Proceedings of the 6th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

BULLOCK, K.R. 1978 c. "Application of a Small Cell Geocoding Method to the Bathurst-Orange Land Resource Inventory", Proceedings of the 6th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

BULLOCK, K.R. 1979 a. "Automated Cadastral Mapping Project for Bathurst", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

BULLOCK, K.R. 1979 b. "Statistical Analysis of the Bathurst Small Cell Land Resource Data Bank", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

BULLOCK, K.R. 1980. "Legal Implications of a Coordinate Register", Proceedings of the 22nd Australian Survey Congress, Hobart.

BURR, M. 1977. "TRAMS: West Midlands", Newsletter of the British Urban and Regional Information Systems Association, BURISA 30, 12-14.

BYATT, P.W. 1976. "Investigations into the Geocoding of Census Data", Proceedings of the 4th Australian Conference on Urban and Regional Planning Information Systems, Melbourne.

BYLANDER, R. and NILSSON, A. 1977. "The Swedish Road Data Bank and its Use in Road Planning", in WASTESSON, O. (Ed), Computer Cartography in Sweden, York University, Canada.

CALKINS, H.W. 1967. "Ottawa Street Address Conversion System", Highway Research Record No. 194, Highway Research Board, Washington, D.C.

CATER, E. 1972. "Computerized Information Systems for Planners", in PERRATON, J. and BAXTER, R.S. (Eds) Models, Evaluations and Information Systems for Planners, MTP Construction, Lancaster.

CARLIN, C.B. 1972. "Property Identifiers for the Maritime Provinces of Canada", in MOYER, D.D. and FISHER, K.P. Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

CARLIN, C.B. 1974. "Computerization of Land Records in the Maritime Provinces of Canada, Cincinnati Law Review, Vol. 43, No. 3, 487-512.

CENTRAL MAPPING AUTHORITY 1972. "Basic Cadastral Mapping: Computation of Mapping Coordinates", Central Mapping Authority of New South Wales, Bathurst.

CENTRAL MAPPING AUTHORITY 1977. "Report on Experimental Adjustment of a Basic Cadastral Pattern, Glenrock 9134-I-S", Parts I and II, Central Mapping Authority of New South Wales, Bathurst.

CENTRAL MAPPING AUTHORITY 1980. "Application of Orthophoto Maps in the Development of a Visual Register of Land Title in New South Wales", Proceedings of the 9th United Nations Regional Cartographic Conference for Asia and the Pacific.

CHAPIN, F.S. 1965. "Urban Land Use Planning" Second Edition, University of Illinois Press, Urbana, Illinois.

CHATTERTON, W.A. 1976. "The Real Property System in Crisis", Proceedings of the Lands Records Symposium, University of Maine at Orono.

CHATTERTON, W.A. and McLAUGHLIN, J. 1975. "Towards the Development of Modern Cadastral Standards", Proceedings of the North American Conference on Modernization of Land Data Systems. Washington, D.C.

CHRZANOWSKI, A. and DORRER, E. (Eds) 1977. "Proceedings of the Workshop on Standards and Specifications for Integrated Surveying and Mapping Systems", Munich.

CHRZANOWSKI, A. 1972. "A Model of a Horizontal Control Network for Integrated Urban Surveys", Canadian Surveyor, Vol. 26, No. 5, 504-507.

CHRZANOWSKI, A. and STEEVES, P. 1976. "A New Technology in Control Surveys in Urban Areas", Paper presented at the Pan American Meeting of Integrated Surveys and Development Countries, Bogota.

CLAPP, J.L. and EPSTEIN, E.F. 1976. "Concepts of a Multi-purpose Cadastre: Problems of Design and Implementation", Proceedings of the Land Records Symposium, University of Maine at Orono.

CLAPP, J.L., CHATTERTON, W.A., EPSTEIN, E.F. and NIEMANN, B.J. 1977. "Incremental Implementation of a Modern Multi-purpose Cadastral System", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

CLARK, T.M. and WOODHAM, C.A. 1974. "Cadastral Surveys by Photogrammetry", Proceedings of the 17th Australian Survey Congress, Melbourne.

CLAWSON, M. 1965. "Land Use Information: A Critical Survey of U.S. Statistics Including Possibilities for Greater Uniformity", John Hopkins, Baltimore.

COLLIER, A.J. 1978. "Brisbane City Council Land Information System", Proceedings of the 6th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

COOK, B.G. 1975. "A Computer Data Bank in a Regional Land Use Study", Proceedings of the 3rd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

COOK, B.G. 1976. "Land Resource Information Systems: Use and Display", Paper presented at the ISSS Workshop on Information Systems for Soil and Related Data, Canberra.

COOK, B.G. and JOHNSON, B.V. 1973 a "A Computer Data Bank for Regional Planning", Proceedings of the 1st Australian Conference on Urban and Regional Information Systems, Newcastle.

COOK, B.G. and JOHNSON, B.V. 1973b "A Data Bank System for Land Resource Survey", Paper presented at the 45th ANZAAS Congress, Perth.

COOK, R.N. 1969 a. "CULDATA System", Canadian Surveyor, Vol. 23, No. 2, 120-127.

COOK, R.N. 1969 b. "Land Law Reform: A Modern Computerized System of Land Records", Cincinnati Law Review, Vol. 38, No. 3, 385-448.

COOK, R.N. 1974. "Land Data Systems: The Next Step", Cincinnati Law Review, Vol. 43, No. 3.

COOK, R.N. 1975. "Where do We Go From Here?", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

COOK, R.N. 1977. "Multi-purpose Land Data System - The Legal Parcel", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

COOKE, D.F. 1977. "Cadastral Geoprocessing", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

COOKE, D.F. 1977. "DIME Variants for Curvilinear Networks", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study on Topological Data Structures for Geographic Information Systems, Harvard University.

CORBETT, J.P. 1973. "Use of the D.I.M.E. System for Identification of Places and Description of Location", in MOYER, D.D. and FISHER, K.P. Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

CORMACK, R.S. 1976. "Data Delineation and Computer Techniques for Line Printer Mapping and Tabulation", Paper presented at ISSS Workshop on Information Systems for Soil and Related Data, Canberra.

COWIE, S.R. 1972 a. "Information Systems for Planning: Some Emerging Principles". in PERRATON, J. and BAXTER, R.S. (Eds) Models, Evaluations and Information Systems for Planners, MTP Construction, Lancaster.

COWIE, S.R. 1972 b. "Spatial Data Processing Project", Proceedings of the 2nd Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, London

COX, N.J. and RHIND, D.W. 1977. "Networks in Geographical Information Systems : A British View", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, Harvard University.

CRAM, A.A. 1974. "Some Computer Graphic Applications in Cartography", Proceedings of the 1st Australian Cartographic Conference, Sydney.

CRISP, L.F. 1974. "Report of the Committee on Integration of Data Systems", Australian Government Publishing Service, Canberra.

CSANDA, F. 1977. "Detection, Survey and Registration of Hidden Underground Ducts in Hungary", Proceedings of the 15th International Congress of Surveyors, Stockholm.

DALE, P.F. 1973. "Correspondence: Cadastral Boundary Disputes", Survey Review, Vol. 22, No. 170, 181.

DALE, P.F. 1974. "The Land Surveyor and Land Information", Chartered Surveyor: Land, Hydrographic and Minerals Quarterly, Vol. 2, No. 2, 24-26.

DALE, P.F. 1976 a. "Cadastral Surveys in theCommonwealth", H.M.S.O., London.

DALE, P.F. 1976 b. "Mathematics Verses Monuments", Canadian Surveyor, Vol. 30, No. 3, 189-191.

DALE, P.F. 1977 a. "The Land Surveyor and Land Information Management", Proceedings of the 15th International Congress of Surveyors, Stockholm.

DALE, P.F. 1977 b. "The Provision of Land Information", Paper presented at Royal Institution of Chartered Surveyor's Annual Conference, Cambridge.

DALE, P.F. 1978. "The Evolution of Cadastral Systems", Proceedings of the 15th Conference of South African Surveyors, Salisbury.

DALE, P.F. 1979. "A Systems View of the Cadastre", Survey Review, XXV, 191.

DALE, P.F. and HOLLWEY, J.R. 1978. "Tasks for the Surveyor in Land Information Management," Proceedings of the FIG Symposium on Land Information Systems, Darmstadt.

DANGERMOND, J., HARDISON, L. and SMITH, L.K. 1981. "Some Trends in the Evolution of Technology", in MARBLE, D.F. (Ed) Background Materials for the Workshop on Specification and Design of Geographic Information Systems, University of New South Wales.

DARBY, J. 1979. "Land Management Systems in New South Wales - A Brief Summary", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

DARLEY, J.A. 1976. "The Number Cruncher as a Planning Decision Maker", Paper presented at International Planning Congress, Adelaide.

DARLINGTON, H.T. 1979. "Computer Graphics and Spatial Analysis at the Prospect County Council", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

DAVEY, A.J. 1976. "Elementary Survey Computations and an Identifier for Parcels of Land", New Zealand Surveyor, Vol. 28, No. 3, 286-336.

DAVIS, J.R. and PAINE, T.A. 1979. "Address Matching of Australian Spatial Data", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

DAVIS, J.R. and WALKER, P.A. 1978. "Computer Usage in Australian Local Government", CSIRO Division of Land Use Research, Technical Memorandum 78/27.

