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DEFINITIVE CONCEPTS AND IDEAS

Although the true power of the quantitative approach is based on the fundamental doctrine of physics — to define, measure and develop conceptual relationships — it is also true that in the broad context of socio-economic phenomena the methods and practice of operations research are an indispensable aid. Land use and transport are conceptualised as a system, and definitions are given for land-use activity (population, employment) and for transport facilities (capacity, speed, costs). Zones and networks are employed to give an analytical representation to land use and transport, and examples drawn from the local, urban and regional scales illustrate the application of these simple ideas as a prerequisite for measurement, analysis and synthesis.

THE LAND-USE AND TRANSPORT SYSTEM — DEFINITIONS

One commonly accepted definition of a 'system' is a 'set of objects together with relationships between the objects' (Hall and Fagen, 1956). It is helpful to conceptualise land uses (football fields, housing estates, factories) and transport facilities (roads, ports, railway stations) as the 'objects' (components) of the system of our particular study. The medium that ties them together to make a system is traffic.

Traffic is sometimes erroneously considered to be synonymous with transport facilities or communications apparatus alone, but the truth is that traffic is the *joint* consequence of land-use activity levels and transport capability. As with any kind of system, the behaviour of one component — land use, or transport — has some effect on, or interaction with, other components. In the land-use and transport system, the 'vehicle' of this interaction is traffic.

Land uses and transport facilities form a closed-loop system. By this we mean that the system, when faced with changes to the individual components, will (like physical systems) settle down in the long term into a state where traffic is in a steady state — that is, the system is in equilibrium, even though this equilibrium state may be far from what society regards as optimum. Obviously, major changes (for example, the advent of the motor car) will produce substantial shifts in the equilibrium. A catastrophe could wreck the system.

Both land use and transport are necessary to generate traffic. For example, there would be no traffic to justify the construction of railway into the sparsely populated interior of the Australian continent — unless, of course, there are mineral resources to extract or a 'Las Vegas' to promote. Similarly, there would be no enthusiasm for a land-use proposal such as a recreational resort in a remote place with no transport links with the outside world and with no future prospects of getting any transport. However, many everyday experiences demonstrate that when land use and transport *do* exist, then the *amount* of traffic that comes into existence is determined by the level of land-use activity and the physical characteristics of transport facilities.

Such a quantitative approach requires the application of systems analysis, which is a scientific method commonly applied in the study of physical, environmental or social systems to allow complex and dynamic situations and interactions to be understood in broad outline. Systems analysis provides a convenient framework for planning, designing and managing large-scale systems.

One of the primary objectives of planning any land-use and transport system is to ensure that there is an efficient balance between land-use activity and transport capability. An example of the imbalance that may occur from mismatching the land-use and the transport components of a system is a hypermarket with parking for 2000 vehicles served by a narrow lane. If this were located in an isolated village of 500 inhabitants there is a further mismatch with the broader socio-economic or socio-political environments. Before any calculations can proceed that might shed light on this degree of 'imbalance' or 'mismatch', the system and its objects (components) must be defined in such a way as to permit an analytical representation. Stripped to its essence, the main components of the system are land-use dispositions and transport facilities. Numbers are to be attached to each component, as explained in the next section.

Land-use activity

Land use is a term from agricultural economics, originally referring to a piece of ground and the economic use to which it was put — pasture, cropland or quarry. This was elaborated in urban planning and is now used in several ways in contemporary literature (Chapin, 1976, p. 3).

In a general sense, 'urban land use' means the spatial distribution or geographical pattern of city functions — residential areas, industry, commercial areas, retail business, and the spaces set aside for governmental, institutional and leisure functions. Traditionally, the land-use survey has been concerned with the use of ground space (or space use within buildings). Uses of developed land have been classified and recorded according to 'functional activities', one abbreviated example of which is shown in Table 1.1.

Table 1.1 A General Land-Use Activity Classification

Activity code*	General land-use activity
1	Extraction activities (including stockpiling and assembly of material incidental to these activities)
2	Processing activities (including refining, fabricating, assembly storage, parking and other space uses incidental to these activities)
3	Communications activities (including related rights-of-way, storage, service, parking and other areas incidental to these activities)
4	Wholesale–retail distribution activities (including customer or employee parking, loading, service and other related areas)
5	Service activities (including customer or employee parking, loading, service and other related areas)
6	General welfare, community service and non-commercial leisure-time activities (including parking, service and other related areas)
7	Residential activities
8	Employment centres (the central business district, industrial estates)
9	Unused space (unimproved and improved land, water areas)

* The original table contains 65 two-digit codes. (Source: adapted from Chapin 1976, Table 22, pp. 278–81).

