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The future of Irish access transport: investigation, modelling and appraisal

(2 volumes)

Volume II: Appendices and References

Warren James Whitney

Thesis submitted to the University of Dublin, Trinity College, in fulfilment of the requirements for the award of the degree of Doctor of Philosophy

Transport Study and Research Group
Department of Civil, Structural and Environmental Engineering

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APPENDIX A GLOSSARY

ACAP	Advisory Committee on Airports Policy (UK).
Appraisal	This term is used in preference to "evaluation" when referring to the process of examining and comparing the performance of alternative strategies. It has been chosen because some sources treat "evaluation" as purely concerned with *ex post* investigations (examining the performance of an already-implemented scheme) rather than the *ex ante* situation concerned here.
ASCE	American Society of Civil Engineers.
ASHI	Air/Sea High Investment strategy.
ASMD	Air/Sea Managed Demand strategy.
AST	Appraisal Summary Table. The format used for summarising evaluation results in NATA (q.v.) and GOMMMS (q.v.).
BA	Buoyant Air strategy.
B/C	Benefit/Cost (Ratio). A decision rule used in CBA (q.v.), equal to (discounted benefits) ÷ (discounted costs).
BMW	Border, Midlands and West region.
Buoyant air transport	Transport system employing aircraft supported at least partly by lifting force derived from buoyancy in air (as in a balloon or airship).
CAA	Civil Aviation Authority (UK).
Car-accompanied travel	Passengers travelling with a car by ferry or rail.
CBA	Cost-Benefit Analysis.
Classic travel	Passenger traffic conveyed as foot passengers (unaccompanied by cars) on ferries and travelling overland by coach or rail.

CMBA	Combined Buoyant Air strategy.
CMFL	Combined Fixed Link strategy.
CO	Carbon monoxide.
CO_2	Carbon dioxide.
COBA	British CBA (q.v.) methodology used in trunk road assessment prior to implementation of NATA (q.v.) and subsequently as a basis for costed elements of NATA. Ultimately superseded by Sugden CBA (q.v.).
CSO	Central Statistics Office.
CTOL	Conventional Take-Off and Landing.
CTRDAC	Civil Tiltrotor Development Advisory Committee (US).
Delphi	Technique for producing a consensus opinion in forecasting studies by iterative submission of a forecast to a panel of experts.
DETR	Department of the Environment, Transport and the Regions (UK)
Direct demand model	Transport demand model that generates trip volumes for each mode on an origin-destination pair as a function of the characteristics of the mode, origin and destination.
DoENI	Department of the Environment for Northern Ireland.
DTI	Dublin Transportation Initiative.
Dynamic lift	In an aircraft, lifting force derived from the motion of a wing (as in an aeroplane) or rotor (as in a helicopter) through the air.
Dynastat	Buoyant aircraft supported partly by static lift and partly by wing-derived dynamic lift.

EUROFAR	European Future Advanced Rotorcraft. European tiltrotor (q.v.) project.
Four-stage model	Transport demand model that predicts flows through four sequential stages of generation, distribution, modal split and assignment.
GAM	Goals Achievement Matrix
GDP	Gross Domestic Product
GNP	Gross National Product.
GOMMMS	Guidance on Methodology for Multi-Modal Studies.
Grand index	An output measure provided by certain appraisal methods, which gives a single-figure assessment of the degree of merit of a plan.
GVA	Gross Value Added. Irish CSO (q.v.) term for the regional (sub-national) equivalent of GDP.
HGV	Heavy Goods Vehicle
Incidence group	A geographical or societal group defined in terms of how it is affected by a project.
IRR	Internal Rate of Return. A decision rule used in CBA (q.v.), equal to the discount rate for which NPV (q.v.) = 0.
ISO	International Standards Organisation; originator of standardised dimensions for freight containers.
JIM	Judgmental Impact Matrix. See chapter 3.
Lo-Lo	Lift On- Lift Off. Unitised (q.v.) freight traffic conveyed in containers lifted on and off ships by crane. See also Ro-Ro.
MAP-1	Multicountry Application for Passengers. Passenger quasi-direct demand model developed by the University of Karlsruhe (and others) and utilised in STEMM (q.v.)
MCA	Multicriteria Analysis. See chapter 3.

MDST	Freight model developed by the British consulting firm MDS Transmodal for certain STEMM (q.v.) case studies.
Meta-mode	In the demand modelling process, a term used to refer to a choice of travel type (e.g. classic or air travel) which encompasses a subset of several transport modes.
Motorail	Passenger train service conveying accompanied cars.
mppa	Million passengers per annum.
NATA	New Approach to Transport Appraisal (UK). See Chapter 3.
NDP	National Development Plan (Ireland).
NI	Northern Ireland.
NO_x	Oxides of nitrogen.
NPV	Net Present Value. The net discounted value of costs and benefits in CBA (q.v.).
NSS	National Spatial Strategy (Ireland).
NSTR	Standard Transport Nomenclature (Revised). Commodity classification applied in many freight transport statistics. See also SITC.
NUTS	Nomenclature of Territorial Units for Statistics. Standard EU nomenclature for regional divisions of countries.
O-D	Origin-Destination.
OD-ESTIM	EU 4^{th} Framework project on the estimation of interregional transport demand matrices from regional economic data.
OPT	Operational Programme for Transport.
Piggyback	Rail freight service providing for the carriage of trucks or trailers
p-km	Passenger-kilometre.

PM	Particulate matter.
Quasi-direct demand model	A transport demand model whose generation and distribution process resemble the direct demand model (q.v.) but in which modal split is treated as a separate stage.
Ro-Ro	Roll On- Roll Off. Unitised (q.v.) freight traffic conveyed in trucks or trailers (sometimes, though not in Irish market, rail vehicles) driven on and off ships. Also, by extension, passenger traffic conveyed in vehicles driven on/off ships. See also Lo-Lo.
Rotastat	Buoyant aircraft (q.v.) supported partly by static lift and partly by rotor-derived dynamic lift.
RUCATSE	Runway Capacity to Serve the South East.
SACTRA	Standing Advisory Committee on Trunk Road Appraisal (UK).
Scenario	Internally coherent projection of one of several possible future outcomes for a set of variables subject to uncertainty.
S&E	Southern and Eastern region.
SEAAF	South East Airports Appraisal Framework. Evaluation structure for the SERAS (q.v.).
Seabus	Surface-skimming ultra-high-speed ferry, derived from EU-sponsored BRITE-EURAM project involving the development of a form of wing-in-ground-effect craft for transport applications.
SERAS	South East (and East of England) Regional Air Services Study.
SGSEA	Study Group on South East Airports.
Shadow price	A price for a commodity which is not traded in the market, e.g. time, pollution. Used in social CBA (q.v.).

SITC	Standard International Trade Classification. System of commodity classification widely used in trade statistics. See also NSTR.
SO_2	Sulphur dioxide.
STAN	Strategic Transportation Analysis. A freight model developed by the University of Montreal in the 1980s and applied in two STEMM (q.v.) case studies and in this project.
Static lift	In an aircraft, lifting force derived from buoyancy in air (as in a balloon or airship).
STEM	Simultaneous Transportation Equilibrium Model. A model which simultaneously solves the different stages of the classical four-stage (q.v.) transport model by translating it into convex program form. See chapter 3 for details. Not to be confused with STEMM.
STEMM	Strategic European Multi-Modal Modelling. EU 4th Framework project involving the modelling of interregional passenger and freight flows with particular reference to intermodal aspects. Not to be confused with STEM.
STOL	Short Take-Off and Landing.
Strategy	Any one of a number of alternative packages of measures for development of the transport system.
Strategy element	A possible transport measure included in one or more strategies (q.v.).
Sugden CBA	Form of cost-benefit analysis endorsed by GOMMMS (q.v.) incorporating a greater focus on the costs and benefits to different incidence groups and the use of market prices (i.e. inclusive of tax) instead of resource costs. It is summarised in the TEE (q.v.) table.
Swap-body	Form of intermodal unit, broadly similar to a container but generally not designed

	to ISO container dimensions and devoid of top lifting points.
TEE	Transport Economic Efficiency. The TEE table is the summary sheet for Sugden CBA (q.v.)
TEU	Twenty Foot Equivalent Unit. Measure of unitised (q.v.) freight movements by volume- equal to one ISO 20' container.
Tiltrotor	A type of V/STOL (q.v.) aircraft with propellers which tilt their axis of thrust to become helicopter-like rotors.
t-km	Tonne-kilometre.
Unitised freight	Freight conveyed in standardised units- either containers or road vehicles.
Vertiport	A terminal facility designed for tiltrotor (q.v.) configuration V/STOL (q.v.) aircraft.
VFR	Visiting friends and relatives.
V/STOL	Vertical/Short Take-Off and Landing.
VTOL	Vertical Take-Off and Landing.
WCML	West Coast Main Line. British railway line providing the main link between London, the West Midlands, the North West and the principal Irish Sea ports.
Wing-in-ground- effect	Transport mode based on vehicles resembling an aircraft operating at very low altitude above a water surface.

APPENDIX B TECHNOLOGICAL OVERVIEW

B.1 INTRODUCTION

B.1.1 Overview

Appendix B deals with the technical background to the information presented in sub-section 3.6.2 of chapter 3, concerning possible technologies for application in the longer-term development of the Irish access transport system. It summarises the work carried out in Task 2 of the project. The preliminary identification of possible technologies made in sub-sections 3.6.1 and 3.6.2 of the thesis has been utilised as a starting point for this analysis.

B.1.2 Structure of Appendix B

This appendix is structured according to transport mode. Sections B.2 to B.7 inclusive deal respectively with conventional air transport (including V/STOL technologies), conventional (low-speed) sea transport, high-speed sea transport, fixed links, buoyant air transport and land modes providing access to terminals.

Within each mode, sub-sections successively examine the scope and background of the technology, performance characteristics (such as vehicle payloads and operating speeds), costs (capital and operating), environmental impacts and requirements for terminal facilities.

Section B.8 summarises the results of the overall analysis.

B.2 CONVENTIONAL AIR TRANSPORT (INCLUDING V/STOL)

B.2.1 Scope and background

"Conventional" air systems, for the purposes of this study, are defined as those where the craft is supported in the air when empty entirely by dynamic lift, i.e. that arising from propelling a wing forward or from vertically-acting rotor thrust. It is implied that the payload is also supported dynamically; however, a craft whose payload is supported dynamically but whose structure is supported by static lift (arising from buoyancy) is considered a buoyant aircraft and is beyond the scope of this chapter. Only vehicles designed for normal operation out of ground effect (aerodynamic interaction between the wing and the earth's surface, which occurs at very low altitudes) are considered to constitute air transport. Those designed for normal operation in ground effect (wing-in-ground-effect craft) are considered as high-speed marine transport (since, in practice, they can only operate over water). Although this latter is a somewhat arbitrary distinction, it appears to agree with the policies of both international regulatory authorities and standard reference sources.

Conventional air transport systems can be further subdivided according to the form of take-off and landing used. Most aircraft are CTOL, Conventional Take-Off and Landing; in simple terms, this includes every aircraft requiring a runway (other than a very short one) for take-off and landing. V/STOL (Vertical/Short take-Off and Landing) aircraft can use short runways and/or take off and land vertically. Both generic types are likely to find applications in the Irish access market, although V/STOL usage is currently negligible.