DAWSON, N.M. and MOORE, A.W. 1976. "Comparative Costs of Handling Data in Land Resource Surveys", Paper presented at ISSS Workshop on Information Systems for Soil and Related Data, Canberra.

DEPARTMENT OF CROWN LANDS & SURVEY 1975. "Official Map and Plan Systems", 3rd Edition, Department of Crown Lands Survey, Victoria.

DEPARTMENT OF CROWN LANDS & SURVEY 1977. "Automated Plan Production in the Department of Crown Lands and Survey of Victoria", Proceedings of the 5th Australian Conference on Urban and Regional Information Systems, Canberra.

DEPARTMENT OF HIGHWAYS 1977. "CLOTS Documentation", South Australian Department of Highways.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT 1968. "Urban and Regional Information Systems: Support for Planning in Metropolitan Areas", United States Department of Housing and Urban Development.

DEPARTMENT OF LANDS 1976. "Manual of the New South Wales Integrated Survey Grid", Government Printer, Sydney.

DEPARTMENT OF MAIN ROADS 1981. "Manual for Surveyors", Department of Main Roads, New South Wales.

DEPARTMENT OF THE ENVIRONMENT 1972. "Report of Gazetteer Working Party", H.M.S.O., London.

DEPARTMENT OF THE ENVIRONMENT 1973 a. "Manual on Point Referencing Properties and Parcels of Land", Department of the Environment, London.

DEPARTMENT OF THE ENVIRONMENT 1973 b. "First Report of the Steering Group on the Recording of Communication and Public Utilities Networks", H.M.S.O., London.

DEPARTMENT OF THE ENVIRONMENT 1974. "Interim Report on Property Numbering", H.M.S.O., London.

DEPARTMENT OF THE ENVIRONMENT 1979. "Property Information Systems for Government. Report of the National Gazetteer Pilot Study", D.O.E. Research Report 30, H.M.S.O., London.

DEPARTMENT OF THE VALUER GENERAL 1976. "Valuation Roll Maintenance System Reference", Department of the Valuer General of New South Wales, Sydney.

DENMAN, D.R. 1974. "Prospects of Cadastre in England", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

DENMAN, D.R. 1977. "Land Economy: An Education and Philosophy for the Surveyor's Profession", Canadian Surveyor, Vol. 31, No. 2, 119-131.

DENMAN, D.R. and PRODANO, S. 1972. "Land Use: An Introduction to Proprietary Land Use Analysis", George Allen & Unwin, London.

DEQUAL, S. 1976. "Italian Digital Cadastre Updating", Proceedings of the 13th Congress of the International Society for Photogrammetry, Helsinki.

DOBNER, H.K. 1975. "Basic Elements in the Planning of a New Land Record System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

DOWSON, E. and SHEPPARD, V.L.O. 1956. "Land Registration", Colonial Research Publications No. 13, 2nd Edition, H.M.S.O., London.

DOYLE, F.J. 1977. "Topological Structure for Exchange of Digital Planimetric Data", Proceedings of the 15th International Congress of Surveyors, Stockholm.

DUEKER, K.J. 1972. "A Framework for Encoding Spatial Data", Geographical Analysis, Vol. 4, No. 1, 98-105.

DUNHAM, A. 1974. "Land Parcel Identifiers and the Uniform Land Transactions Act", Cincinnati Law Review, Vol. 43, No. 3, 469-486.

DUNHAM, A. 1975. "Organizational Structure of a Land Records System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

DUNN, J.R. and HEARLE, E.F.R. 1972. "Wichita Falls Integrated Municipal Information System: Prototype for Cities", Proceedings of the 2nd Annual European Sympsoium on Urban Data Management, Planning and Transportation Research and Computation, London.

DYMOND, W.A. 1972. "Economic Aspects of Urban Surveying and Base Mapping from the Viewpoint of the Private Aerial Surveying Industry", Canadian Surveyor, Vol. 26, No. 5, 591-593.

EDDINGTON, R.A. 1980. "Computer Based Land Information System", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

EDDINGTON, R.A. 1981. "Standards and Land Information Systems", Proceedings of the 9th Australian Conference on Urban and Regional Planning Information Systems, Geelong.

EDITORIAL, 1970. The Australian Surveyor, Vol. 23, No. 2.

EEKHOUT, L. 1966. "Photogrammetry and the Cadastral System", Australian Surveyor, Vol. 21, No. 4, 909-924.

ELFICK, M. 1974. "Development of a Cadastral Data Base for Rural Lands", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

ELFICK, M.H. 1979. "The Design and Structure of the Mark Management System for Integrated Surveys in N.S.W.", Australian Surveyor, Vol. 29, No. 5, 305-314.

EMERY, K.A. and LYNCH, L.G. 1976. "A Regional Information System for the Bathurst-Orange Growth Area", Proceedings of the 4th Australian Conference on Urban and Regional Planning Information Systems, Melbourne.

EVANS, W.R. 1976. "Notes on Land Data Banks", Shoalhaven Shire Council, Nowra.

FANT, J.E. 1977. "Cadastre: Why? What? When?", Proceedings of the 11th National Surveying Teacher's Conference, Department of Surveying Engineering, University of New Brunswick, Fredericton.

FERRUGA, A. 1972. "Geocoding in France - Some Practical Experiences", Proceedings of the 2nd Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, London.

FLEMMING, N.L. 1975. "Continuous Updating - An Essential Requirement of a Modern Cadastre", Canadian Surveyor, Vol. 29, No. 1, 64-67.

FLETCHER, L.N. 1968. "Integration of Surveys", Australian Surveyor, Vol. 22, No. 4, 311-317.

FLETCHER, L.N. 1969 a. "Integrated Surveys", Report of Investigating Committee, convened by the Surveyor General of N.S.W., Department of Lands, Sydney.

FLETCHER, L.N. 1969 b. "Integration of Surveys", Australian Surveyor, Vol. 22, No. 4.

FLETCHER, L.N. 1970. "Present and Future Mapping Requirements in N.S.W., Report of Committee convened by the Surveyor General of N.S.W., Department of Lands, Sydney.

FLETCHER, L.N. 1971. "Integration of Title, Engineering and other Detailed Surveys", Australian Surveyor, Vol. 23, No. 8. 490-498.

FLETCHER, L.N. (Chmn) 1972. "Report of N.S.W. Government Services Data Bank Committee", Department of Lands, Sydney.

FLETCHER, L.N. 1973. "Integrated Survey Systems and Modern Mapping in N.S.W.,", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

FLETCHER, L.N. 1980. "Integration of Surveys: Promise and Progress", Australian Surveyor, Vol. 30, No. 1, 51-59.

FITZGERALD, L. 1955. "State Rectangular Co-ordinate Systems", Australian Surveyor, Vol. 15, 234-248.

FITZGERALD, L. 1967. "Rectangular Co-ordinate Systems and Their Application to Integrated Surveys", Australian Surveyor, Vol. 21, No. 7, 223-230.

FOGARTY, T. and RASKALL, P. 1976. "The 1976 Sydney Central Business District Land-Use Survey", Proceedings of the 4th Australian Conference on Urban and Regional Planning Information Systems, Melbourne.

FORD, A.D. 1972. "Administration and Organizational Structures", Canadian Surveyor, Vol. 26, No. 5, 581-585.

FRYER, J.G., MACLEOD, I.D.G. and SMITH, D.R. 1973. "A Rational Approach to Automated Cartography", Paper presented at the 45th ANZAAS Congress, Perth.

FURMSTON, B.E. 1980. "Geodetic Frameworks - Their Relevance for Development", Proceedings of the 9th United Nations Regional Cartographic Conference for Asia and the Pacific.

GALE, L.A. 1969. "Recommendations on the Type of Coordinate System for Correlating Files in a Data Bank System", Canadian Surveyor, Vol. 23, No. 1, 40-45.

GAMBLE, S.G. 1975. "Hotine Lecture", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

GAMBLE, S.G. 1976. "Reference Grids and the Metric System", Canadian Surveyor, Vol. 30, No. 3, 205-206.

GARDNER, W. 1981. "Proposed National Computerised Land Information System for New Zealand", Proceedings of the 9th Australian Conference on Urban and Regional Planning Information Systems, Geelong.

GARDNER-HILL, R.C. 1971. "Automated Cartography in the Ordnance Survey", Proceedings of the Conference of Commonwealth Survey Officers , Cambridge.

GARDNER-HILL, R.C. 1973. "Data Structure for Digital Mapping Used by the Ordnance Survey", Paper presented at the International Cartographic Association Commission III Meeting, Budapest.

GASTALDI, F. 1974. "French Use of Automatic Data Processing (A.D.P.) for Land Consolidation", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

GIBBINS, O.C. 1946. "Application of National Co-ordinate System to Cadastral Survey and Title Deeds", Australian Surveyor, Vol. 11, No. 2, 44-47.

GLENDINNING, D.I., HUTCHINSON, R.G. and SHAW, P. 1971. "Report on Land Data Bank Model of Wanneroo Shire", Department of Lands and Surveys, Perth.

GOODRICK, B.E. 1974a "Cartographic Data Bases in Australia", Proceedings of the 1st Australian Cartographic Conference, Sydney.

GOODRICK, B.E. 1974b "Coordinates and Grid References", Proceedings of the 2nd Australian Conference on Urgan and Regional Planning Information Systems, Newcastle.