In some of the literature the meaning of 'land use' involves two related parts: first, in terms of activity patterns of people, firms and institutions as they use space; and, second, in terms of the physical structures or facilities which are made to accommodate these activity patterns and functions. The socio-economic environment is a determinant of the level or the amount of activity both in time and in space. It is straightforward to specify measures of land-use activity, and some simple ones appropriate for the general classification in

Table 1.1 are set out in Table 1.2. By treating land use in terms of detailed land-use activity classifications, its spatial distribution, and associated measures of activity levels, definitions of an analytical character are possible.

Table 1.2 Typical Examples of Measures of Land-Use Activity

Activity code	General land-use activity	Measure of activity level
1	Extraction	Agricultural hectares, head of stock, reserves of ore, output capacity
2	Processing	Floor-space area, number of factory employees, production units
3	Communications	Parking spaces, number of platforms, berths, or service channels
4	Wholesale–retail	Floor-space area, retail sales, number of customer parking spaces, service channels
5	Service	Seating capacity, office employees, number of motel beds, parking spaces
6	General welfare, community service and leisure	Student enrolment, hospital beds, number of church pews, parking spaces
7	Residential	Population, dwelling units, vehicle ownership, resident workforce
8	Employment centres	Number of jobs
9	Unused	None

Transport facilities

Transport capability, or transport supply, represents the potential for communication between land-use activities. The capability is provided by a range of separate transport modes — road, rail, sea and air, and most importantly walking or manhandling — for every trip is either a door-to-door or a floor-to-floor event. A passenger transport mode may be operated to provide individual movement (e.g. private car) or mass movement (e.g. public transport). Transport capability can also be a multi-modal link because there is interdependence amongst the different modes: a journey from home to work may involve a drive to the station, a train, then a walk. Such interrelationships throw into correct perspective the interfaces, or transfer facilities, between two modes — rail–bus interchanges, railway stations, bus terminals, airports, docks and parking.

For analytical purposes, it is appropriate to concentrate on the general operational characteristics of transport facilities, not on specific mode technology (heavy rail versus light rail) nor on detailed designs (a Cadillac versus a Volkswagen). Suitable measures of operational levels of service are door-to-door or floor-to-floor travel times (including waiting times); transport costs (fares, freight rates, and vehicle running costs); or some combination of the two — called 'generalised cost'. All modes and technologies can be reduced to a set of travel times or costs for a modal, or multi-modal, journey.

The impedance of a transport element (or system of elements that forms a network) is conveniently measured by a suitable function which is synonymous with the 'difficulty' of travelling over the link or progressing through the network. Simple functions of time and cost provide sufficient measures of transport impedance for many practical applications.

To summarise, the system that lies at the heart of our interest is composed of types of spatially separated human activities connected by traffic flows of people, goods (and information). The physical manifestations of the land-use and transport system are buildings and their curtilages, open spaces, agricultural land, mineral resources and other adapted spaces, while traffic is accommodated by roads, railways, canals, sea and air routes, pipelines, terminal facilities and wires and cables serving as communications channels. Many different groups have professional and lay responsibility for the various aspects of land-use and transport planning, management, operations and policy, so there is a need to formalise the concepts involved in order that they may be advanced as a basic discipline.

REPRESENTATION OF LAND-USE AND TRANSPORT SYSTEM

A widely acceptable representation of the land-use and transport system — amenable for further analysis — is essential to provide the building blocks for a discipline of transport science. At first, this seems a daunting task because examples of land-use and transport systems can be drawn from a wide range of geographical 'scales' — local, urban-wide and regional — as illustrated in Fig. 1.1. All three systems start off as an isolated land-use activity (supermarket, zone or city) connected to a transport facility (frontage access road, main road, or state highway/railway/air service). A number of such elements of an isolated land-use activity and transport connection may be combined