At one end of the V/STOL spectrum are conventional aircraft capable of short-runway take-offs and landings (STOL), though retaining the capability for a longer (and more economical) ground run where possible. At the opposite extreme is the vertical take-off and landing (VTOL) helicopter; however, this craft requires vertical thrust throughout flight, which increases noise, vibration, wear and fuel consumption. Many attempts have been made over the years to develop an aircraft capable of combining the advantages of CTOL and VTOL. The principal example at present, and the only one likely to become feasible by 2020, is the tiltrotor (Figure B.1), consisting of a conventional aircraft fuselage

and wings with large rotors mounted at the wingtips. The rotors can, as the name implies, be tilted to vary the angle of thrust between horizontal (for cruising flight with the wings supplying all the lift) and vertical (for VTOL). STOL is possible using intermediate thrust angles.

The historical background of CTOL aircraft is well-known and does not require description in any great detail. The technology was developed in the early years of the 20th century, first saw significant use in World War I, and was gradually applied to civilian transport- including access to Ireland- in the 1920s and 1930s. Further development after World War II led to technological innovations such as gas turbine engines, which gave rise in turn to a rapid increase in the role of air in both passenger and freight transport. In practice, since the arrival of jet aircraft in the 1960s, change in short-range aircraft technology has tended to be evolutionary in nature. Any major technological developments in the near future are likely to centre on high-speed (possibly supersonic) and very large aircraft, neither of which areas is of particular relevance to this market. Incremental refinements in areas such as propulsive efficiency may, however, take place. Although potential exists for alternative fuels such as hydrogen, it does not appear that these will make a significant contribution by 2020.

V/STOL has a more convoluted and less successful history than CTOL. The concept originated shortly after World War II; one early objective was the development of a military fighter aircraft independent of vulnerable runways, but interest in civilian use appears to have grown in the 1960s. A very wide range of configurations has reached test flight stage. Amongst these have been tiltrotors, tilt-wings (aircraft whose entire wing structure tilts along with the engines and rotors), vectored-thrust jets and many more. Technical difficulties seem to have been the principal explanation as to why a workable aircraft took so long to evolve.

It appears that the tiltrotor is the principal, perhaps the only, form of V/STOL technology likely to become available in a suitable form for commercial airline service by 2020. The US Bell/Boeing Osprey military tiltrotor project has been under way since 1982. Though economic and safety problems have slowed development, a craft capable of transporting a payload of 9t or 24 troops at a 509 km/h cruise speed over 3,336 km (Jackson 1998) is now in service. Civil spin-off designs have been considered. The furthest-advanced civil spin-off of the Osprey is the Bell/Agusta 609, service entry of which is anticipated for 2003

(Jackson 2001). With only nine seats, scheduled transport is clearly not a viable market for this design. Ashford and Wright (1992) describe a range of projected future civilian tiltrotors with 19 to 75 seats. For the purposes of the major study carried out by the Civil Tiltrotor Development Advisory Committee [CTRDAC] (1995) a 40-passenger craft, whose characteristics are outlined in Table B.3, was assumed.

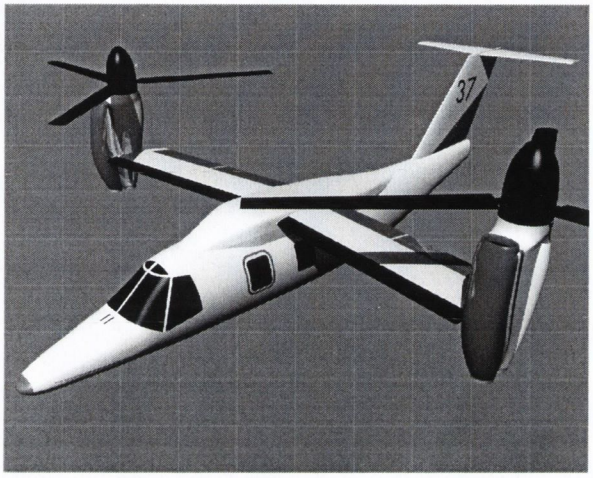


Figure B.1 Small civil tiltrotor- artist's impression (© NASA)

The European counterpart of the Osprey programme was EUROFAR (European Future Advanced Rotorcraft). This project involved the development of a 30-seat civilian tiltrotor with a range of 1,230km and a cruising speed of 620km/h. The first flight was scheduled for 2004 and entry into service projected in 2010 (Jackson 1998). This design is also included in Table B.3. The project is no longer active in its original form, but several of the participants have expressed interest in building similar aircraft. The Eurotilt and Erica projects in Table B.3 are representative of the latter.

B.2.2 Performance

The most obvious transport characteristic of conventional air systems is a very high cruise speed compared with other modes. Short-range jet aircraft (e.g. Boeing 737) cruise at around 700-900km/h. Turboprop aircraft are rather slower, but cruise speed makes comparatively little difference to overall time on the relatively short routes typical of the Irish access market.



Figure B.2 Boeing 737-800 medium-range jet airliner (© Ryanair)

The aircraft types currently used in the Irish access transport market can be broadly classified into three generic classes. Medium-range narrow-body twin jets (B737, A320 series, DC9/MD80 etc.) dominate the principal routes (e.g. Dublin to London) and virtually all low-cost operations. These aircraft (Figure B.2) typically have 100-200 seats, are powered by twin turbofan engines and cruise at around 900 km/h over ranges of 3,000-5,000 km. The more important of the secondary routes are operated by regional jets (BAe 146, Canadair RJ etc.) with 50-100 seats, two or four turbofan engines and cruise speeds of 700 km/h over 2,000 km. Lesser secondary routes utilise regional turboprop airliners (Fokker 50, ATR42 etc.) which have 30-70 seats and a cruise speed of around 500-700km/h over about 2,000km, with two turboprop engines. See also Table B.1.

Unitised freight conveyed by air almost invariably travels in airline containers, which are considerably smaller than ISO size and therefore unsuitable for intermodal use. ISO containers can be conveyed by one or two large wide-body freight aircraft types- none in use in the Irish market. Ro-ro trailers cannot be carried by air; air services carrying accompanied cars did exist in the Irish market at one time, but disappeared (as in other countries) soon after the advent of ro-ro ships.

Aircraft used for air freight are principally variants of the passenger types described above. In the event of a high-capacity dedicated freight service being implemented, it would probably be necessary to consider larger freighters. The largest aircraft evaluated by KPMG and CHL (1990) as part of a strategy for increasing freight capacity was the Douglas DC8, an obsolete four-engined, narrow-bodied airliner with a 40t payload capability. Wide-body freight aircraft would probably be worthy of consideration, although relatively few designs would be suitable for short-range operation. The most promising

appear to be the freighter variants of the Boeing 767 and Airbus A300. These offer payloads of around 50t over medium ranges (circa 3,000-5,000km) at speeds of about 900km/h (Jackson 1998). A few even larger freight aircraft do exist, but are generally appropriate only to long ranges and/or specialised payloads. Some possible high-capacity freighters are summarised in Table B.2.

Table B.1 Selected Short/Medium-Range Passenger Aircraft

(Source: Phillips 1999)

Manufacturer	Airbus	Airbus	Saab	British Aerospace (Avro)	British Aerospace (Avro)	Boeing	Boeing	ATR
Model	A320	A321	2000	RJ85	RJ100	737-400	737-800	ATR 42-500
Passenger seats	150	185	50	85	100	146	162	42
Payload (t)	19	22	6	11	12	20		5.5
Length o/a (m)	38	45	27	29	31	36	39	23
Wingspan(m)	34	34	25	26	26	29	34	25
Max. speed (km/h)	977	977	682	870	870	977	870	?
Operating speed (km/h)	929	929	594	720	720	888	935	563
Engines	2×120kN turbofan	2×133kN turbofan	2×3,096kW turboprop	4×31kN turbofan	4×31kN turbofan	2×98kN turbofan	2×107kN turbofan	2×1,610kW turboprop
Range (km)	4,843	4,181	2,185	2,129	2,129	3,629	3,565	1,852
Capital cost (€ million)	?	?	?	26.3	?	43.9	43.3	13.0

Table B.2 High-Capacity Freight Aircraft

Manufacturer	Airbus	Boeing	Boeing
Model	A300-600 Freighter	767-300F	747-400F
Payload (t)	55	51	113
Length o/a (m)	53	55	71
Wingspan (m)	45	48	64
Max. speed (km/h)	484	?	?
Operating speed (km/h)	472	?	?
Range (km)	3,519	5,556	8,149

Source: Jackson (1998)

The operating characteristics of tiltrotors were studied exhaustively by CTRDAC (1995). The committee identified short-range scheduled passenger transport as the principal market, based on a vehicle with the characteristics outlined in Table B.3. Three main segments of this market were distinguished:

- Line-haul service, operating between dedicated terminals (vertiports) in city centre and/or suburban areas of major conurbations and thus providing an inter-city service bypassing congested airports. A service between inner city vertiports in Dublin and London would be a relevant example in the Irish market.
- Feeder service, operating between an existing airport in a smaller city and a vertiport in a major conurbation. A possible example in Irish access would be Cork Airport-central London.
- Transfer service, between an urban or suburban vertiport, or a small-city airport, and a vertiport facility at a major hub airport (bypassing the congested runway system). Kerry-London Heathrow would be one possible Irish example.

Table B.3 Current Tiltrotor Projects

Manufacturer	Bell/ Agusta	Bell Boeing/ NASA	EUROFAR	Eurotilt	Agusta
Model	BA609	CTR2000	EUROFAR	Eurotilt	Erica
Length o/a (m)	13	19	20	?	?
Width o/a (m)	18	26	26	?	?
Max. speed (km/h)	509	648	?	?	?
Operating speed (km/h)	463	583	620	556	?
Range (km)	1,400	1,110	1,230	370-1,481	?
Passenger seats	9	40	30	12-19	20
Engines	2× 1,447kW	2×5,445kW	2×3,200kW	2×?	2×?
Capital cost (€ million)	7.7-9.6	19.3	?	?	?

Sources: CTRDAC (1995), Jackson (1998, 2001).

B.2.3 Costs

Air transport, given its technological complexity and energy requirements, tends to be characterised by high operating costs. However, at least in the market in question, it is also characterised by a fierceness of competition between carriers seldom equalled by other modes, which tends to reduce profit margins and reinforce the importance of cost savings.

Vehicle capital costs are quite high for the air mode. As an example, a large order of Boeing 737-800 jet aircraft (a typical short-haul type) currently being delivered to an Irish airline is costing roughly US$ 45 million (€43.3 million) per unit. Depreciation periods for aircraft are typically around 15 years. For purposes of analysis, the author has assumed capital costs of €43 million for a conventional airliner (as used by mainline and low-cost carriers), €50 million for a high-capacity freight aircraft and €25 million for a regional airliner.

The operating costs of air transport are complex in structure and many aspects are commercially confidential. They are typically classified into direct and indirect (Doganis 1991). Direct costs vary according to aircraft type and include flight crew salaries, fuel,

landing charges, maintenance and depreciation. Indirect costs are independent of aircraft type; examples are airport-based ground staff, cabin crew, advertising and administration.

On a worldwide average, the most important operating cost components are ticketing/sales/promotion (18%), fuel (15%), "station" expenses (the cost of running the airline's ground operations at airports) (13%), maintenance (12%), "passenger services" (cabin crew, catering etc.) (11%) and administration (9%). The considerable risk arising from oil price fluctuations is clearly seen in the importance of fuel costs. Allocation of costs to flights, or between passengers and freight on the same flight, generates a range of possible solutions, the choice between which is generally a matter of individual airline policy.