GRANT, C.A. 1976. "Large Scale Mapping in an Engineering Environment", Proceedings of the 19th Australian Survey Congress, Gold Coast.

GREAT BRITAIN, 1970. "Geocoding in the 1971 Census", General Register Office, Census Division, Information Paper 1, London.

GREULICH, G.H. 1977. "201 Years of Voluntary Land Recording - Cause and Effect", Proceedings of the 15th International Congress of Surveyors, Stockholm.

GRIFFITH, D. 1972. "Review of Urban Data Management Theory in U.K. Local Authorities", Proceedings of the 2nd Annual European Symposium on Urban Data Management, PTRC, London.

GRIFFITH, J.A. 1972. "Metrication and the Registrar General's Department of N.S.W.", Proceedings of the 15th Australian Survey Congress, Newcastle.

GRIFFITH, J.A. 1973. "Computerization in the Registrar General's Office of N.S.W. And Some Related Observations", Australian Surveyor, Vol. 25, No. 3, 180-188.

GRIFFITH, J.A. 1974. "Automation of Torrens System as a Prelude to a Land Data Bank", Australian Law Journal, Vol. 48, 40-46.

GRIFFITH, J.A. 1975. "Legal Descriptions and Their Use in Developing and Cadastre", Canadian Surveyor, Vol. 29, No. 1, 49-63.

GRIFFITH, J.A. 1976. "Land Registration and Current Trends in the Office of the Registrar General", Supplement to the N.S.W. Surveyor's Monthly Bulletin, Vol. 13, No. 10.

GRIFFITH, J.A. 1978. "Letter to the Editor: General Boundaries and Strata Titles", Australian Surveyor, Vol. 29, No. 4, 295.

GRIFFITH, J.A., HANCOCK, H.J. and HARRIS, R.C. 1971 a. "Land Data Banks", Australian Surveyor, Vol. 23, No. 8, 502-506.

GRIFFITH, J.A., HANCOCK, H.J. and HARRIS, R.C. 1971 b. "Report on Inspections of Overseas Land Registries", Registrar General's Department of N.S.W., Sydney.

HADFIELD, C.D. 1966. "The Relationship of Legal Surveys to Coordinate Systems", Canadian Surveyor, Vol. 20, No. 2, 97-106.

HADFIELD, C.D. 1970. "Land Registration and Legal Surveys - The Basic Problem", Canadian Surveyor, Vol. 24, No. 4, 420-438.

HADFIELD, C.D. 1974. "Computerization of Land Title Records", Cincinnati Law Review, Vol. 43, No. 3, 513-525.

HALLMANN, F.M. 1973. "Legal Aspects of Boundary Surveying as Apply in New South Wales", Institution of Surveyors, Australia, New South Wales Division.

HAMER, K.E. 1967. "Some Aspects of Title Boundary Location in N.S.W.", Australian Surveyor, Vol. 21, No. 6, 91-113.

HAMILTON, A.C. 1969. "Problems in Land Registration and in Filing Environmental Data", Canadian Surveyor, Vol. 23, No. 1, 12-29.

HAMILTON, A.C., CHRZANOWSKI, A. and McNAUGHTON, N. 1976. "Analysis of Infrastructure Information Requirements", Paper presented at the Canadian Institute of Surveyors, Annual Meeting, Winnipeg.

HAMILTON, A.C., CHRZANOWSKI, A., VANICEK, P. and CASTONGUAY, R. 1975. "Map Projections, Grid Coordinates and Geocodes", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

HANNA, J. 1979. "Geographical Information Systems in Local Government", Paper presented at the Seminar/Workshop on Geographical Information Systems, Canberra.

HANSSEN, E.S. and GOTTLIEB, S.E. 1973. "GBIS: Development of a Geographic Index System", in MOYER, D.D. and FISHER, K.P. Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

HARLEY, I.A. 1978. "Establishment of an Integrated Survey Network by Photogrammetry", Paper presented at the Winter School: Proclaimed Survey Areas, Queensland Institute of Technology, Department of Surveying, Brisbane.

HARRISON, D.G. 1974. "The Geocode Project Point In Polygon Algorithm", Management Systems Development Department, City of Calgary.

HARRISON, J.C. 1976. "LAMIS : Spatial Referencing", Newsletter of the British Urban and Regional Planning Information Systems Association, BURISA 20, 13-16.

HARRISON, J.C. 1977. "LAMIS in Wirral", Newsletter of the British Urban and Regional Planning Information Systems Association, BURISA 30, 14-16.

HARRISON, J.C. 1979. "The LAMIS System", Chartered Land Surveyor, Vol. 1, No. 2, 5-8.

HÄRRY, H. 1972. "Photogrammetric Cadastral Survey and Land Registry", World Cartography, 12, 101-104.

HART, A.L. 1973. "Population Census as a Data Base", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

HART, A. 1974. "Towards a Common Spatial Indexing System for Australia", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

HART, A.L. 1975. "A Theory of Geocoding", Proceedings of the 3rd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

HART, A.L. (ed) 1976. "Geocoding: Theory and Practice", State Statistical Co-ordination Unit, The Treasury, Sydney.

HENSSEN, J.L.G. 1972. "Some Remarks on Cadastres in General and on some Features of the Establishment of a Cadastre, Seen in the Light of Present Day Surveying Possibilities", Surveying and Mapping, Vol. 32, No. 4, 463-470.

HENSSEN, J.L.G. 1975 a. "Cadastres, Including Some Aspects of Assessment of Real Property", Candaian Surveyor, Vol. 29, No. 1, 114-122.

HENSSEN, J.L.G. 1975 b. "Maintenance of Cadastres", World Cartography, 13, 57-61.

HERZFELD, G. 1978. "Description of Land Property," Proceedings of the FIG Symposium on Land Information Systems, Darmstadt.
HILL, M.K. 1977. "Transportation Planning Aspects of Land Information Systems", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.
HOLDEN, G.J.F. 1970. "Integrated Surveys and Large Scale Mapping", Australian Surveyor, Vol. 23, No. 1, 15-20.
HOLM, K. 1968. "Provisional Information Regarding Adaption of Photogrammetric Coordinates into Classical Dense Network", Proceedings of the 12th International Congress of Surveyors, London.
HOLM, N. 1974. "Alternative Forms of Spatial Referencing: An Evaluation", Proceedings of the 1st BURISA Annual Meeting, University of Warwick.
HORAK, T.E. 1977. "Reform or Rejection - A Critical Decision on Public Land Records", Proceedings of the 37th ACSM Annual Meeting, Washington, D.C.
HOSCHKE, F.G. 1974. "Management Planning Information Systems in Forestry", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.
HOSCHKE, F.G. 1976. "Use of Computers in Resource Mapping", Proceedings of the Symposium on Land Resource Evaluation, University of N.S.W., Sydney.
HOSCHKE, F.G. and SQUIRE, R.H. 1976. "Review of FORINS", New South Wales Forestry Commission, Sydney.
HOSCHKE, F.G. and WILSON, R.F. 1974. "The FORINS Information System for Land Use Studies", Proceedings of the 7th Triennial Conference of the Institute of Foresters, Australia, Caloundra.
HOWE, R.T. 1970 a. "Time to Step Toward a Modern System of Land Parcel Records", Surveying and Mapping, Vol. 30, No. 1, 87-90.
HOWE, R.T. 1970 b. "Coordinates Versus Confusion", Journal of the Surveying and Mapping Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. SU2, 191-200.
HOWE, R.T. 1972. "How Land Surveying is Being Modernized", Journal of the Surveying and Mapping Division, Proceedings of the American Society of Civil Engineers, Vol 98, No. SU1, 17-26.
HSU, M.L., HOZAR, K., ORNING, G.W. and STREED, P.G., 1975. "Computer Applications in Land-use Mapping and the Minnesota Land Management Information System", in DAVIS, J.C. (Ed) Display and Analysis of Spatial Data, Wiley, London.
HUBERT, P.J. 1969. "Small Areas in the Canadian Census", Canadian Surveyor, Vol. 23, No. 2, 151-160.
HUMPHRIES, B. 1971. "The Computer and the Surveyor Data Base Feasibility", Proceedings of the 14th Australian Survey Congress, Hobart.
HUMPHRIES, B. 1972. "A Land Information System: Progress Report on Data Base Feasibility", Proceedings of the 15th Australian Survey Congress, Newcastle.
HUMPHRIES, B. 1973. "Land Information Systems for Planners", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.
HUMPHRIES, B., JOHNSON, R. and PITKEATHLY, W. 1971. "Land Information System - An Introductory Study", I.B.M. Systems Development Institute, Canberra.

HUMPHRIES, B. and KENNEDY, G. 1974. "A Land Data Bank - A Working Model", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

HUNTER, W.L. 1972. "Integrated Municipal Information System Development - The Reading Experience", Proceedings of the 2nd Annual European Symposium on Urban Data Management, London.

INSTITUTION OF SURVEYORS, AUSTRALIA 1979. "Report of the Council 1978-79: Land Parcel Identifiers in Computerized Systems", Australian Surveyor, Vol. 29, No. 7, 545.

INSTITUTION OF SURVEYORS, N.S.W. 1974. "Proposal for A Bill to Provide For an Integrated Survey System", Institution of Surveyors, Australia, N.S.W. Division, Sydney.