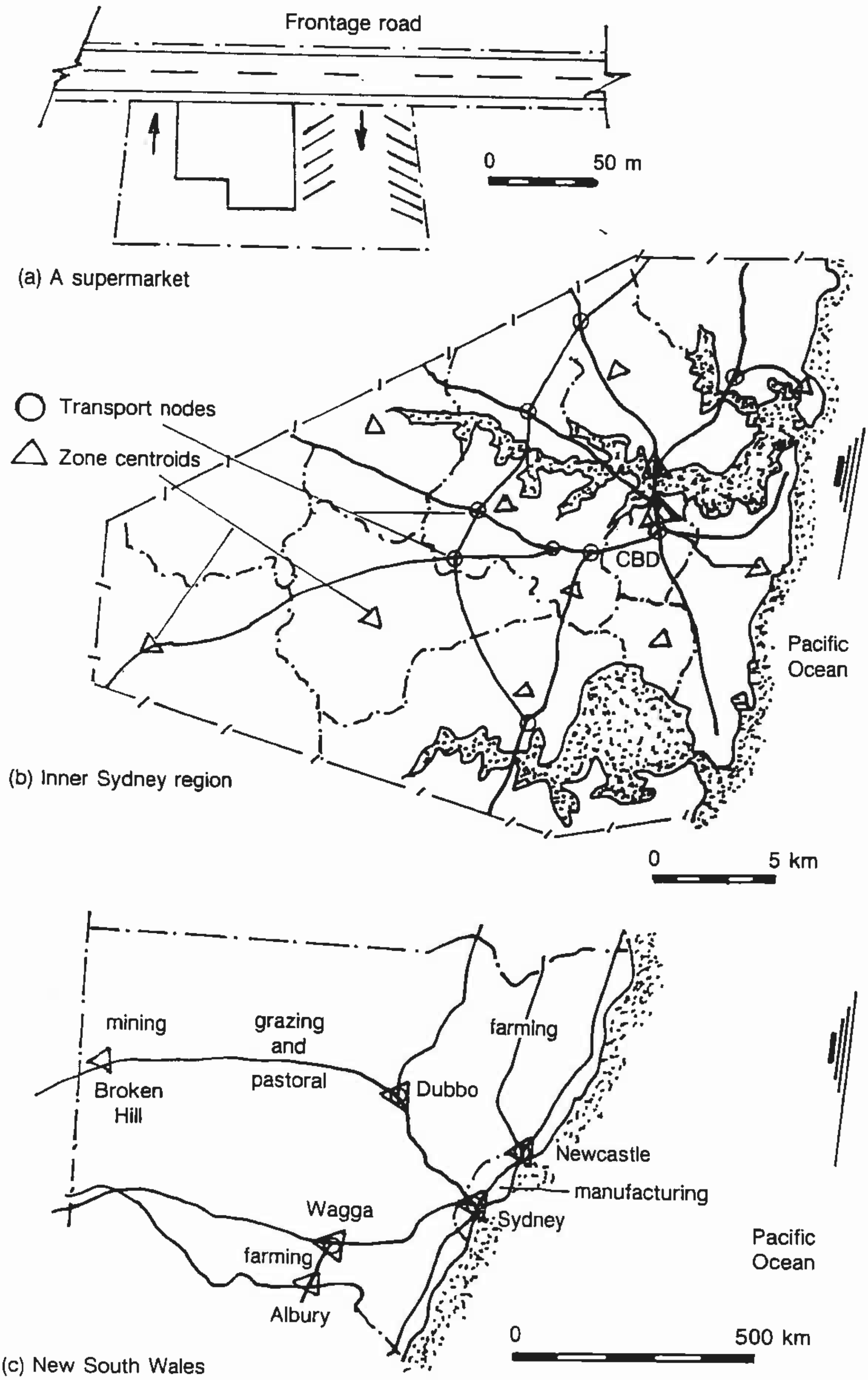
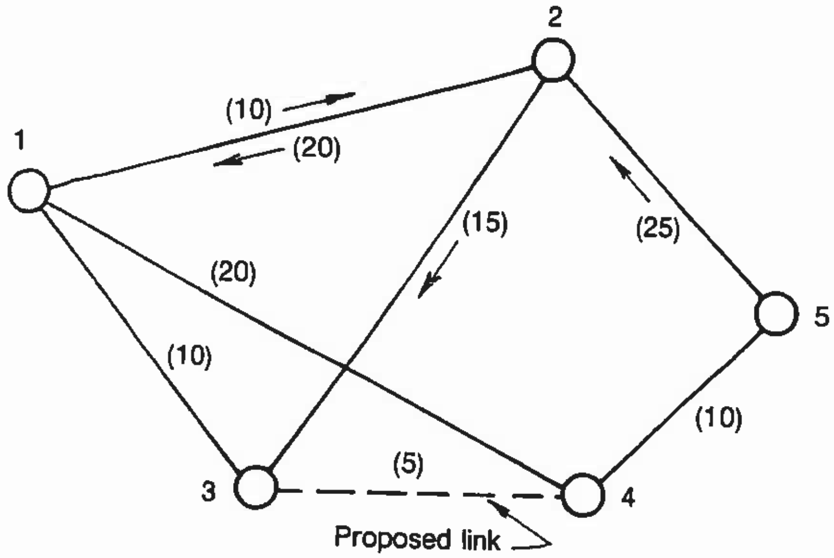


Fig. 1.1 Examples of local, urban and regional land-use and transport systems

to make up a town, a metropolitan area, a region, a nation or a grouping of nations. Land-use zones and transport links provide the building blocks for analysis and synthesis.

The technologies of different transport modes, their right-of-way configurations and their operational features can be expressed in a simple network. The mathematical theory of graphs is exploited to represent transport as an assemblage of links and nodes with travel times, costs or generalised costs associated with each link. By labelling the nodes, the connectivity properties of the network may be specified as a node–node matrix.