European airlines tend to have higher operating costs than those elsewhere (mainly due to labour cost levels), and operating cost per km rises as route length shortens (because of lower aircraft and crew utilisation). Although they are relatively short, Irish access routes have comparatively low fare levels, largely due to the intensity of competition in the market. As previously mentioned, the relative strength of low-cost carriers is one notable characteristic of Irish air services. Such firms appear to keep costs down by providing a minimal cabin service, maximising utilisation through short turn-round times, minimising administrative overheads and operating their aircraft at high load factors.. Use of minor airports, where landing charges are low or, in some cases, the airport operator subsidises the airline, is another common feature of such operations.

Apart from low-cost carriers, airlines can be broadly divided into two categories. Mainline operators use similar jet aircraft to the low-cost operators but serve major airports, provide full cabin service and two-class seating, and have considerably higher costs. Regional carriers have similar service characteristics to mainline carriers, but serve thinner routes with smaller jet or turboprop aircraft at still higher cost.

The relationship of fares to costs is complex and uncertain. Examples cited by Doganis (1991) suggest that the average fare paid may be around 65% of the full economy class fare. Freight rates are often around 30% of those published.

Evidence from CAA (1996) suggests that average yield (revenue per passenger-kilometre) is, in 1999 prices, around €0.084/p-km for UK low-cost carriers, €0.184/p-km for mainline carriers and €0.274/p-km for regional carriers. These figures have been assumed to be

typical for the purposes of the modelling work carried out in this study. A figure of €0.49/t-km was assumed for air freight, based on published rates, with this being approximately halved for subsidised services.

V/STOL costs are more of an unknown quantity, given the absence of commercial experience. CTRDAC (1995) carried out a very full examination of the economics of tiltrotor V/STOL aircraft. The capital cost of an individual 40-seat vehicle was estimated at US$18.5million in 1995, or about €24.6 million at 1999 prices. Terminal capital costs were projected to lie in the range US$6-40 million for a new site, depending on the location, size and site characteristics. Operating costs naturally vary with range, but on 200-400 nautical mile (370-740km) routes, typical of the Irish access market, they would range from €0.13 to €0.18 per seat-km (CTRDAC 1995, Fig. E9.2.3-1).

Government subsidies are sometimes provided for airline services. They are applied to domestic routes in Ireland and have been proposed for the promotion of international routes from Northern Ireland (NIEC 1993) as well as certain air freight services (e.g. TPRI 1995). Marginal routes can also be protected through differential charging by airport operators, capital aid to selected airports or restrictions on airlines' route networks (e.g. the obligation on transatlantic operators from Dublin to provide an equal number of flights from Shannon). However, some of these measures may have serious market distortion effects.

B.2.4 Environmental impact

Conventional air transport is a relatively energy-intensive mode, owing principally to its requirement for power to keep the craft in the air (by pushing the wings forward to generate lift) in addition to that required to overcome resistance to motion. Quoted figures for the mode's energy consumption at typical load factors (Hirst 1973; Waters 1992; Barrett 1993; CE 1998) vary between 1.6 and 6.4 MJ/p-km. It is important to note that energy consumption is not entirely a function of distance, as landing and, more especially, take-off phases of flight account for a large proportion- CE (1998) show that a 1500km flight uses nearly 40% less energy per passenger-km than a 500km one.

Associated with high energy use are several pollution problems. A wide range of figures exist, varying with range and aircraft type. However, the data in Table B.4 below have been derived from a synthesis of information contained in CTRDAC (1995), CE (1998) and INRETS (1999). The aircraft type assumed for mainline, low-cost and freight service is the Boeing 737; regional airliners are assumed to be turboprops of the Saab 2000/ Fokker 50 type in 1995, and jets broadly corresponding to the Fokker 70 in 2020. The V/STOL craft assumed is the CTRDAC's CTR2000 design. Emission improvements in the period 1995-2020 are taken from INRETS (1999).

Table B.4 Aircraft Emissions

Poll-utant	Mainline/ low-cost airline 1995 (g/p-km)	Regional airline 1995 (g/p-km)	Air freight 1995 (g/t-km)	Mainline/ low-cost airline 2020 (g/p-km)	Regional airline 2020 (g/p-km)	Air freight 2020 (g/t-km)	V/ STOL 2020 (g/p-km)
CO_2	142	178	1150	106	177	858	178
NO_x	0.42	0.52	3.40	0.28	0.47	2.28	0.52
SO_2	0.44	0.50	3.56	0.33	0.50	2.66	0.50
VOC	0.05	0.07	0.41	0.03	0.065	0.23	0.07
CO	0.09	0.11	0.73	0.06	0.103	0.51	0.11
PM	0.29	0.37	2.35	0.22	0.37	1.75	0.37

Noise is a further, extremely well researched and publicised, factor in aviation's environmental impact. It is of concern principally in airport areas, but its importance cannot be underestimated. Of course, at many of the airports in question- particularly in Britain- traffic on routes within the terms of reference of this study accounts for a relatively small proportion of total movements and therefore of the noise problem, but the impact of strategies involving various different levels of air traffic on noise nuisance will presumably be of concern. The noise implications of any strategy which proposes the creation of new airport facilities, either on an existing airfield or a greenfield site, could also be considerable, depending on the location.

Land requirements for aviation are very small in terms of en-route demands- essentially confined to navigational facilities- and thus overall, compared to, say, highways, but become more significant in terms of terminals. A conventional airport uses a large area of land (4,000ha is not entirely unusual for modern examples) and is likely to be situated close to major urban areas; many are also on prime agricultural land and/or near the coast. The impacts of a new or significantly extended airport in terms of land use changes, demands on the local surface transport system, severance, visual effects etc. can be immense and are usually controversial. In the London area, for instance (treated as an appraisal case study in chapter 3 of the thesis), runway capacity expansion has been almost impossible for many years.

V/STOL environmental issues are somewhat less well defined. As mentioned previously, one of the principal aims in the development of these craft for civilian applications was to

produce a vehicle that had the VTOL capability of the helicopter but posed fewer environmental problems, particularly with respect to noise. V/STOL aircraft would also be expected to have lower fuel consumption and associated emissions than the conventional helicopter, given that they cruise in the lower-energy aeroplane mode.

However, a V/STOL aircraft would be likely to consume more energy and emit more noise overall than a CTOL one, given the fact that it would be operating as a helicopter during VTOL phases of flight. (To balance this, the noise "footprint" of the mode's terminals is much smaller than that for an equivalent airport, owing to the steeper descent angles possible, and the vehicle's noise performance in helicopter mode is superior to that of the helicopter.) According to CTRDAC (1995) the notional 40-passenger CTR2000 would have an energy consumption about 20% higher than that of a Boeing 737 jet, but lower than that of turboprop airliners in the 30-50 seat range.

V/STOL terminals could be expected to have limited impact in terms of land take, ecology, severance etc., since they would be relatively small and most new terminals would either be sited close to city centres (probably on dockland or other "brownfield" sites) or within existing airport complexes. However, noise exposure could become a significant issue in the case of inner-city locations.

B.2.5 Terminal requirements

As mentioned above, CTOL air transport has a considerable demand for terminal land. Airports are particularly complex and costly pieces of transport infrastructure; the location of appropriate sites for construction of a new airport is extremely difficult for a variety of environmental, political and geographical reasons. In addition, it is by no means guaranteed that traffic would justify the investment involved. However, the concept may be valid in certain circumstances. Expansion of existing secondary or military airfields into full-scale civilian airports is an alternative possibility, as in the current plans for Finningley in England or the proposals for Dublin's Baldonnel facility (O'Byrne 1995). This course of action may be of particular relevance to low-cost carriers. There may also be merit in investigating the relative merits of policies which concentrate services and investment on a

small number of airports in Ireland as against those which involve dispersion of traffic over a number of regional airports.

V/STOL terminal requirements are much less than for CTOL, but different issues arise. The V/STOL mode can operate from very short runways or from simple helipad-type parking areas (generally called "vertiports" in the case of tiltrotor aircraft). In both cases, inner-city sites are feasible. Although locations on top of existing buildings have sometimes been mooted, these would face problems in terms of public acceptance, safety and possibly capacity for frequent services. Small inner-city sites, at ground level or possibly integrated into new developments, would be more likely. Dockland areas (cf. the existing London City Airport, which caters for STOL rather than V/STOL traffic) and other inner city brownfield sites (heavy industrial, railway etc.) would be appropriate. As described above, V/STOL could play a second (and, in the Irish context, possibly even more important) role in linking minor regional airports to main hubs. In such cases, little new infrastructure would be required as the vehicles would utilise the existing facilities at the regional airports and existing or expanded VTOL facilities at the hubs.

Ireland is relatively well supplied with conventional airports. Some potential may also exist for additional sites. Furthermore, it does not appear that the physical or other constraints on expansion at any of the major existing airports are so severe as to prevent the accommodation of the traffic likely by 2020. Some (e.g. Belfast City, Cork) are relatively constrained by physical features, but apparently not enough to endanger the capacity of the whole system.

At Dublin, the island's busiest airport, it appears that considerable land reservations for expansion- including provision for a second parallel runway and an additional passenger terminal- exist. This should allow expansion to cater for 40 million passengers per annum (mppa), compared to 13mppa anticipated in 1999. Airport capacity in some of the parts of Britain where major Irish air routes terminate- notably the southeast of England- is under far greater pressure, with no clear strategy for expansion. However, as was noted above in relation to noise, Irish access services within the terms of reference of this study account for a far lower proportion of traffic at these airports than they do in Ireland itself.

Surface access issues are particularly important for airports. The pressure on road and parking space in the immediate vicinity of airports created by heavy car use for access

purposes has become intolerable in many locations, Dublin amongst them. This has led to a trend towards improvement of public transport links to and from many British airports, which Dublin is also following. Domestic air services play a further minor part in access to airports on the "inland" leg of a journey, particularly in Ireland. Volumes are small; many Irish services exist only through public subsidy under the Essential Air Services Programme. Some minor development of these can be expected in the future, but their competitive position is likely to remain fundamentally the same.

Access to airports for freight does not appear anywhere near as critical an issue as for passengers, except insofar as road traffic congestion around airports such as Dublin, resulting primarily from passenger demand, causes delays to freight movements. Airport access infrastructure intended specifically for freight traffic (other than service roads within the airport complex) is rare.

B.3 CONVENTIONAL SEA TRANSPORT

B.3.1 Scope and background

In this study, "conventional" sea transport systems are understood as operating on the water surface at a maximum speed under 45km/h. All conventional (not high-speed) ro-ro vessels currently operating to and from Ireland are encompassed by this definition, along with all present lo-lo and bulk vessels.

As outlined in chapter 2 of the thesis, sea transport to and from Ireland has had a long and distinguished history, with the emergence of steam propulsion in the early 19th century and unitisation of freight (through containerisation and the introduction of ro-ro ships) in the 1960s marking the principal revolutionary changes in technology. A steady increase in vessel size has generally accompanied the evolution of shipping services in this market. Developments in high-speed sea transport (see also B.4 below) will probably increase the degree of competition to be expected from that quarter, but will still leave the majority of the market in the hands of conventional shipping technologies.