INSTITUTION OF SURVEYORS, N.S.W. 1977 a. "Report of Proceedings of Seminar on the Need for Common Standards in the Recording and Charting of Underground Services", Institution of Surveyors, Australia, N.S.W. Division, Sydney.

INSTITUTION OF SURVEYORS,N.S.W. 1977 b. "Information Needs of Surveyors in the Eighties, Second Major Report", Institution of Surveyors, Australia, N.S.W. Division, Sydney.

INSTITUTION OF SURVEYORS, N.S.W. 1980. "Real Property Computer Register", N.S.W. Surveyors' Monthly Bulletin, Vol. 17, No. 6.

INSTITUTION OF SURVEYORS, VICTORIA 1971. "The Improvement of Land Title Records", Traverse 34, 9-11.

INSTITUTION OF SURVEYORS, VICTORIA 1976 a, "Introduction to the Concept of Survey Integration - History, Needs and Aims", Traverse 52, 8-9.

INSTITUTION OF SURVEYORS, VICTORIA 1976 b. "Title Surveys and Legal Aspects", Traverse 53, 10-11.

INSTITUTION OF SURVEYORS, VICTORIA 1976 c. "Survey Integration - The Value to Surveyors Economically and Professionally in Present and Long Range Terms", Traverse 54, 10.

INSTITUTION OF SURVEYORS, VICTORIA 1976 d. "Survey Integration - The Present System in Victoria", Traverse 55, 8-12.

INSTITUTION OF SURVEYORS, VICTORIA, 1977. "Local Grids", Traverse 58, 12-13.

INTERNATIONAL FEDERATION OF SURVEYORS 1981. "Resolutions of the Commission 3 of the International Federation of Surveyors", Montreux.

IRVING, G.C. 1971 a. "Aspects of Integration of Cadastral Surveys", Australian Surveyor, Vol. 23, No. 4, 253-260.

IRVING, G.C. 1971 b. "Cadastral Integration and Zone Widths", Australian Surveyor, Vol. 23, No. 6, 359-363.

IRWIN, M. 1971. "Developments in Automated Cartography at the Ordnance Survey", Cartographic Journal, December Issue.

JAKSIC, Z. 1972. "Photogrammetric Data in Urban Information Systems", Canadian Surveyor, Vol. 26, No. 5, 558-566.

JAKSIC, Z. 1974. "On-Line Computational Photogrammetry in Surveying and Mapping", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

JAKSIC, Z. 1977. "Interfacing Analytical Photogrammetric Instruments with Digital Cartographic Systems", Proceedings of the 15th International Congress of Surveyors, Stockholm.

JAMES, G.C., HEARD, K.S. and SUTTIE, I.E. 1975. "Point-in-Polygon Project", Research Report 2, Department of Environment, London.

JERIE, H.G. 1978. "Integrated Collection and Recording of Regional Planning Data", Proceedings of the Inter-Regional Workshop on Cadastral Surveying, Mapping and Land Information, Hanover.

JOHNSON, T.R. 1981. "Evaluation And Improvement of the Geographic Information System Design Model", in MARBLE, D.F. (Ed) Background Materials for Workshop on Specification and Design of Geographic Information Systems, University of New South Wales, Sydney.

JOHNSTON, D. 1973. "A Common Large Scale Mapping System for Use Throughout Western Australia", Cartography, Vol. 8, No. 1, 19-22.

JOINT LOCAL AUTHORITY STUDY TEAM 1972. "General Information System for Planning", H.M.S.O., London.

JONES, A. 1974. "A Computer-Integrated Ground Surveying System", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

KATONA, A. 1974. "New Uniform Registration System of Public Services in Hungary", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

KEARSLEY, A.H.W. 1972. "Integration Survey System in N.S.W.", Australian Surveyor, Vol. 24, No. 4, 196-202.

KEDGE, R.W.N. 1974. "Development of Information Systems in a Metropolitan County - A District Viewpoint", Proceedings of the 1st BURISA Annual Meeting, University of Warwick.

KELLY, B.P. 1980. "Cadastral Mapping in an Electricity Utility", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

KENNEDY, G.H.C. 1970. "Integrated Programme of Surveying and Mapping", Proceedings of the 13th Australian Survey Congress, Adelaide.

KENNEDY, G.H.C. 1971. "The Legal Cadastre", Unpublished, Adelaide.

KENNEDY, G.H.C. 1978. "Survey Co-ordination in South Australia", Proceedings of the 21st Australian Survey Congress, Adelaide.

KENNEDY, W.D. 1975a "Report on Progress of Survey Integration in Australia", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

KENNEDY, W.D. 1975b. Discussion on Survey Integration, Proceedings of the Conference of Commonwealth Survey Officers,Cambridge.

KERR, J. and GOOD, W. 1978. "Computerization of Land Indexes and the Use of Geocodes in the Ontario Ministry of Natural Resources 1977" Supplement to Canadian Surveyor, Vol. 32, No. 2.

KING, C.W.B. 1977. "The Automated Census Mapping Program", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.

KINZY, S. 1980. "Urban Geoprocessing: A Staged Development Concept", Proceedings of the Speciality Conference on the Planning and Engineering Interface with a Modernized Land Data System, Denver.

KIRBY, M.D. 1980. "Surveying and Law Reform", Australian Surveyor, Vol. 30, No. 2, 121-132.

KISCHKEL, R. 1971. "The Classification System of Road Data Banks In Federal Republic of Germany", Proceedings of the 13th International Congress of Surveyors, Weisbaden.

KNEEBONE, D.C. 1977. "Centralized Information for Planning - A Consultant's View", Proceedings of the 5th Australian Conference on Urban and Regional Information Systems, Canberra.

KOLLAR, K. 1977. "The Problem of Digitalised Cadastre of Underground Circuits", Proceedings of the 15th International Congress of Surveyors, Stockholm.

KONECNY, G. 1969 a. "Basic Considerations Related to Cadastral Surveying of Cities", Canadian Surveyor, Vol. 23, No. 4, 399-408.

KONECNY, G. 1969 b. "Control Surveys as a Foundation for an Integrated Data System", Canadian Surveyor, Vol. 23, No. 1, 34-39.

KONECNY, G. 1969c. "Proceedings of the Symposium on Land Registration and Data Banks," Canadian Institute of Surveying, Ottawa.

KONECNY, G. 1971. "Organizational Solution to an Integrated Multi-purpose City Surveying System", Plan Canada, Special Issue, 66-75.

KONECNY, G. 1976. "Methods of Data Acquisition for the Establishment of a Multi-purpose Land Registration System in Urban and Rural Areas with Special Emphasis on Photogrammetry", World Cartography, 14, 97-102.

KONECNY, G. 1978. "Data Acquisition for Land Information Systems," Proceedings of the FIG Symposium on Land Information Systems, Darmstadt.

KRATKY, V. 1976. "Use of Analytical Photogrammetry in Cadastre", Paper presented at the Pan American Meeting of Integrated Surveys and Development of Countries, Botota.

KROLL, F. 1977. "Interactive Systems for Large Scale Mapping", Proceedings of the 15th International Congress of Surveyors, Stockholm.

KROTKI, K.J. 1969. "Data Banks and Population Statistics", Canadian Surveyor, Vol. 23, No. 2, 98-103.

KUMMER, J. 1977. "The Introduction of Cable and Pipeline Cadastre, in the View of the Public Utilities", Proceedings of the 15th International Congress of Surveyors, Stockholm.

LAMBDEN, D.W. 1970. "Integration of Surveys", Australian Surveyor, Vol. 23, No. 1, 21-35.

LAMBDEN, D.W. 1975. "Educational Background of an Information Manager in Surveying", Canadian Surveyor, Vol. 29, No. 5, 495-500.

LAMBDEN, D.W. 1976. "Parcels and Titles", Canadian Surveyor, Vol. 30, No. 3, 143-155.

LAND REGISTRATION AND INFORMATION SERVICE 1977. "Maritime Cadastral Accuracy Study", Project Report by Department of Surveying Engineering, University of New Brunswick, Fredericton.

LARSEN, H.K. 1971. "An Economic Study of the Atlantic Provinces Control Survey, Mapping Land Titles and Data Bank Program", Department of Surveying Engineering, University of New Brunswick, Fredericton.

LARSEN, H.K. 1972. "On the Economics of Land and Property Information Systems", Canadian Surveyor, Vol. 26, No. 5, 587-590.

LARSEN, H. and McLAUGHLIN, J.D. 1977. "Economic Criteria for Multi-purpose Cadastral Systems Development", Proceedings of the 15th International Congress of Surveyors, Stockholm.

LARSSON, G. 1971. "Land Registration in Development Countries", World Cartography, 11, 33-49.

LARSSON, G. 1975. "Social and Administrative Function of a Cadastre: Environmental Studies, Planning, Administration", Canadian Surveyor, Vol. 29, No. 1, 75-81.

LARSSON, G. 1976. "Role and Functioning of a Cadastral System in a Modern Society", Paper presented at the Pan American Meeting of Integrated Surveys and Development of Countries, Bogota.

LARSSON, G. 1977 a. "The Evolution of the Existing Cadastres Towards the Multi-purpose Cadastre", Proceedings of the 15th International Congress of Surveyors, Stockholm.

LARSSON, G. 1977 b. "Land Information Systems - Basis for Planning and Valuation", Proceedings of the 15th International Congress of Surveyors, Stockholm.