Figure 1.2 gives an example of a simple network expressed as a node–node matrix. The network is comprised of five nodes and eight



(a) A transport network. The nodes are numbered serially. Travel times (costs, distances) are shown in parenthesis. For two-way operation and equal travel times (costs, distances), directional arrows are usually not included.

From *i* \ To *j*	1	2	3	4	5
1		10	10	20	
2	20		15		
3	10			(5)	
4	20		(5)		10
5		25		10	

(b) Node–node matrix for t_{ij} (c_{ij}, d_{ij}). This completely defines the network, spatially and operationally.

Fig. 1.2 Representation of the transport subsystem directional links (these represent two-way streets unless indicated by a directional arrow). Transport impedance of each link is travel time in minutes and is shown in parentheses in Fig. 1.2(a). The node–node matrix of direct connections and transport impedances is shown in Fig. 1.2(b). Changes in transport capability arise when: travel time changes (transport operations); directional flows are altered (traffic management); or additional transport links (or increased capacity of an existing link) are added (transport construction).

Having defined the land-use and transport system and indicated how to represent such a system for analysis and synthesis, we are now ready to define more precisely the 'traffic' in this system. The term 'traffic' immediately conjures up an image of physical movement; and by reconsidering both Figs 1.1 and 1.2, it is easy to conceptualise traffic as a flow over the transport facilities that link the land-use activities represented in the diagrams as triangular zone centroids. Traffic is a process, a medium, a flux (using an analogy with physics) of communication.

In general, there are two kinds of communication: the physical process involving people and goods; and the telecommunication process involving information. This book concentrates on traffic as a process of physical communication, although we are well aware of the substitution implications: no longer do we run for the doctor but ring for him. Indeed, revolutionary developments in computer data storage, handling and transmission and automatic control are harbingers of further substitution. Incidentally, traffic theory has benefited from contributions by the great information traffic institutions — Bell Telephone Company and the Post Office — and from the work of Erlang, the Danish pioneer of the application of queueing theory to telephone traffic, and from Moore, who developed an algorithm to find the minimum path through a maze.

Appropriate *measures* of traffic are counts of the number of pedestrians, vehicles, passengers or freight tonnage in a given direction (i.e. between an origin and a destination)*. Such measurements lead to the following four observations.

1. Traffic from a given origin to a destination is analogous to a vector, in that it has magnitude, direction and sense.

2. When represented as a total demand, traffic corresponds to the load in statics.

3. When the time intensity of traffic (vehicles per hour, tonnes per day) is specified, it is analogous to stress.

* The widely used measure in highway practice is average annual daily traffic (AADT) which counts trips in *both* directions and may lead to confusion with the double counting of trip ends (see Overgaard, 1966, p. 28, for an early discussion of this point).

4. A related measure, analogous to a scalar in physics, is travel which is the aggregate product of the amount of traffic (trips, persons, tonnes) and its distance, time taken or cost — akin to work done or energy.

EXAMPLES OF LAND-USE AND TRANSPORT SYSTEMS

Examples are given at the local, urban and regional scales, with typical data to assist in reinforcing the above concepts. These data are exploited in later chapters.

A local area example

A common local area problem — one central to the assessment of development applications — is how much traffic is generated by well-defined land-use activities such as a regional shopping centre, a hospital, a supermarket or a petrol service station, and whether the surrounding streets can handle this traffic.

The land-use example chosen is a large commuter parking station in a city centre, with an entry and an exit point fronting on to a main road (Fig. 1.3). Because of the need to examine traffic manoeuvres, the land-use and transport system is represented as a set of vehicle turning movements and two-way traffic flows on the main road.

The appropriate measure of land-use activity level is the number of parking spaces — 750 in this case. Traffic generation is a function of the magnitude of this activity level, but traffic varies, of course, from moment to moment. Traffic generation intensity is the equivalent number of vehicles per unit time. Figure 1.3 plots the entries and exits averaged over a half-hour interval as a function of time of day; data were collected from 7 am to 10 pm. If the parking station is thought of as a destination or a 'sink' (i.e. in the morning), then the intensity of traffic generation is given by the positive values on the graph. Considered as an origin of trips, or a 'source', then the lower curve is the relevant intensity function. The traffic generation intensities vary from a few vehicles per hour to a maximum 430 vehicles per hour in-bound or 330 vehicles per hour out-bound.

The problem of 'access' to and from such frontage land uses from a road is one of queueing for gaps in a priority stream. Exiting vehicles are required to give way to main-road traffic in both directions, and right-turn entries must give way to the opposing traffic stream (when driving on the 'left-hand side' of the road, as in Australia and Great Britain). In the busiest hour of the morning, the following traffic movements are observed:

Left-turn in	360 vehicles per hour
Right-turn in	70 vehicles per hour
Left-turn out	20 vehicles per hour
Right-turn out	0 vehicles per hour