Increased vessel sizes are particularly noticeable in ro-ro traffic. They offer economies of scale in terms of fuel efficiency, crewing, terminal arrangements etc., permit closer

integration of passenger and freight services (thus balancing out the effects of differing seasonal peaks) and also allow a very high standard of passenger amenities to be offered (distinguishing such services from their higher-speed competitors). The early generation of ro-ro ships introduced to the Irish Sea in the late 1960s and early 1970s were around 10,000 gross tons. Coopers & Lybrand (1987) observed that the newest ferries then in service on the English Channel were of up to 20,000 gross tons[1], and that the replacements for the first generation vessels on the Irish Sea could be expected to be similar in size. In fact, the current 1990s generation of Irish Sea vessels lay in the range 20,000-40,000 gross tons, and furthermore a 50,000 gross ton multi-purpose vessel (Figure B.3) entered service in 2001 on the Dublin-Holyhead route.

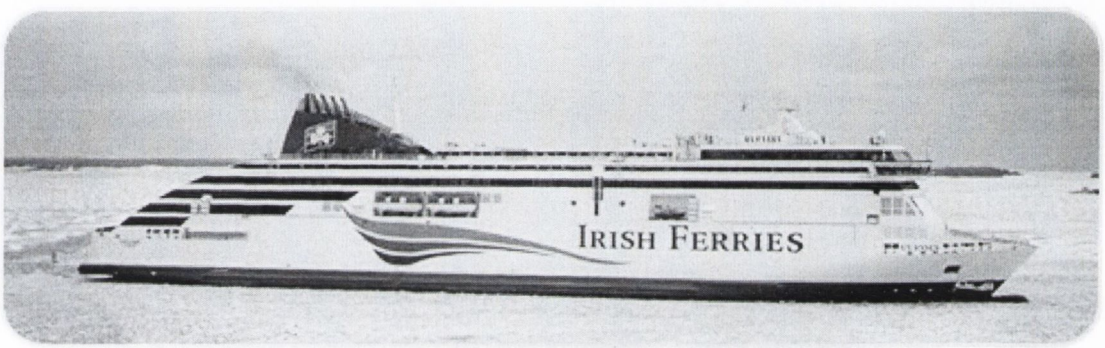


Figure B.3 MV *Ulysses*, ro-ro "superferry" now in service between Dublin and Holyhead. (© Irish Ferries)

It is difficult to foresee any fundamental changes in ro-ro vessel technology coming about by 2020. Loading procedures, navigation systems etc. may well be subject to a certain degree of optimisation. Increased safety requirements are likely, given the known problems posed by the bow loading doors and large undivided vehicle decks on these vessels.

Propulsion systems can be expected to remain fundamentally the same. Alternative fuels are unlikely to contribute significantly. Sail propulsion is a technology specific to sea transport whose prospects for development in the medium term are reasonably good, but it appears to be most appropriate to large, slow vessels with extensive clear deck areas (e.g. supertankers) operating on deep-sea routes (Schönknecht et al. 1983, p.87). Hence, it is not judged to be of significance to the present study.

One special case of the ro-ro vessel deserving at least a passing mention is that of the train ferry. The introduction of such services on the Irish Sea could arguably assist in promoting the shipment of freight by rail rather than road on internal Irish and British/Continental

[1] Gross tons are a measure of volume rather than weight (1 ton = 100 cubic feet)

European legs of the journey. Given the rail track gauge difference, gauge changing (exchange of axles or bogies) would have to take place at one or other port (presumably the Irish terminal, as the ferry's own tracks would almost certainly be to the 1,435mm British gauge). This problem also arises to a certain degree with rail fixed links.

Lo-Lo developments to date have been somewhat slower in pace than their counterparts in the ro-ro market. The current state of the art (Figure B.4), while representing something of an improvement over the vessels used in the 1980s, does not appear likely to progress much further in the foreseeable future other than, perhaps, through a minor increase in average vessel size.



Figure B.4 MV *Jane*, a 700 TEU lo-lo ship in service between Belfast, Dublin and Rotterdam (© Eucon)

Bulk vessels are of many, often specialised, types (e.g. tankers, grain and ore carriers) and those operating in the Irish access market are rarely built specifically for their region of operation (as opposed to type of cargo). It is difficult to generalise about their characteristics, but technological evolution generally appears less significant than in unitised ships.

B.3.2 Performance

Sea transport, in diametric contrast to air, is traditionally seen as a slow and cheap mode. Commercial speeds on ro-ro services are usually below 30km/h; lo-lo vessels are even slower, generally around 25km/h. On sailings between Ireland and Continental Europe, the problem is exacerbated by the indirect routing imposed by geographical constraints.

Current lo-lo vessels are generally around 300-700 TEU (roughly 5,000-8,000t in theory, but practically limited by the average number of tonnes per TEU, which generally lies below 10) in payload. These are small by overall world lo-lo standards (5,000 TEU or larger vessels are increasingly common in deep-sea container shipping) but broadly typical for the short-sea segment of the market. Ro-ro vessels in service at present can carry between 40 and 120 (multi-purpose vessels) or 160 (freight-only vessels) trucks, plus 30-850 cars and 250-2,300 passengers (multi-purpose vessels only).

Lo-Lo vessels can carry any containerised freight; this includes certain bulk commodities conveyed in, for example, tank or open-top containers. Ro-ro vessels, likewise, can convey freight in any form of road vehicle (including, on occasion, containers on road trailers) along with freight which itself consists of vehicles. However, heavy flows of new vehicles tend to be handled as a bulk commodity by dedicated vessels. Freight can be carried "accompanied" (trailer plus tractor and driver) or "unaccompanied" (trailer only).

B.3.3 Costs

The economics of shipping are a complex area, dominated on a world scale by the effects of a heavily-cyclical market and changing trade patterns (Stopford 1997). On the much smaller scale addressed by this study, the performance of the individual economies involved can be expected to be the principal determinant of demand levels (as discussed at greater length in the report of Task 1). The supply side of the industry is partly- at least in the case of lo-lo and bulk shipping- a component of the wider world shipping sector and therefore subject to its influences. Nevertheless, it is not unreasonable to consider the Irish access market in isolation, particularly given the fact that many of the unitised vessels currently in service are dedicated to these routes.

The capital cost of the vessels themselves can be considerable. A new multi-purpose ro-ro vessel of 50,000 gross tons, for instance, can easily cost € 100 million. However, vessels are frequently chartered rather than acquired outright, particularly in lo-lo and bulk traffic. Capital costs of € 100 million per ro-ro vessel and € 25 million for a lo-lo vessel have been assumed for the purposes of this project; no analysis is made of bulk ship capital costs because it is assumed that changes in the Irish access market would not make a significant

difference to the operators' fleet sizes. Depreciation over the typical marine period of 20 years is assumed.

Port capital costs vary widely according to the scale of the investment involved. In many cases, they are funded primarily from commercial sources (predominantly revenue from charges to vessel operators), but large-scale expansion, as has taken place at several Irish ports over the past decade, almost invariably requires public investment. Port access improvements are generally also funded by government, and can represent a very high proportion of port-related investment costs (as in the case of Dublin).

Operating costs for marine transport in general are typically divided into fixed and variable costs (McConville 1999, chapter 7). The latter represent only those components of cost which vary with the number of tonne-km performed (including payload-based, voyage-based and distance-based costs). The principal determinants of cost levels are vessel size (since resistance rises as the square of size but capacity as the cube, larger vessels offer economies of scale; however, the size of the market and the need to maintain a minimum frequency of service probably limit vessel size on Irish routes), speed (fuel consumption and the related costs increase approximately as the cube of speed, but scheduled shipping services have only limited opportunities to vary speeds), voyage distance (the longer the voyage, the larger the optimal vessel size) and time spent in port (which can, of course, be extremely significant for short routes).

Drewry Shipping Consultants (1993) present an analysis of short-sea lo-lo costs. This indicates that the viability of the shipping service itself is, at typical rates, borderline; however, it is pointed out that the shipping element must be considered as one part only of an overall transport package.

SINTEF et al. (1998) found that, at 1994 prices, the line-haul cost of truck on ferry ranged between €0.11/t-km for food products and €0.147/t-km for fertiliser. For lo-lo (and bulk) shipping, the range was €0.006-0.009/t-km. Train ferry costs were in the region €0.011-0.013/t-km (this time, fertiliser being lower in transport cost than food products). These latter are identical to the quoted railway rates. Port costs were excluded from the above; these lay in the range €4.5-21.7/tonne depending on the mode combination (road to ro-ro ferry and rail to train ferry at the lower end of the range, rail to ro-ro ferry at the upper end and others in between).

For the purposes of this study, operating cost levels have been assumed to be €0.068/t-km for ro-ro freight, €0.004/t-km for bulk and lo-lo freight, €0.00068/t-km on inland waterways (all based on SINTEF et al. (1998), which is also the source for assumed transfer costs), and €0.32/p-km for conventional passenger ferries.

B.3.4 Environmental impact

Conventional sea transport is relatively economical in its use of energy, although this tendency is not as pronounced over short ranges. A variety of sources (CE 1997, Drewry 1993, SINTEF et al.1998) suggest energy demands of 0.6-0.9 MJ/p-km and 0.8-2.3 MJ/t-km for ro-ro ferries, 0.2-0.4 MJ/t-km for lo-lo ships and 0.1-0.3 MJ/t-km for bulk ships.

Air pollution effects from ships are principally of concern in port areas; there appears to have been relatively little attention given to this area in Britain or Ireland, possibly because sea transport is relatively energy-efficient (though, owing to the types of fuel used, this does not automatically translate into low emissions) and ports generally contain other significant sources of emissions (oil refineries, petrochemical plants, thermal power plants, heavy road traffic). Nevertheless, they cannot be ignored; neither can CO_2 emissions which are, of course, of equal concern at sea as in port, given the global nature of their effects.

The emissions data shown in Table B.5 are those used for purposes of analysis. They have been derived from a number of sources, with INRETS (1999) providing the basic emission information and the assumed reductions in the period 1995-2020, and supporting information being taken from Clifford (1997), Drewry (1997) and SINTEF et al. (1998). It is assumed that low-speed diesel engines are used in bulk and lo-lo ships, with medium-speed engines in ro-ro vessels, and that emissions from ro-ro vessels are divided by weight between freight and passenger traffic.

Table B.5 Conventional Sea Transport Emissions

Pollutant	Bulk ship 1995 (g/t-km)	Lo-lo 1995 (g/t-km)	Ro-ro freight 1995 (g/t-km)	Passenger ferry 1995 (g/p-km)	Bulk ship 2020 (g/t-km)	Lo-lo 2020 (g/t-km)	Ro-ro freight 2020 (g/t-km)	Passenger ferry 2020 (g/p-km)
CO_2	30	24	200	35	30	24	200	35
NO_x	0.82	0.656	3.56	0.623	0.57	0.459	2.49	0.436
SO_2	0.188	0.15	1.25	0.219	0.038	0.03	0.25	0.044
VOC	0.023	0.018	0.15	0.026	0.023	0.018	0.15	0.026
CO	0.069	0.055	0.463	0.081	0.069	0.055	0.463	0.081
PM_{10}	0.011	0.009	0.075	0.013	0.011	0.009	0.075	0.013

Noise emissions from sea transport do not appear to be seen as a serious problem. The only issue which might conceivably arise is that of round-the-clock freight handling activity close to residential or other sensitive land uses; in practice, this does not appear to be a major concern. Road and rail traffic to and from ports is, without doubt, a significant generator of noise and a source of public concern for this and other reasons; the matter does not, however, relate directly to sea transport.