LAWTIE, G.J. and HUTCHINSON, R.G. 1976. "An Introduction to CADMAPS", Surveyor General's Division, Department of Lands and Surveys, Perth.

LAY, J.C. 1977. "Preparing Property Identification Maps for Land Data Systems", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

LEE, L.P. 1974. "The Search for an Improved Coordinate System for New Zealand Surveys and Maps", New Zealand Surveyor, Vol. 27, No. 5, 545-568.

LEUPIN, M.M. 1976. "Analytical Photogrammetry, an Alternative to Terrestial Point Determination", Australian Surveyor, Vol. 28, No. 2, 73-80.

LOELKES, G.L. 1969. "Orthophotography as a Data Base for Land Descriptions", Canadian Surveyor, Vol. 23, No. 1, 54-60.

LOGAN, R.A. 1977. "Modernization of Land Registration Systems in Ontario", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

LONGLY, M.P. 1976. Letters, Newsletter of the British Urban and Regional Information Systems Association, BURISA 22, 14.

LOVE, A.R. 1975. "An Integrated System of Mapping Using Grid Values for Sheet Identification", Proceedings of the 18th Australian Survey Congress, Perth.

LOVE, R.J. 1968. "Land Tenure in Australia", Proceedings of the 12th International Congress of Surveyors, London.

LYNCH, L. 1976. "Input Methods and Facilities Available for Land Survey Data", Paper presented at the ISSS Workshop on Information Systems for Soil and Related Data, Canberra.

McCALDEN, G. 1973. "Design Considerations for URPIS in the Australian Context", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

McCALDEN, G. 1974 a. "Geocoding Alternatives for Australia", Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

McCALDEN, G. 1974 b. "Geocoding Issues", Discussion Session V, Proceedings of the 2nd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

McCALDEN, G. and JARVIE, J. 1976. "How Transferable is Geocoding Technology?", Proceedings of the 4th Australian Conference on Urban and Regional Planning Information Systems, Melbourne.

MacINTOSH, C.W. 1976. "The Development of Legislation to Support a Computerized Land Transfer System", Proceedings of the Land Records Symposium, University of Maine at Orono.

MacISAAC, A.J. 1969. "Application of a Plane-Coordinate System to Cadastral Surveys", Australian Surveyor, Vol. 22, No. 5, 395-401.

McLAUGHLIN, A.W. 1974. "Heresy or Clairvoyance?", The Legal Corner, Canadian Surveyor, Vol. 22, No. 1, 139-140.

McLAUGHLIN, J.D. 1971. "Modelling Techniques for the Design of Land Survey Systems and Some Initial Conclusions", Canadian Surveyor, Vol. 25, No. 1, 49-53.

McLAUGHLIN, J.D. 1975 a. "The Cadastral Surveying Challenge", Canadian Surveyor, Vol. 29, No. 1, 131-136.

McLAUGHLIN, J.D. 1975 b. "The Nature, Function and Design Concepts of Multi-purpose Cadastres", Ph.D Thesis, University of Wisconsin - Madison.

McLAUGHLIN, J.D. 1979. "An Assessment of Multi-purpose and Registration and Information Systems", Proceedings of the ACSM, 39th Annual Meeting, Washington, D.C.

McLAUGHLIN, J.D. and CLAPP, J.L. 1977. "Toward the Development of Multi-purpose Cadastres", Journal of the Surveying and Mapping Division, American Society of Civil Engineers, Vol. 103, No.SU1, 53-73.

McLAUGHLIN, J.D. and LARSEN, H.K. 1976. "Economic Considerations in the Development of Modern Cadastre Systems", Proceedings of the Land Records Symposium, University of Maine at Orono.

McLAUGHLIN, J.D. and THOMSON, D.B. 1977. "Accuracy Standards for Modern Cadastral Systems", Proceedings of the ACSM, 37th Annual Meeting, Washington, D.C.

MACLEAN, W.J. 1972. "Mapping Requirements for Urban Planning and Development", Canadian Surveyor, Vol. 26, No. 5, 479-483.

McLELLAN, C.D. 1972. "Survey Control for Urban Areas", Canadian Surveyor, Vol. 26, No. 5, 496-503.

MACLEOD, I.D.G., FRYER, J.G. and SMITH, D.R. 1973. "A Thematic Mapping Data Base", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

MACLEOD, M.H. 1972. "Semi-automated Large Scale Mapping", Proceedings of the 12th Congress of the International Society for Photogrammetry, Ottawa.

MACLEOD, R. 1977. "The Development of an Automated Standard Mapping System in the South Australian Department of Lands", Proceedings of the 15th International Congress of Surveyors, Stockholm.

McLOUGHLIN, J.B. 1969. "Urban and Regional Planning. A Systems Approach", Faber and Faber, London.

McCLUSKEY, D. 1973. "Automation in Cartography", Proceedings of the 16th Australian Survey Congress, Canberra.

MAGGS, P.B. 1973. "An Evolutionary approach to Compatible Identifiers for Computerized Land Records", in MOYER, D.D. and FISHER, K.P. (Eds) Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

MAHON, E.W. 1944. "The Zoning of Azimuths and Survey Coordinates", Australian Surveyor, Vol. 10, 111-121.

MAINTHORPE, J. 1979. Discussion on Cadastre, Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

MARBLE, D.F. 1979. "Integrating Cartographic and GIS Education", Proceedings of the 39th ACSM Annual Convention, Washington, D.C.

MARRIOTT, G.E. 1976. "Photogrammetry as a Means of Cadastral Surveying", South African Survey Journal, Vol. 15, No. 93, 57-64.

MARSHALL, O.J. and MONOGHAN, J.W.L. 1972. "Economic Aspects of Urban Surveying and Mapping", Canadian Surveyor, Vol. 26, No. 5, 594-597.

MASSER, F.I. and WILLIS, J. 1974. "The Use of an Experimental Swedish Data Base for Optimizing Primary School Catchment Areas", Proceedings of the 1st Annual Meeting of the British Urban and Regional Information Systems Associations, University of Warwick.

MELLOY, C.R. 1981. "Digital Cadastral Map Production in Queensalnd", Proceedings of the 9th Australian Confernece on Urban and Regional Information Systems, Geelong.

MILEV, G.K. 1977. "Some Unsolved Problems in Building of Conduit Cadastre", Proceedings of the 15th International Congress of Surveyors, Stockholm.

MILLBURN, I. 1981. "The Torrens Register Automation Project (TRAP)", Proceedings of the 23rd Australian Survey Congress, Sydney.

MINISTERE DE L'EQUIPMENT 1976. "Concepts used in Segment-Oriented Information Systems - The R.G.U.", International Segment-Oriented Referencing System Association (SORSA) Working Paper No. 4.

MITCHEL, W.H. 1976. "Information Technologies and Government Processes", Paper presented at the Pan American Meeting of Integrated Surveys and Development of Countries, Bogota.

MITCHELL, R.J. 1971. "Discussion: Coordinates Versus Confusion", Journal of the Surveying and Mapping Division, Proceedings of the American Society of Civil Engineers, No. SU1, 143-147.

MITCHELL, W.G., GUPTILL, S.C., ANDERSON, K.E., FEGUS, R.G. And HALLAM, C.A. 1977. "GIRAS: A Geographic Information Retrieval and Analysis System for Handling Land Use and Land Cover Data", Geological Survey Professional Paper 1059, U.S. Department of Interior, U.S. Government Printing Office, Washington, D.C.

MITTELSTRAß, . 1978. "The Conception of the AdV (Association of German Survey Authorities) Concerning the Automated Cadastral Plan", Proceedings of the FIG Symposium on Land Information Systems, Darmstadt.

MONAGHAN, P.A. 1971. "Review of Basic Procedures in City Surveying and Mapping", Plan Canada, Special Issue.

MONTERO, F.J. 1975. "Field and Aerial Surveying in Cadastre", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

MOORE, A.W. 1976. "Some Impressions of Overseas Developments in Information Systems", Paper presented at the ISSS Workshop on Information Systems for Soil and Related Data, Canberra.

MOORE, D.W.G. 1976. "Report on Review of Computer Requirements, Surveyor General's Division," Western Australian Regional Computing Centre, Perth.

MOORE, J.W. 1977. "Implications of the Emerging Computer Environment in N.S.W. Local Authorities", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.

MORGAN, J.F. 1973. "Survey Integration - A Western Australian Concept", Proceedings of the 16th Australian Survey Congress, Canberra.

MORGAN, J.F. 1979. "Land Information Systems in Australia", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

MOYER, D.D. 1969. "Three Automated Land Data Systems in the U.S.", Canadian Surveyor, Vol. 23, No. 2, 132-141.

MOYER, D.D. 1971. "Data Banks", Plan Canada, Special Issue, 57-65.

MOYER, D.D. 1973. "County Cadastres and Compatible Parcel Identifiers: Needs and Costs", in MOYER, D.D. and FISHER, K.P. (Eds) Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

MOYER, D.D. 1974 "Multi-purpose Land Parcel Data Systems", Proceedings of the 12th Annual Conference of the Urban and Regional Information Systems Association, Montreal.

MOYER, D.D. and FISHER, K.P. 1973. "Land Parcel Identifiers for Information Systems", American Bar Foundation, Chicago.

MULCAHY, D.L. 1980. "Conversion of General Law Land (Old System) to the Real Property Act (Torrens System) without Cadastral Survey", Proceedings of the 22nd Australian Survey Congress, Hobart.