Land use demands for sea transport, as in the case of the air mode, are essentially limited to terminals (ports). However, the necessarily coastal location of such facilities increases their visual intrusion, severance and other related impacts. Loss of sites of scientific interest, landscape and views scheduled for preservation or wildlife habitats is a distinct possibility in the construction of any new port facility. Reclamation of land for port facilities, as is often necessary, raises further significant problems of impact on the marine ecosystem, and has been a long-running issue of public concern in Dublin. Dredging to permit the passage of vessels through shallow water near ports can have similar effects.

B.3.5 Terminal requirements

Sea transport poses some quite severe problems with respect to terminal location and access between the terminals and their hinterlands; anyone familiar with, for instance, Dublin's port access situation could not fail to be aware of this. Port locations are constrained by the coastline, the need for a location convenient to one or other of the established shipping corridors, the need for sheltered water of a sufficient depth to accommodate the vessels involved, availability of land, and the requirement for good inland access. Unfortunately, some older ports (such as Dublin) which do not meet all of these criteria continue in use, because of their historical pre-eminence and the environmental and geographical obstacles to the relocation of their functions.

No entirely new port (as opposed to relocating certain elements of an existing port complex to a downstream site, as in the cases of Belview at Waterford and Ringaskiddy at Cork) has been constructed in Ireland, north or south, since the early years of the 20th century; the fundamental changes resulting from unitisation have been accommodated principally

through the adaptation of existing harbour facilities. Proposals have emerged from time to time (Haren 1990; Meehan 1990) for the construction of a new port in the Central Corridor serving either all unitised traffic or ro-ro only, situated relatively close to Dublin but remote from built-up areas and readily accessible by motorway and rail. Some of the more ambitious variants of this scheme have postulated the closure of the unitised facilities at Dublin Port. With the development of the Port Tunnel scheme, interest in the idea of a "greenfield" port has decreased somewhat, but the Forfás Transport and Logistics Group (1996) believed that the idea merited continuing examination in a scaled-down form which would exclude lo-lo facilities.

As has been noted above, the inland access problems of ports can be considerable. A number of solutions are possible. Road access can be improved through demand management measures, priority routes for port traffic on existing roads or new and improved infrastructure. For lo-lo and bulk traffic, rail can contribute significantly (though not on relatively short hauls, limiting its relevance within Ireland). New forms of intermodal road/rail transport, such as piggyback (truck on rail wagon), swap-body (similar to containers, but more versatile and more economically handled) and bi-modal vehicles (road trailers which can have rail bogies attached) may also contribute in this field.

Access for passengers to port facilities is not generally considered a critical issue. Road provision primarily intended for freight usually adequately meets the needs of passenger traffic. Existing passenger rail links to many ferry ports are a legacy of the past involvement of railway companies in the shipping industry. However, it is unlikely that new rail links will be provided to ports where they currently do not exist, given the small numbers of "classic" passengers and generally low frequency of service.

B.4 HIGH-SPEED SEA TRANSPORT

B.4.1 Scope and background

In the context of this study, the term "high-speed sea transport" encompasses all systems included in the scope of "Jane's High Speed Marine Transportation"(Phillips 1999), broadly corresponding to vehicles having a maximum speed in excess of about 45 km/h. Wing-in-ground-effect craft (which operate just above the water surface, gaining lift from

the aerodynamic interaction between their wings and the surface) are classed as high-speed sea vehicles rather than aircraft; this is in accordance with the approaches of "Jane's High Speed Marine Transportation" and of the International Maritime Organisation (IMO).

Catamarans are the commonest type of high-speed vessel currently in use; they are conventional displacement vessels (i.e. supported by buoyancy rather than dynamically-generated lift) consisting of two hulls joined by a common superstructure. Catamarans have the advantage of combining high stability and spacious vehicle decks with slender, low-drag hulls. Other types of multihulled vessel do exist, but very few are in regular operation at present. The most important of these latter would be the trimaran (three hulls); the so-called "pentamaran" hull (a proprietary development) for high-speed vessels is more accurately classed with monohulls, since it consists essentially of a single main hull with four small stabilising hulls ("sponsons") on outriggers.

High-speed monohulls are the other principal class of displacement craft. As the name implies, these vessels have a single hull; it is normally relatively slender and streamlined in profile. Aspects such as propulsion systems, loading/unloading etc. are generally similar to those for catamarans. The "pentamaran" described above is a variation on the monohull, designed to enhance stability at very high speeds.

More unusual types of high-speed craft include the hydrofoil, air-cushion vehicle (ACV or hovercraft) and surface effect ship (SES). All these craft rely in part on some form of support other than buoyancy. The hydrofoil, at speed, utilises dynamic lift (analogous to aircraft wing lift) from foils. The ACV operates on a cushion of air maintained by blowers and contained by a flexible skirt, is usually propelled by air propellers and has a limited capability for operation over land. The SES is a catamaran with an ACV-like air cushion between the two hulls, such that the vessel is partly supported by buoyancy and partly by the cushion; it is simpler than a hovercraft, but has no amphibious capability. These vessel types are rare and of relatively little relevance to the Irish access situation, though reference is made below to one potential hydrofoil/displacement hybrid craft design.

Most exotic and highest-performing of all high speed water craft technologies is the wing-in-ground-effect craft (also known as WIG, WIGE, ram-wing, Ekranoplan, Wingship and by various other names). Like the hovercraft, it is supported on a cushion of air; unlike the hovercraft, the cushion is formed dynamically through the aerodynamic behaviour of the

craft's wings rather than statically through pressurisation (Stinton 1995a). It is more efficient than conventional flight, but permits higher speeds than hovercraft or hydrofoil technologies. Wing-in-ground-effect craft resemble very low-flying aircraft (for effectiveness, the altitude of flight must not exceed the span of the vehicle's wings), but are generally classified as high-speed sea transport (being generally impractical for operation over land) rather than as air transport. Some types can fly out of ground effect as aircraft, but only very inefficiently. Many variants and hybrids of the ground-effect craft exist, at least in theoretical form. The Seabus design described below is a Wing Assisted Hydrofoil (WAH) resembling a conventional hydrofoil in that the craft's propellers and stabilisers remain continuously in the water, but gaining its lift primarily from the ground effect of the vessel's main hull rather than the water lift of foils.

High-speed sea transport is largely a late 20th century development. The hydrofoil was the first development in this area, appearing first as long ago as 1905, but not entering commercial passenger-carrying service until 1953 (on inland routes) and 1955 (on sea crossings). The first demonstration of a full-size hovercraft took place in 1959 and the first scheduled passenger services ran five years later. Lightweight high-speed catamarans were developed for passenger service, principally in Scandinavia, in the 1970s and early 1980s; in the latter half of the 1980s, InCat of Australia introduced the concept of the high-speed catamaran car ferry, the first example entering service on the English Channel in 1990 (Hynds 1995).

In 1980, a hydrofoil service, apparently the first high-speed service on the Irish Sea, was inaugurated between Dublin and Liverpool, but proved unsuccessful and was withdrawn the following year (Gilligan 1988, chapter 25). In the wake of the aforementioned introduction of high-speed ferries on the English Channel, the operators of Irish routes were quick to follow, with the first such services operating on the Northern Corridor in 1992 and the Central Corridor a year later. Subsequently, the Irish Sea saw the introduction of some of the largest and most advanced high-speed catamarans in the world, the Finnyards HSS 1500 series (Figure B.5), which entered service on the Northern and Central Corridors in 1996. Table B.6 below presents the salient details of the high-speed vessels operating in 1999 on routes serving Ireland.

The wing-in-ground-effect craft apparently evolved in the decades following World War II, most initial development being carried out in the then USSR with military purposes in

mind. The mode has been the subject of sporadic interest in many other countries since then, but has never entered service in any role, although some very large prototypes were operated in the USSR.

The single largest development likely to occur in the world of catamaran/ monohull fast ferries in the next few years is the development of vessels suitable for large-scale freight traffic. The majority of the designs under discussion at present are of monohull type, but some catamaran types are also proposed. Table B.7 presents a summary of current designs, including- in addition to displacement-based systems- the Techno Superliner TSL-F hydrofoil. It will be seen that a very wide variety of approaches exists. The FastShip TG560 is a short-range derivative of a fast deep-sea monohull container vessel. The Blohm+Voss Fast Trailer Carrier is more in the traditional mainstream of freighters, differing from the classical form only in hull cross-section below the waterline. The Austal designs are an attempt to exploit the well proven technology of fast catamarans for freight purposes; this appears to impose size limitations and reflects a general view in the industry that structural considerations favour monohull designs for large freight craft. The Techno Superliner is essentially a hydrofoil (although the fact that it has a continuously-immersed lower hull might justify classing it as a hydrofoil/displacement hybrid). It is projected as carrying up to 1000t over 925km at 92.5km/h, and capable of regular service at Sea State 6 (6m significant wave height), with at least 98% reliability (Phillips 1999).

In time, it is possible that current large fast ferries and high-speed ro-ro freighters might merge into a single technology, at least in operations on routes similar to those to and from Ireland. Such vessels would give similar advantages over dedicated passenger and freight craft to those which the modern conventional "superferry" possesses in relation to earlier dedicated passenger and freight ro-ro vessels.

Another major line of development is likely to be the ultra-high-speed vessel, carrying traffic mixes similar to current high-speed craft (predominantly passengers and cars). Already, passenger-carrying catamarans capable of 100km/h are in service (though not in the Irish market). Gee (n.d.) describes design work on vessels with speeds of up to 140km/h and predicts that 185km/h displacement ships will be in operation by the early 2010s, with the next step being hybrid displacement/wing-in-ground-effect vehicles.