MURPHY, B.T. 1958. "The Coordination of Cadastral Surveys in Victoria, Australian Surveyor, Vol. 17, 56-61.

MURPHY, B.T. 1980. "Title Boundaries in Victoria", Australian Surveyor, Vol. 30, No. 1, 7-23.

NAGY, G. and WAGLE, S. 1979. "Geographic Data Processing", Computing Surveys, Vol. 11, No. 2, 139-181.

NASH, K.R., DAVIDSON, I. and SMITHIES, A. 1973a "City of Sydney Council - City Planning Department Information System: Problems and Alternatives", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

NASH, K.R., DAVIDSON, I. and SMITHIES, A.P. 1973b "Urban Information Systems Overseas with Particular Reference to U.S.A.," Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

NASH, K.R. and MOLL, A.P. 1976. "Council of the City of Sydney Land Information System: Description of Planning Applications", Proceedings of the 4th Australian Conference on Urban and Regional Planning Information Systems, Melbourne.

NATIONAL MAPPING COUNCIL, 1977. "Map Co-ordinate Systems - 1976", Australian Surveyor, Vol. 28, No. 5, 299-302.

NEAL, P. 1971. "Cadastral Integration and Zone Widths", Australian Surveyor, Vol. 23, No. 8, 499-501.

NEALE, G.A. 1968. "The National Large-Scale Survey of Great Britain", Proceedings of the 12th International Congress of Surveyors, London.

OBEE, K.E. 1973. "Locational Referencing Questionnaire", Department of Environment, London.

OGILVIE, M. 1977. "Experience in Building the Cadastre in the Maritime Provinces", Proceedings of the 37th ACSM Annual Convention, Washington, D.C.

ONTARIO LAW REFORM COMMISSION, 1971. "Report on Land Registration", Ontario Law Reform Commission, Department of Justice, Ontario.

OPENSHAW, S. and RAMSEY, J.B.H. 1978. "An Automatic Address Matching and Survey Coding Program (AC))", Newsletter of the British Urban and Regional Information Systems Association BURISA 33, 7.

ORDNANCE SURVEY, 1975. "The Restructuring of Ordnance Survey Digital Map Data", Ordnance Survey Consultative Papers 75/1.

ORDNANCE SURVEY, 1977 a. "The Restructuring of Ordnance Survey Digital Map Data" Ordnance Survey Consultative Papers 77/3.

OORNANCE SURVEY, 1977 b. "The 1:2500 Digital Map", Ordnance Survey Consultative Papers 77/4.

OVERALL, J.W. 1974. "Report of the Inquiry on the Proposal to Establish a System of Survey Integration in New South Wales", Department of Lands, Sydney.

P.A. CONSULTING SERVICES PTY. LTD., 1979. "Framework for a Land Information System for Western Australia", Vols. 1 and 2., Western Australian Government.

P.G. PAK-POY AND ASSOCIATES PTY. LTD., 1976. "Land Administration and Information System for the Northern Territory - Feasibility Study and Strategic Design", Vols. 1 and 2, Department of the Northern Territory.

PAINE, T.A. and DAVIS, J.R. 1980. "ADMATCH Users' Manual", CSIRO Division of Land Use Research, Technical Memorandum 80/3.

PATAKY, T. 1974. "Establishment of a System for Registration and Information Related to Urban Roads and Various Technical Networks by Data Banks", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

PAWSON, K. 1974. "The Calgary 1:1000 Cadastral Plan Series", Land, Hydrographic & Minerals Quarterly Supplement to the Journal of the Royal Institute of Chartered Surveyors, Vol. 2, No. 1.

PAYNE, A.D. 1974. "Computer-Based Land Transfer and Registration", Australian Computer Journal, Vol. 7, No. 5.

PENNY, R.A. 1975. "D.M.A. Automated Cartographic Systems", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

PENNY, R.A. 1977. "Cartographic Automation and Digital Data Standardization in the U.S.", Proceedings of the 15th International Congress of Surveyors, Stockholm.

PERRATON, J. 1970. "Urban Systems: Collection and Management of Data for a Complex Model", LUBFS Working Paper 46, Cambridge.

PERRETT, K. 1976 a. "Transport Referencing and Mapping System (TRAMS)", Mimeograph, Transport and Road Research Laboratory, Crowthorne.

PERRETT, K. 1976 b. "Spatial Referencing", Newsletter of the British Urban and Regional Information Systems Association BURISA 22, 13.

PERRETT, K. 1978. "TRAMS Feasibility Study: Report into the Feasibility of using a Computer to Match the Property Gazetteer held in Tyne and Wear with TRAMS Network Files", Mimeograph, Transport and Road Research Laboratory, Crowthorne.

PHILLIPS, J. (Chmn) 1975. "Proceedings of the North American Conference on the Modernization of Land Data Systems," Washington D.C.

PODEHL. W.M. 1975. "The Role of a Cadastre in Statistical Information Systems", Canadian Surveyor, Vol. 29, No. 1, 82-90.

POLMAN, . 1974. "Automation in Land Consolidation in the Netherlands", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

POPE, K.S. 1978. "Opening Session : Overview", Proceedings of the Queensland Institution of Surveyors' Mini-Congress on Land Information Systems, Brisbane.

PRIDDLE, R.E. 1975. "Report of the Resolutions Committee, Conference on Concepts of a Modern Cadastre", Canadian Surveyor, Vol. 29, No. 1 123-124.

RAINSFORD, K.J. 1976. "Unique Identification for Land Parcels", Paper presented at the Real Estate Institute of South Australia Land Brokers' Seminar, Adelaide.

READ, J.R. 1975. "The Advantages of 6° Wide Zone Integration Over the 2° Narrow Zone Integration in Australia", Australian Surveyor, Vol. 27, No. 1, 29-40.

RICHARDS, A.G. 1979. "Feasibility Study of Proposed Developments in Automation in the Office of Titles", P.A. Consulting Services Pty. Ltd., Western Australian Government.

RHIND, D.W. 1977. "Storage and Retrieval of Information", Paper presented at the Royal Institution of Chartered Surveyors' Annual Conference, Cambridge.

RHIND, D.W. 1979. "Developments in Britain and Europe in Geographical Information Systems", Paper presented at the Seminar/Workshop on Geographical Information Systems, Canberra.

RHIND, D.W. and TREWMAN, T. 1975. "Automatic Cartographic and Urban Data Banks - Some Lessons from the U.K.", International Yearbook of Cartography, 15, 143-157.

RINNER, K. 1969. "Reflections of a European on the Symposium on Land Registration and Data Banks", Canadian Surveyor, Vol. 23, No. 1, 46-53.

RIORDAN, W.T. 1978. "Digital Data Bases - The Wave of the Future", Paper presented at the 38th ACSM Annual Convention, Washington, D.C.

RISK, R.C.B. 1969. "The Computer and the Title to Land", Canadian Surveyor, Vol. 23, No. 2, 89-93.

ROBERTS, R.G. 1973. "Photogrammetry in South Australia", Proceedings of the 16th Australian Survey Congress, Canberra.

ROBERTS, R.G. 1976. "Automated Cartography: Its Purpose and Problems", Proceedings of the 2nd Australian Cartographic Conference.

ROBERTS, R.G. 1978. "Coordination of Survey Marks by Photogrammetry", Proceedings of the 21st Australian Survey Congress, Adelaide.

ROBERTS, W.F. 1966. "Integrated Surveys in New Brunswick", Canadian Surveyor, Vol. 20, No. 2, 84-89.

ROBERTS, W.F. 1969. "Some Basic Features of an Environmental Integrated Data Bank", Canadian Surveyor, Vol. 23, No. 1, 30-33.

ROBERTS, W.F. 1970. "The Maritime Provinces Mapping and Land Registration Program", Surveying and Mapping, Vol. 30, No. 1, 77-80.

ROBERTS, W.F. 1971. "The Canadian Approach to Urban Mapping", Papers from the 1971 ASP Annual Meeting.

ROBERTS, W.F. 1975. "Legal Measures as a Prerequisite of a Modern Land Data System", Proceedings of North American Conference on Modernization of Land Data Systems, Washington, D.C.

ROBERTS, W.F. 1979 a. "Land Related Information Systems", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

ROBERTS, W.F. 1979 b. "Land Records and Resource Information Systems: An Assessment From a Political Point of View", Proceedings of the 39th ACSM Annual Convention, Washington, D.C.

ROBERTS, W.F. 1980. "Keeping Land-Related Information Up-to-date", Canadian Surveyor, Vol. 34, No. 1.

RÖNNBERG, A., SALOMONSSON, O. and SELANDER, K. 1974. "Geocoding", National Swedish Building Research Summaries 52 : 1974.

ROZOVSKY, L.E. 1969. "Torrens Land Titles System", Canadian Surveyor, Vol. 23, No. 1, 5-10.

RUOFF, T.B.F. 1957. "An Englishman Looks at the Torrens System", The Law Book Company Pty. Ltd., Sydney.

RUOFF, T.B.F. 1968. "English Registered Titles to Land and The Function of Ordnance Survey Maps", Proceedings of the 12th International Congress of Surveyors, London.

RYSTEDT, B. 1977 a. "Development Work at the Swedish Central Board for Real Estate Data", Segment-Oriented Referencing Systems Association Working Paper No. 10.