Table B.6 Current Irish Sea High-Speed Vessels (source: Phillips 1999)

Name	*Stena Explorer, Stena Voyager*	*Jonathan Swift*	*Jetliner*	*Stena Lynx III*	*SeaCat Scotland*	*SuperSeaCat 2*	*SeaCat Danmark*
Route	Dún Laoghaire-Holyhead, Larne-Stranraer	Dublin-Holyhead	Larne-Cairnryan	Rosslare-Fishguard	Belfast-Stranraer, Belfast-Troon	Dublin-Liverpool	Belfast-Heysham
Builder	Finnyards	Austal	Mjellem & Karlsen	InCat	InCat	Fincantieri	?
Model	HSS 1500	Auto Express 86	n/a	81m WPC	74m WPC	MDV 1200	?
Hull config.	Catamaran	Catamaran	Monohull	Catamaran	Catamaran	Monohull	Catamaran
Passengers	1500	800	600	600	431	800	500
Cars	375	200	160 (+12 buses)	155	80	175	80
Freight	50 trucks (+ 100 cars)	n/a	n/a	n/a	n/a	n/a	n/a
Length o/a (m)	120	86.6	95	81.1	74	100	?
Engines	4 gas turbine	4×7,200kW diesel	4×7,200kW diesel	4×5,500kW diesel	4×4,050kW diesel	4×6,875kW diesel	?
Max. speed (km/h)	?	78	70	81	?	?	?
Operating speed (km/h)	74	74	65	70	65	70	67
Service entry	1996	1999	1996	1996	1992	1998	1999



Figure B.5 Finnyards HSS 1500 high-speed catamaran *Stena Explorer*, in service between Dún Laoghaire and Holyhead (© Stena Line)

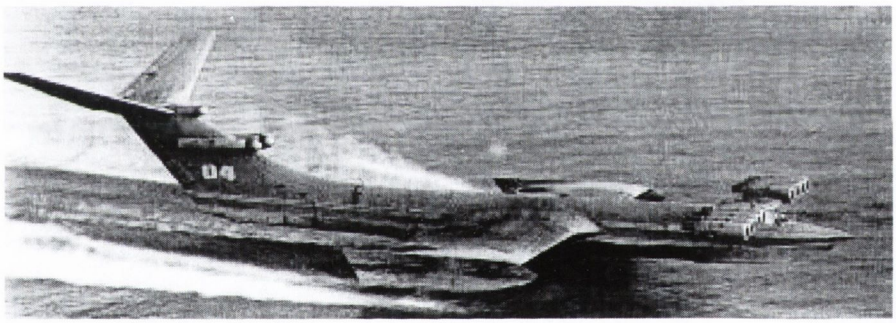


Figure B.6 Soviet prototype wing-in-ground-effect craft (© A. Belyaev)

Table B.7 Selected Current High-Speed Freight Vessel Projects
Sources: Phillips 1999, Austal WWW site (http://www.austal-ships.com.au/)

Builder/ designer	Thornycroft Giles	Blohm+Voss	Austal	Austal	Techno Superliner
Model	FastShip TG560	FM 130 Trailer Carrier	Ro-Con Express	Ro-Ro Express	TSL-F
Hull config.	Monohull	Monohull	Catamaran	Catamaran	Hydrofoil
Payload (vehicles)	c.175 trailers/130 trucks?	97 trailers	n/a	30-40 trucks	?
Payload (TEU)	736	n/a	80-140	n/a	?
Payload (t)	5,250	2,910	?	1,200-1,600?	1,000
Length o/a (m)	?	144	95-116	95-116	85
Engines	Total power 65 MW; no. & type unknown	2× 16,800kW diesel	?	?	Gas turbines, no. & power unknown
Max. speed (km/h)	?	?	?	?	93
Operating speed (km/h)	60	53	56-83	56-83	?
Service entry	post 2000	?	?	?	?
Capital cost (€ million)	?	?	?	?	?

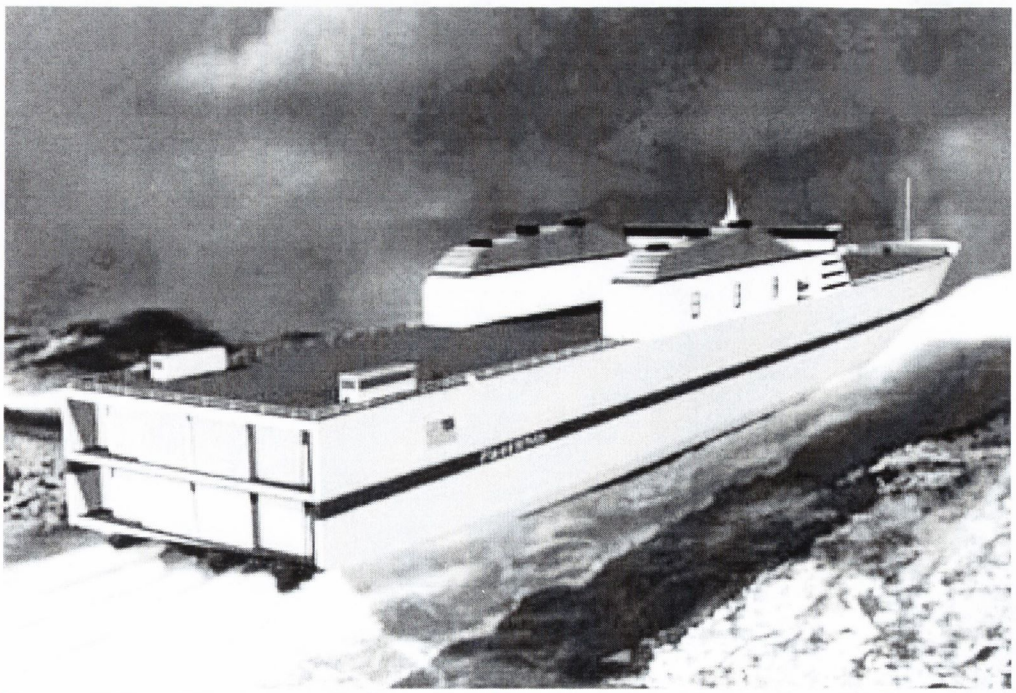


Figure B.7 Thornycroft Giles FastShip: artist's impression (© Fast Ship Atlantic, Inc.)

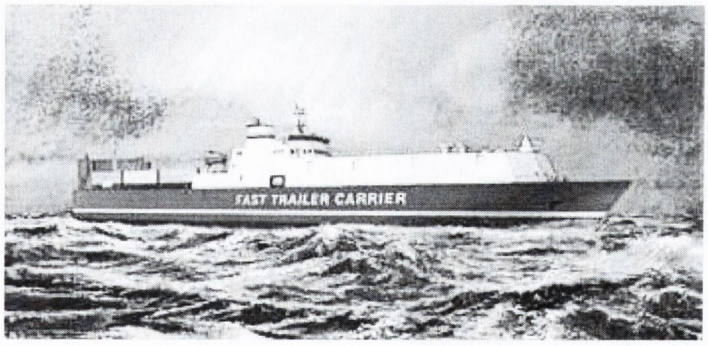


Figure B.8 Blohm+Voss Fast Trailer Carrier: artist's impression (© Blohm+Voss)

Beyond these speeds, the logical progression is to a wing-in-ground-effect vehicle. The most likely to prove viable of all the possible variants on this technology is one which offers speeds somewhat beyond what even the fastest displacement ships can achieve while remaining rooted as far as possible in marine rather than aeronautical technology. From this point of view, the approach of the Seabus-Hydaer "wing assisted hydrofoil" concept (see below) has much to commend it. The propulsion, steering and obstacle detection systems, in particular, appear to tend towards existing high-speed vessel practice. Table B.8 describes the Seabus and some other recent projects in this field. However, it may be noted that there are no concrete plans for series production of transport-capable wing-in-ground-effect vehicles anywhere.

Table B.8 Selected Current Wing-In-Ground-Effect Vehicle Projects

Builder/ designer	Seabus	Alexeyev	Alexeyev	Alexeyev	Alexeyev	Central Design Bureau of Hydrofoils
Model	SPW-02	MPE-100	MPE-200	MPE-300	MPE-400	A90.150
Passengers	800 (+ 120 cars)	150	250	340	460	350
Payload (t)	250	?	?	?	?	30
Length o/a (m)	55	?	?	?	?	58
Wingspan (m)	110	?	?	?	?	32
Engines	Gas turbines, total 24,000kW	?	?	?	?	1 11,000kW turboprop for cruising + 2×105kN turbofans for take-off
Significant wave height at take-off (m)	5-6	1.5	2	2.5	3	?
Operating speed (km/h)	220	320	400	450	500	400
Service entry	2004	?	?	?	?	Extant as prototype
Capital cost (€ million)	28.8	?	?	?	?	?

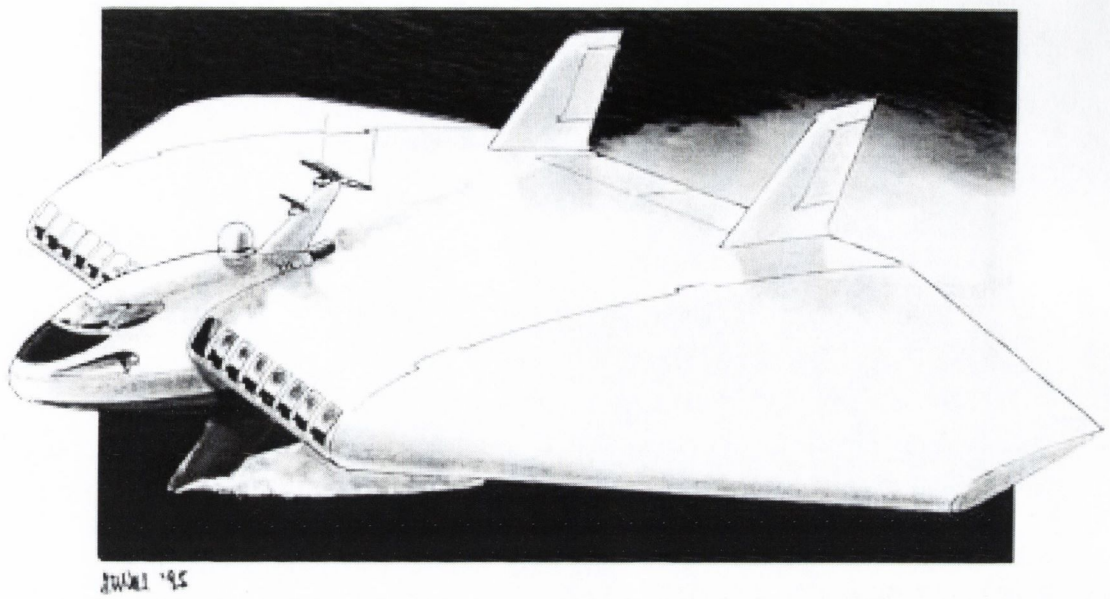


Figure B.9 Seabus-Hydaer SPW-02 Wing-Assisted Hydrofoil: artist's impression (© European Communities)

B.4.2 Performance

Compared to conventional shipping, high-speed sea transport is a faster (and more costly) mode. Fast ferries currently in service typically cruise at about 70-75km/h; scheduled speeds are in the region of 60km/h. It is considered possible to push standard displacement technology up to 110 or even 130km/h; wing-in-ground-effect craft (in sizes practicable for scheduled transport) start at around 160km/h and can theoretically achieve speeds close to those of aircraft.

While vessel size may vary considerably, in practice most craft currently in service can be classified into a number of size ranges. At one end of the scale are the first-generation high-speed car-carrying catamarans (and also some monohulls) carrying 400-600 passengers and 80-160 cars. Next in line are the larger, more modern vessels with capacity for roughly 800 passengers and 200 cars; finally, very large high-speed craft can transport upwards of 1,000 passengers and 300 cars, or a combination of cars and trucks. Coaches can also be conveyed on an increasing number of high-speed vessels (not only the very large examples).

Freight carried on present-day passenger-carrying fast ferries is presumably entirely accompanied, since the extremely tight turn-round times typical of the mode would appear to preclude unaccompanied trailers. This does not imply that containers or unaccompanied trailers could not form important parts of a transport system based around high-speed freight vessels designed with these types of traffic explicitly in mind. Indeed, Iles (1997) states that "It is not impossible to conceive of freight ships carrying 2,000 lane metres of freight, much of it unaccompanied, achieving a one hour turnaround". Many current high-speed freight vessel projects are intended to be capable of carrying containers, usually with some form of ro-ro handling. A few designs (such as some of the Austal variants in Table B.7) can carry freight on pallets similar to those utilised by airlines.

High-speed train ferries are theoretically possible, but the market for such vessels is small and declining. The need to accommodate heavy rolling stock would be difficult to reconcile with the lightweight structures of high-speed vessels, and the demand for high speed on most possible train ferry routes would be questionable. Nevertheless, it is believed that at least one design has been developed in outline.