RYSTEDT, B. 1977 b. "The Swedish Land Data Bank: A Multi-purpose Information System", in WASTESSON, O. (Ed) Computer Cartography in Sweden, York University, Canada.

SABATIER, J.P. 1977. "First Uses of RGU, The French Geocoding System", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, Harvard University.

SALOMONSSON, I. 1969. "Data Banking Systems for Urban Planning", Information Paper No. 8, Vol. 2, Centre for Environmental Studies, London.

SALOMONSSON, O. 1972. "Geocoding: Background Paper for the Geocoding Study Group", Proceedings of the 2nd Annual European Symposium on Urban Data Management, London.

SALOMONSSON, O. 1977. "Planning-Oriented Topological Analysis Methods - Some Practical Applications with the NIMS System", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, Harvard University.

SCHMIDT, G. 1971. "Title Insurance Companies and Their Place in Land Registration in the U.S.A.", Proceedings of the 13th International Congress on Surveyors, Wiesbaden.

SCOTT, R.F. 1981. "The Multipurpose Land Information System in the Public Sector Community of the North American Continent", Land Information Institute Newsletter, Vol. 3, No. 1.

SEDUNARY, M.E. 1977. "Development and Extension of the South Australian Land Ownership and Tenure System", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.

SEDUNARY, M.E. 1980. "LOTS - An Operational Land Information System for South Australia", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

SEDUNARY, M.E. 1981. "LOTS - A South Australian Approach to a Total, Fully Integrated Land Information System", Proceedings of the 23rd Australian Survey Congress, Sydney.

SERISIER, J.M. 1978. "Proclaimed Survey Areas in Queensland", Paper presented at the Winter School: Proclaimed Survey Areas, Queensland Institute of Technology, Department of Surveying, Brisbane.

SHARNI, D. 1977. "An Integrated System for Cadastral Survey Utilizing Digitization, Polar/Orthogonal Surveying, Computer Data Processing and Automated Plotting", Proceedings of the 15th International Congress of Surveyors, Stockholm.

SHEAVES, D.J. 1977. "Experience and Possibilities in Automating the A.C.T. Cadastre", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.

SHERWOOD, P.C. 1976. "Comments on Proposals for Establishing an Underground Cadastre with Special Reference to Greater London", Survey Review, Vol. 23, No. 181, 316-318.

SILVER, J. 1977. "GBF/DIME System - An Overview", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study on Topological Data Structures for Geographic Information Systems, Harvard University.

SIMMONDS, R. 1977. "Land Registration and Information Service in the Maritime Provinces", Paper presented at the 15th International Congress of Surveyors, Stockholm.

SIMPSON, S.R. 1967. "The Role of Maps and Boundaries in Land Registration", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

SIMPSON, S.R. 1976. "Land Law and Registration", Cambridge University Press.

SMAILES, P.J. 1966. "The Large Scale Cadastral Mapping Coverage in Australia and the Parish Maps of N.S.W.", Australian Geographer, Vol. 10, No. 2, 81-94.

SMITH, C.C. and BOMBERGER, D. 1974. "DIME Technology: Factors Affecting Development and Use", Proceedings of the 4th Annual European Symposium on Urban Data Management, Madrid.

SMITH, G.L. 1977. "Analytical Photogrammetry Applied to Survey Point Coordination", Australian Surveyor, Vol. 28, No. 5, 263-272.

SMITH, G.L. 1978. "Survey Coordination: A Review of Research and Development", Proceedings of the 21st Australian Survey Congress Adelaide.

SMITH, R.A. 1972. "Legislation for Urban Surveying and Mapping", Canadian Surveyor, Vol. 26, No. 5, 571-577.

SOLARI, R. 1974. "Report on the Miltipurpose Cadastre", Paper presented at the 14th International Congress of Surveyors, Washington, D.C.

SOUTH AUSTRALIA, 1977. "Report: Outlining Future Development Stages of a Land Information System in the South Australian Public Service", Adelaide.

SPICER, J. 1977 a. "Property Numbering Systems Part 1 : A Neglected Field", Newsletter of the British Urban and Regional Information Systems Association, BURISA 28, 7-8.

SPICER, J. 1977 b. "Property Numbering Systems Part 2 : Hourses for Courses", Newsletter of the British Urban and Regional Information Systems Association, BURISA 29, 5-8.

STANDARDS ASSOCIATION OF AUSTRALIA, 1981. "Australian Standard AS2482 Interchange of Feature Coded Digital Mapping Data", Standards Association of Australia.

STAPLETON, M.J. 1979. "Output and Graphics with Particular Reference to Digital Cartography", Chartered Land Surveyor, Vol. 1, No. 2.

STEPHENSON, M. and YOUNGER, K. 1972. "Problems of Introducing a Point Referenced Data System in an Urban Authority", Proceedings of the 2nd Annual European Symposium on Urban Data Management, Planning and Transportation Research and Computation, London.

SUMMER, H. 1973. "The Marketing of Urban and Regional Planning Information Systems to Potential Users", Proceedings of the 1st Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

SWITZER, P. 1975. "Estimation of the Accuracy of Qualitative Maps", In DAVIS, J.C. (ed) Display and Analysis of Spatial Data, Wiley, London.

SYCHUK, M.J. 1975. "Legal Problems in Establishing Boundaries for a Cadastre", Canadian Surveyor, Vol. 29, No. 1, 29-38.

SYMONS, D.C. 1972. "Automatic Mapping and its Relation to Urban Information Systems", Canadian Surveyor, Vol. 26, No. 5, 545-557.

SYMONS, D.C. 1974. "An Urban Information System", Proceedings of the 4th Annual European Symposium on Urban Data Management, Madrid.

TARRANT, A.E. 1977. "Law Relating to Title Survey", Reprint from the Journal of the Hong Kong Land Surveyor, Vol. 1 No. 1.

TERNRYD, C. 1975. "The Real Estate Data Bank in Sweden and the Connections to Other Data Banks - Experiences and Further Development", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

TESSARI, E.J. 1974 a. "Land-Related Information Systems Report Part II: Location Identifiers", Task Force on Urbanization and the Future, Edmonton.

TESSARI, E.J. 1974 b. "Coordination of Land Related Information in Alberta", Proceedings of the 14th International Congress of Surveyors, Washington, D.C.

THIGPENN, J.A. 1968. "Problems of Mapping and Surveying for Land Title Records", Surveying and Mapping, Vol. 28, No. 3, 487-492.

THIGPENN, J.A. 1969. "Some Thoughts on the Improvement of Land Title Records", Canadian Surveyor, Vol. 23, No. 2, 83-89.

THOMPSON, C.N. 1979 a. "Digital Mapping in the Ordnance Survey 1968 - 1978", Chartered Land Surveyor, Vol. 1, No. 2, 15-28.

THOMPSON, C.N. 1979 b. "The Need for a Large Scale Topographic Data Base", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

THOMPSON, I.C. 1977. "LAMIS in Wirral", Newsletter of the British Urban and Regional Information Systems Association, BURISA 30, 14-16.

THOMPSON, M.M. 1975. "Highlights of Atlanta Conference on Compatible Land Identifiers", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington,D.C.

THOMSON, D.B., McLAUGHLIN, J.D. and CHRZANOWSKI, A. 1977. Cadastral Standards for Integrated Survey Areas", Canadian Surveyor, Vol. 31, No. 4, 307-322.

THORNTON, H. 1979. "File Linkage with LAMIS", Newsletter of the British Urban and Regional Information Systems Association, BURISA 38, 11-12.

TOFT, G.S. 1967. "Australian Cadastral Concepts and Their Application to a Developing Country", Australian Surveyor, Vol. 21, No. 6, 115-133.

TOFT, G.S. 1968. "The Registration and Cadastral Survey of Native Held Land in the Territory of Papua and New Guinea", Master of Surveying Thesis, University of New South Wales.

TOMLINSON, R.F., CALKINS, H.W. and MARBLE, D.F. 1976. "Computer Handling of Geographical Data", UNESCO Natural Resources Research 13, UNESCO Press, Paris.

TOMS, K.N. 1976. "The Dimensions of Cadastre: Historical Approach", Australian Surveyor, Vol. 28, No. 4, 187-216.

TOMS, K.N. 1978 a. "The Multi-Purpose Cadastre and Proclaimed Survey Areas", Paper presented at the Winter School: Proclaimed Survey Areas, Queensland Institute of Technology, Department of Surveying, Brisbane.

TOMS, K.N. 1978 b. "The Technology of Urban Parcel Delimitation and Mapping Under Federal Systems of Government: A Comparative Study", Australian Surveyor, Vol. 29, No. 4, 211-267.

TOMS, K.N. and LEWIS, S. 1974. "Cadastral Surveying and Land Registration : A Comparative Analysis of the English and Tasmanian Systems", Australian Surveyor, Vol. 26, No. 4, 243-264.

TURNER, D.R. 1977. "LAMIS", Newsletter of the British Urban and Regional Information Systems Association, BURISA 30, 9-12.

URBAN, V.F. 1973. "Large Scale Mapping in New South Wales", Proceedings of the 16th Australian Survey Congress, Canberra.

URBAN, V.F. 1977. "GDB, Everest and Orthophotomaps", Proceedings of the 5th Australian Conference on Urban and Regional Planning Information Systems, Canberra.

URBAN, V.F. 1978. "Letter to the Editor - Integrated Surveys: Grids and Railway Gauges", N.S.W. Surveyors' Monthly Bulletin, Vol. 15, No. 6.

VAN DE STERR, W.C. 1975. "Our Survey System and its Economic Value", Collated by DALE, P.F. Survey Review, Vol. 13, No. 175, 29-33.

VAN DER WEELE, A.J. 1974. "Photogrammetry for Cadastral Surveys", ITC Journal, 1974-5, 617-627.

VAN WIJK, M.C. 1970. "Orthophotographs in Cadastral Surveys", Papers from the 1970 ASP Annual Meeting.

VAN WIJK, M.C., MULLEN, R., VISSER, J. and VAN ZUYLEN, L. 1972. "Performance and Applications of Orthophotomaps", Proceedings of the 12th Congress of the International Society for Photogrammetry, Ottawa.

VISSER, J. 1974 a "Photogrammetry for Cadastral Surveys", ITC Journal 1974-5, 628-637.

VISSER, J. 1974 b "Photogrammetry for Urban Mapping", ITC Journal 1974-5, 638-649.

VISSER, J. 1976. "The Use of Large Scale O.P.M.s in Cadastral Survey and for Rural and Urban Development Projects", Proceedings of the 13th Congress of the International Society for Photogrammetry, Helsinki.

VITELLI, E. 1976. "The Italian Digital Cadastre: Organisation and Methods", Proceedings of the 13th Congress of the International Society for Photogrammetry, Helsinki.

VOLOHATUKE, W.J. 1975. "Cadastral Surveys: An Alternative to Monument Control", Canadian Surveyor, Vol. 29, No. 3, 295-299.

WAALER, A. 1974. "Developing and Using a Central Property Register in Oslo", Proceedings of the 4th Annual European Symposium on Urban Data Management, Madrid.

WAHL, B.J. 1975. "Technical Features Essential to a Modern, Multi-purpose Land Data System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

WALKER, P.A. and DAVIS, J.R. 1978. "The Nelligen Geographic Processing System: System Design", DSIRO Division of Land Use Research Technical Memorandum 78/11.

WALKER, R.N. 1979. "A System for Mapping - Data Acquisition, Edit and Presentation", Proceedings of the 7th Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

WALLNER, H. 1969. "The Cadastre as the Basis fo an Environmental Data System", Canadian Surveyor, Vol. 23, No. 2, 142-150.

WALLNER, H. 1971. "The New Land Data Bank in Sweden", Proceedings of the 13th International Congress of Surveyors, Wiesbaden.

WARD, F.Y. 1975. "Some Technical Features of a Multipurpose Land Data System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

WARNE, D.K., LEECH, P.R. and MacLEOD, I.D.G. 1975. "Landsat (ERTS) Imagery as a Tool in Regional Planning", Proceedings of the 3rd Australian Conference on Urban and Regional Planning Information Systems, Newcastle.

WARREN, D.E. 1978. "By Whose Standards?", Survey Review, Vol. 23, No. 187. 195-201.

WATTLES, G.H. 1972. "Some Thoughts on Land Title Records and Computerization", In MOYER, D.D. and FISHER, K.P. (Eds) Land Parcel Identifiers for Information Systems, American Bar Foundation, Chicago.

WATTLES, G.H. 1975. "Surveying Accuracies as the Basic Consideration in a Land Record System", Proceedings of the North American Conference on Modernization of Land Data Systems, Washington, D.C.

WAUGH, T.C. 1974. "GIMMS - An Example of a User-Oriented, Integrated System with Special Reference to Locational Description and Mapping Capabilities", Proceedings of the 4th Annual European Symposium on Urban Data Management, Madrid.

WEALD, D.E. 1971. "The Collection, Processing and Retrieval of Data for Town Planning and Development", Paper presented at the 13th International Congress of Surveyors, Wiesbaden.

WEATHERHEAD, E. 1970. "Geocoding - A Technique in the Development of Urban Information Systems", Ontario Economic Review, Vol. 8, No. 5, 4-12.

WEISSMANN, K. 1975. "Cadastral Surveying by Photogrammetry", World Cartography, 13, 41-66.

WELLS, J.M. 1976. "A Brief Background and Description of Current Spatial Referencing Activities at the Division of Land Use Research, CSIRO", Segment-Oriented Referencing Systems Association Working Paper No. 7.

WELLS, J.M. 1978. "Planning Information System Activity in Australian Local Government (Edition 2)", DSIRO Division of Land Use Research Technical Memorandum 78/15.

WEST, C.J.L. 1974. "Identification Surveys in N.S.W.", Australian Surveyor, Vol. 26, No. 1, 51-61.

WHALAN, D. 1967. "Electronic Computer Technology and Torrens System", Australian Law Journal, Vol. 40, 413-424.

WHITE, B.M. 1973 a. "The Place of Survey in Land Registration", Survey Review, Vol. 22, No. 167.

WHITE, B.M. 1973 b. "Correspondence: Cadastral Boundary Disputes", Survey Review, Vol. 22, 170. 181-183,

WHITE, M.S. 1977. "Topological Encoding of Land Records", Proceedings of the 37th ACSM Annual Meeting, Washington, D.C.

WILKINSON, M. 1980. "The Integration of the N.S.W. Valuer General's Computer System into the Sydney Water Board's Computer System", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

WILLIAMS, E.P.J. 1974. "The Development of Urban Cartographic, Planning and Management Data Banks", Paper presented at the 7th International Conference on Cartography, Madrid.

WILLIAMS, O.W. 1976. "The Navstar Global Positioning System and a First Order Framework for Information Systems", Proceedings of the Land Records Symposium, University of Maine at Orono.

WILLIAMS, R. 1980. "Development of a Central Land Data Base and Map Base Systems for Townsville City Council", Proceedings of the 8th Australian Conference on Urban and Regional Planning Information Systems, Surfers Paradise.

WILLIAMSON, I.P. 1981. "The Assessment of a Swiss Cadastre from an Australian Perspective", Australian Surveyor, Vol. 30, No. 7, 423-453.

WILLIAMSON, I.P. 1982. "The Role of the Cadastre in a Statewide Land Information System", Proceedings of the 10th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

WILLIAMSON, I.P. and HOLSTEIN, L.C. 1978. "Aspects of Title Surveys in Australia", Proceedings of the 21st Australian Survey Congress, Adelaide.

WILLIS, J. 1972. "A Strategy for Developing Computerized Information Systems for Local Government: The End of the Mega-System", In PERRATON, J. and BAXTER, R.S. (Eds) Models, Evaluations and Information Systems for Planners, MTP Construction, Lancaster.

WILLIS, J. 1978. "British Urban Information Systems: A Review of Developments 1968-1978, and Examples of Current Practice", Proceedings of the 6th Australian Conference on Urban and Regional Planning Information Systems, Sydney.

WOLLEY-DOD, W.A. 1975. "The North American Conference on Modernization of Land Data Systems - A Multipurpose Approach", Canadian Surveyor, Vol. 29, No. 5, 531-534.

YOUNGS, C.W. 1969. "Coordination of Property Surveys in an Integrated System", Surveying and Mapping, Vol. 29, No. 4, 687-690.

YOUNGS, C.W. 1972. "History and Objectives of Large-Scale Urban Mapping Within Survey Control Areas in Alberta", Canadian Surveyor, Vol. 26, No. 5, 508-509.

ZARZYCKI, J.M. 1978. "An Integrated Digital Mapping System", Canadian Surveyor, Vol. 32, No. 4, 443-452.

ZARZYCKI, J.M., HARRIS, L.J. and LINDERS, J.G. 1975. "Topographic-Cartographic Data Base and Automated Cartography in Canada", Proceedings of the Conference of Commonwealth Survey Officers, Cambridge.

ZIEMANN, H. 1970. "Recent Developments in Urban Surveying and Mapping in West Germany", Papers from the 1970 ACSM-ASP Technical Conference, 514-542.

ZIEMANN, H. 1975. "Technical and Legal Aspects of a Cadastre - based Land Information System", Canadian Surveyor, Vol. 29, No. 1, 9-21.

ZIEMANN, H. 1976 a. "Land Unit Identification: An Analysis", NRC 15736, National Research Council of Canada, Ottawa.

ZIEMANN, H. 1976 b. "Requirements of a Land Data Management System", Proceedings of the Land Records Symposium, University of Maine at Orono.

ZIEMANN, H. 1977 a. "A Data Base for Geographic Referencing in a Land Data System", Proceedings of the 37th ACSM Annual Convention, Washington, D.C.

ZIEMANN, H. 1977 b. "Spatial Partitioning in Land Data Management (Cadastral) Systems", In DUTTON, G. (Ed) Proceedings of the 1st International Advanced Study on Topological Data Structures for Geographic Information Systems, Harvard University.

ZIMMERMANN, R.H. and DUEKER, K.J. 1977. "An Automated Land Use Information System: Needs, Possibilities, Recommendations and Problems", Proceedings of the 37th ACSM Annual Convention, Washington, D.C.

ZWART, P.R. 1980 . "Limited Titles - Instruments of Change", Australian Surveyor, Vol. 30, No. 3, 163-169.

ZWART, P.R. 1981 a. "Monumented Control in Urban Areas - An Anachronism?", Australian Surveyor, Vol. 30, No. 7.

ZWART, P.R. 1981 b. "Administrative Reform for Land Information Systems - A Necessity", Proceedings of the 9th Australian Conference on Urban and Regional Planning Information Systems, Geelong.