Bad-weather reliability is one of the classic problems of any high-speed sea concept. It was amongst the factors which brought the Irish Sea hydrofoil operations of the early 1980s to a premature end; even large modern vessels such as the HSS 1500 series have suffered quite severely from service cancellations through such causes. It would therefore be necessary for new technologies in high-speed sea transport to be capable of a reliability level at least equal to that of present fast ferries. On the basis of the data presented above, it will be seen that the wing-in-ground-effect craft generally performs poorly in this respect. Some of the smaller types would be incapable of year-round operation in Irish waters, even in calm conditions; only the Seabus-Hydaer project appears to offer any prospect of comparable reliability to the conventional fast displacement ship.

It is likely that improvements to the reliability of displacement-based high-speed ferries will continue in the future, partly as a consequence of increasing vessel size. If they are to further increase their share of the Irish access market, a very high level of reliability indeed will be necessary.

B.4.3 Costs

Operating costs for high-speed vessels are invariably higher than for the equivalent conventional craft, owing principally to their very high fuel consumption but also factors such as more intensive maintenance requirements. However, they typically command (in the Irish market) a 20%-40% premium on passenger and accompanied vehicle fares.

Much of the economic literature on high-speed ferries is, in fact, devoted to the issue of their comparative performance relative to conventional vessel types. Hynds (1996) shows that, on a 56km route (comparable to some of the short Northern Corridor routes on the Irish Sea) and in the absence of premium fares, a conventional ferry is the most profitable relative to capital cost. This would suggest that premium fares are generally a necessity for the long-term viability of high-speed ferry operations. Hynds further notes that charter rates in the mid-1990s were in the region of US$13,000-US$17,000 per day for a medium-sized high-speed vessel, with operating crew (officers and engineers) typically being included in the contract and cabin and deck crew provided by the charterer. Østergård (1997) shows that fast ferry costs are approximately 20% higher than those of conventional craft overall; fuel is relatively more important and crew salaries less so.

Capital costs for a high-speed catamaran or monohull car ferry in the mid-1990s are quoted by Hynds (op. cit.) as being in the region of US$30-40 million (€29-38 million). The HSS 1500 was expected to have a unit cost of about US$100 million (€96 million). Its actual out-turn cost was closer to US$120 million (€115 million). About US$20 million (€19 million) in port modification expenditure was incurred for the initial three-vessel order (implying, given that the craft operate on three entirely independent routes, six ports at just over US$3 million or €2.9 million per port). Maintenance costs may be higher than for conventional ferries, as the technical complexity of fast craft favours an aviation-type planned maintenance regime.

Although fast car-carrying ferries are a relatively new development and so little information on achievable service lives is available, the author considers a 15-year period- shorter than that used for conventional ships, and comparable to that for aircraft- to be a prudent assumption.

Dedicated high-speed freight-carrying vessels are an area of even greater uncertainty than their passenger/car equivalents, largely because of the absence of operating experience to date. Drewry Shipping Consultants (1993) quote from a Danish/Swedish design study of high-speed ro-ro freighters which implied that, relative to a conventional 32km/h, 135-trailer ferry, a 50km/h, 135-trailer fast monohull would cost 5.4% more, a 60km/h, 120-trailer trimaran 54% more and a 65km/h, 45-trailer catamaran (broadly similar to the Finnyards HSS 1500) 165% more to operate. This closely reflects the trends in relative fuel consumption of the different hull configurations and suggests at least one good reason why so much of current high-speed freight vessel development is concentrated on monohulls.

Little or no data exist on the economic aspects of wing-in-ground-effect vehicles. Although the general literature indicates that favourable operating economics in certain markets have been demonstrated by past design studies, little hard information is available. However, the known fuel consumption and speed projections for various current designs suggest that the technology could compare with some existing fast catamaran ferries on economic factors. The Seabus SPW-02 has a projected capital cost of US$30 million (€ 29 million). Operating cost data are not available in the public domain at the time of writing (but see below).

For the purposes of this study, a cost of €0.37/p-km (based on actual current fare levels) is assumed for passenger high-speed ferries. Using information on fast ferry costs from Østergård (1997) and published data on the Seabus design, assuming higher insurance and maintenance costs but savings through higher speed in certain other areas, and referring to the above data, €0.24/p-km is assumed for Seabus, though this analysis is very tentative. €0.15/t-km is assumed for freight on fast ferries, based on the proportion of car and passenger space lost when freight (at an assumed 25t/unit) is conveyed on the HSS 1500. Other fast freight ships are based on the Danyard DY 1800 conceptual design (Drewry 1993, table 7.8). The quoted rate for this design was 3,900 Danish kroner per trailer on a 1000km route, i.e. 0.156 kroner/t-km or (in 1999 euro) €0.026/t-km.

B.4.4 Environmental impact

Compared to the classical ship, high-speed vessels are characterised by a much higher energy consumption. This issue is not generally well-publicised, but an examination of the available quantitative data shows that it can hardly be ignored in an analysis such as this.

Clifford (1997) suggests that energy demands for a variety of high-speed craft lie between 3.8 and 15.9 MJ/seat-km, averaging 7.8MJ/seat-km or (if one very high value is excluded) 5.1MJ/seat-km. Drewry (1993, Table 7.8) quote performance details for a range of design studies of high-speed freight vessels made with reference to a possible route between Sweden and Belgium, as referred to above in relation to operating costs. The 50km/h monohull carrying up to 135 trailers would require 1.28MJ/t-km (same assumptions as before), the 65km/h, 45-trailer catamaran 5.48MJ/t-km and the 60km/h, 120-trailer trimaran 2.18MJ/t-km.

Wing-in-ground-effect craft designs are generally projected to have energy demands ranging from 1-2MJ/p-km (Grad 1995). A notional freight-carrying version of the Seabus SPW-02 (assuming 100% load factor and that the entire payload capacity is used for freight, with no container/trailer deadweight) would achieve roughly 8.4 MJ/t-km.

Table B.9 below contains the emission assumptions used for this study. Clifford (1997), Drewry (1993) and INRETS (1999) are the sources used to produce these data.

Table B.9 High-Speed Vessel Emissions

Pollutant	Fast ferry 1995 (g/p-km)	Fast ferry 2020 (g/p-km)	Fast freighter 2020 (g/t-km)	Freight on fast ferry 2020 (g/t-km)	Seabus 2020 (g/p-km)
CO_2	740	144	197	275.2	391
NO_x	16.2	0.63	3.02	1.204	1.957
SO_2	4.63	1.8	6.16	3.44	0.49
VOC	0.694	0.135	0.18	0.258	0.024
CO	2.083	0.405	0.554	0.774	0.061
PM	0.347	0.068	0.092	0.129	0.135

Fast ferry noise is more of a source of concern than comparable emissions from conventional vessels. Hagman (1997) describes political problems arising from high-speed

vessel noise levels in Scandinavia, leading ultimately to the setting of more rigorous noise standards. It appears that gas turbine propulsion and the low-level location of engine exhausts on some vessel designs are the major contributory factors. However, no cases of public concern over fast ferry noise levels in Irish or British ports are currently known to the author; possibly the ports' location and configuration are such as to reduce the potential for noise nuisance. Wing-in-ground-effect craft generate noise levels comparable to aircraft, with similar implications for terminal location (Stinton 1995b). A hybrid design propelled by water jets, such as the Seabus-Hydaer, should pose fewer problems in this respect.

A problem specific to high-speed sea transport is that of the waves generated by such craft while running at speed in shallow coastal waters. These pose a particular danger to recreational users (swimmers, small craft etc.) and fatal accidents have occurred, including at least one in Ireland. The problem is normally dealt with by reducing speed, with obvious commercial disadvantages. In the longer-term, multi-hull vessels, semi-SES and semi-hydrofoil designs offer the best prospects for ameliorating the wave problem (Phillips 1999, Foreword). Effects of the propulsion systems of high-speed craft on marine ecology have become an issue in some countries (Hagman 1997), although again the author is unaware of any significant attention being given to the matter in Britain or Ireland.

B.4.5 Terminal requirements

In most respects, the terminal requirements and associated inland access systems for high-speed marine transport are similar to those for the conventional sea mode. Indeed, in many cases, most port facilities are shared. The vessels have slightly different berth requirements (because mooring, loading and unloading are all carried out via the stern and loading ramps are exceptionally wide), and often require dedicated berths, but these are generally accommodated without any major alteration to the overall form of the port facility. High-speed freight services are still something of an unknown quantity, and alterations to port facilities in order to expedite the processing of traffic would seem logical (to prevent the time gains from faster ships being squandered through terminal delays) though it is doubtful as to whether this would require changes on a very large scale. One possible effect of the introduction of such vessels would be a shift towards ro-ro handling, even for container traffic (possibly moving containers on air cushions as is proposed for the

Thornycroft Giles FastShip project), since conventional lo-lo handling cannot give the rapid turnarounds required; it appears that all current high-speed freight vessel projects are based on some form of ro-ro handling.

Most of the remarks made about the provision of entirely new ports for conventional shipping apply equally well to any similar (or indeed combined) provision for high-speed vessels. One point possibly worthy of note is that wing-in-ground-effect craft can negotiate very shallow water (needing only a flat surface rather than any specified depth), so that port facilities for such vehicles are not as constrained in location as those for more conventional displacement vessels. However, the terminal must still presumably be in a coastal location, given the many problems with operating a craft of this nature over land. If the vehicle is fitted with landing gear, it can be taxied out of the water and onto a ramp for loading and unloading (Stinton 1995b), similar to current practice with hovercraft.

The basic port access requirements for high-speed vessels seem to be, to all intents and purposes, identical to those for conventional ships (assuming the same traffic mix). In any case, virtually all port facilities used by high-speed services to and from Ireland are shared with conventional ro-ro services. Development of high-speed freight vessels might possibly affect the relative viability of road and rail for port access. If such development leads to a shift away from lo-lo towards ro-ro, it would naturally have adverse effects- assuming no development of piggyback or equivalent facilities- on rail. However, new methods of container handling (e.g. the FastShip air cushion system) could make ro-ro loading of containers possible without the expense of transferring them to a road trailer, as well as potentially eliminating the need for lifting gear in loading and unloading trains at both ports and inland railheads.

B.5 FIXED LINKS

B.5.1 Scope and background

The term "fixed link" is here interpreted as encompassing all strategies involving the construction of some infrastructural link between Britain and Ireland enabling through operation by normally land-based modes between the two land masses. Fixed links may take a number of forms, but can broadly be divided into bridges and tunnels. The mode

operating across a fixed link is usually either road or rail, although more novel systems are an outside possibility.

Tunnels are understood to include all forms of fixed link below the surface of the sea. Three broad categories of tunnel can be distinguished: bored tunnels are constructed by mining methods through the rock below the sea bed (as in the case of the Channel Tunnel), immersed tubes involve dredging of a trench in the sea bed, in which prefabricated tunnel units are then buried (as in the Lee and Øresund Tunnels) and submerged floating tunnels (not known to have been successfully applied anywhere, although several designs- for much shorter crossings than would be involved in this case- are at an advanced stage of development) are buoyant structures held floating a safe distance below the surface by tethering to the bed (see also Hakkaart et al. (1993)). All of these methods have been proposed at one time or another for links between Britain and Ireland.

Bridges are understood to include all fixed links above the surface of the sea. In this case, there are fewer distinct variations in technology than in the case of tunnels. A bridge linking Britain to Ireland would probably consist of a number of long-span cable-stayed or suspension structures spanning main shipping lanes, with the lesser spans being either structures of a similar type or simpler, shorter beams. A bridge/tunnel combination is possible; this would involve constructing artificial islands at either side of the main shipping channels, with an immersed or submerged tube beneath these channels, the roadway (there would appear to be significant problems, principally gradient-related, with applying a rail solution in this case) ramping up via the islands at either end to join bridges linking the islands to their respective mainlands.

Rail and road are the two principal modes expected to enter consideration as candidates for the operation of a fixed link. The choice of mode has implications for the types of infrastructure that are feasible. Road tunnels pose serious ventilation and traffic management problems at the lengths necessary for most possible Irish fixed links. The gradients involved in a bridge/tunnel scheme would almost certainly rule out the provision of a rail link. Dynamic response problems might arise with a rail submerged tube. A link which provides a combination of road and rail facilities is a possibility; several variants on this theme exist. A tunnel with road and rail traffic sharing the same space but separated in time was at one stage suggested as a solution for the English Channel (Land Use Consultants 1986), but the ventilation, safety and other problems would seem to make it

completely unworkable. Indeed, it may be noted that the promoters of the Channel scheme abandoned it in favour of separate road and rail tunnels- the modified plan, of course, still ultimately lost out to a rail-only proposal). An immersed tube tunnel with separate road and rail provision within a common structure appears a superior engineering proposition, but it is questionable whether the likely flows would ever justify the expense (particularly given that the viability of any fixed link whatsoever remains very much to be proven). A road/rail bridge would be broadly feasible, as would single-mode bridges. It is suggested, however, that a rail-only bridge would not be an especially logical solution, as it would fail to exploit the advantages a bridge offered relative to a tunnel for road traffic. Options including entirely separate road and rail tunnels, or a road bridge plus a rail tunnel, would be even more prohibitively expensive than a multi-mode immersed tube and can probably be dismissed. While an embankment- possibly incorporating tidal power generation facilities- has been proposed on occasion as a fixed link to Ireland, it would raise considerable problems in the areas of effects on currents and shipping, to say nothing of the question of locating and transporting the vast amounts of fill material involved; accordingly, it will not be further discussed.

Modes other than road and rail can be ruled out on the grounds that they are extremely unlikely to come to prominence in the general European transport market by 2020. New guided modes, in particular (e.g. magnetically-levitated vehicles) appear unlikely to reach a level of market penetration by 2020 that would make them an adequate substitute for conventional road or rail fixed links. Pipelines are, of course, a form of fixed link, currently used in the Irish market for the importation of natural gas. However, they are limited to transporting certain types of bulk freight, and have not been studied further .

If a rail-only fixed link is provided, it should be possible to provide shuttle trains to transport road vehicles between terminals close to the ends of the link, as in the case of the Channel Tunnel. Indeed, it is hardly likely that a rail-only scheme would prove viable in the absence of such a facility.

The history of fixed link proposals for the Irish Sea is long and complex, intertwined with those of both islands' railway networks and of the English Channel fixed link. Table B.11 presents a summary of all the projects known to the author (sources: Murray 1995, Nolan 1990, Davies 1998). In examining the details of tunnel lengths and depths, it is useful to remember that the Channel Tunnel is 50km long and 130m below sea level at its lowest

point. All the projects in the Table (excepting Nolan's outline options) are rail links, usually (though by no means always) double-track and electrified. No evidence of detailed proposals for road links could be found, although the idea had apparently been discussed on a conceptual level in the past.

The proposed routes can be broadly classified into six options (Figure B.10) within the three shipping corridors (the nomenclature is the author's):

Northern Corridor:

N-1 Antrim Glens-Kintyre.

N-2 East Antrim/North Down-Stranraer area.

N-3 South Down-Isle of Man-Cumbria.

Central Corridor:

C-1 Co. Dublin (or possibly north Wicklow)-west Anglesey.

C-2 South Wicklow-Bardsey Sound.

Southern Corridor:

S-1 South Wexford-Fishguard/St.David's area.

Table B.10 Irish Sea Fixed Link Proposals, 1860-1997

Year	Proposer	Type	Corridor[2]	Irish landfall	British landfall	Length (km)	Max. depth[3] (m)
early 1860s	?	Embankment	N	Torr Head	Mould	?	n/a
1868	Macassey/Scott	Bored tunnel	N	Cushendall	Glenstrone	55.5	?
1883	Watkin	Bored tunnel?	N	Torr Head	Kintyre	?	?
1886	Ormsby	Bored tunnel	N	Co. Down?	?	34.6	c.305
1890	McCullough	Bored tunnel?	N	Whitehead	Millbarn	43.4	200+?
1890	Maxton	Submerged tube	N	?	?	?	?
1890	Barton	Bored tunnel	N	Whitehead	Weirston	?	c.200
1894	LeSeuer	Embankment	N	?	?		n/a
1914	Tyrrell	Bored tunnel?	N?	?	?	?	?
1934	?	Bored tunnel?	N	Black Head	Lochnawe Bay	52.3	?
1964	Wells	Submerged tube	N	?	?	37.0	?
1990	Nolan[4]	n/a	N	Larne	Stranraer	85.7	260
1990	Nolan[4]	n/a	N	Ardglass[5]	Seascale[5]	112	?
1990	Nolan[6]	Immersed tube	C	Dublin	Holy I.	c.100	100
1990	Nolan[4]	n/a	C	Mizen Head(Co. Wicklow)	Bardsey Sound	87.9	110
1990	Nolan[5]	n/a	S	Rosslare	St. David's Head	78.5	110
1997	Symonds Group	Immersed tube	C	Howth	Holyhead	c.100	100

[2] Corresponds to the shipping corridors (see Chapter 2). N = Northern, C = Central, S = Southern.
[3] Depth below sea level of deepest point in tunnel, unless otherwise noted.
[4] Options examined in outline by Nolan. No specific tunnel type assumed.
[5] Via Isle of Man; IoM landfalls at Dalby and Maughold Head.
[6] Nolan's recommended option.

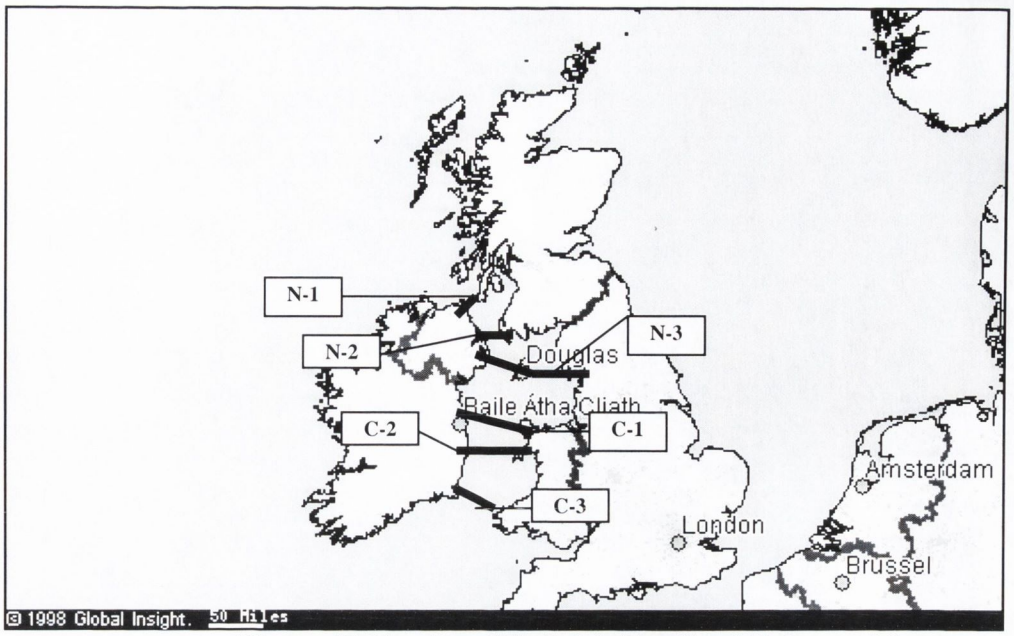


Figure B.10 Possible Irish Sea fixed link corridors

Although it has not, to the author's knowledge, been proposed as a serious component of policy in recent years, the idea of a fixed link between Ireland and Britain remains alive in some quarters. Mentioned in passing above was the proposal put forward by the Symonds Group, initially in 1997 (Davies 1997), for a Dublin-Holyhead immersed tube rail tunnel. The author understands that this project is still being pursued by Symonds, and has made contact with the principal individual involved. Because it is the only recent project known to the author in this field, the Symonds proposal is worthy of consideration in some detail.

Davies (1998), in a general description of the Symonds scheme, outlines four options for the routing of a fixed link between Ireland and Britain. These correspond to N-1, N-2, C-1 and S-1 as described above. In terms of possible link types, Davies first rejects bridge options because of the technical difficulties involved in the construction of numerous deep piers and the navigational safety hazards posed by such a structure. Bored tunnels are "unlikely to be practicable" because of high hydrostatic pressures at the depths involved and poor geological conditions; an immersed tube tunnel is considered the only feasible option. It appears that a rail link is assumed throughout.

The Central Corridor route (C-1 in the context of this chapter) is chosen principally because it combines moderate water depths with the provision of a direct link between major population centres. No detailed design for portal locations or terminal facilities is developed. A general outline of train service patterns for a rail link is given; vehicle shuttle trains from terminal to terminal would take 45 minutes and high-speed passenger rail

services would connect Dublin with Liverpool, Manchester, Birmingham and London, journey times ranging from 2 hours to Liverpool up to 3.5 hours to London. There would also be through services from Dublin to Paris and Brussels, taking 6 to 6.5 hours. Certain services would operate to/from Belfast, subject to provision of variable-gauge wheelsets for operation on 1600mm gauge track and the electrification of the Dublin-Belfast line. Freight trains would run through to/from all parts of Ireland by means of gauge changing.

The tunnel would be a composite concrete/steel structure, constructed in 250m units under "assembly line" conditions at four casting facilities, two either side of the Irish Sea. The structure would contain two rail lines separated by a service passageway (as in the bored Channel Tunnel).

Certain rail upgrading works are assumed; these include the West Coast Main Line modernisation, upgrading and electrification of the North Wales Coast Line and construction of the dedicated Channel Tunnel Rail Link from London to the Channel Tunnel. All (apart from the North Wales Coast upgrade) are included in current "do-minimum" plans and should be complete long before a fixed link would open.

The capital cost involved is estimated at £stg14 billion in 1997 prices (a private communication from Mr. Davies confirmed that an outline breakdown of costs existed, but indicated that it was considered commercially confidential). This corresponds to €21.7 billion at 1999 prices. The figure is (again according to private communications between Mr. Davies and the author) inclusive of the tunnel, terminals, rolling stock for shuttle trains, and rail access schemes (specifically the upgrading and electrification of the North Wales Coast line and the provision of a link to Dublin). However, it excludes rolling stock for through rail operations.

Davies assumes attraction of 60-70% of air traffic between Dublin and northern English cities, 20-25% of Ireland-London, Dublin-Bristol and Belfast-northern England traffic, and generally rather less on other routes. 50% of Republic of Ireland car/coach traffic and 40% of its Northern Ireland equivalent are assumed to divert to the tunnel, along with 30% of all sea foot passengers (excepting the Central Corridor, where the figure is 70%). 60% of container traffic between Britain and the island of Ireland would divert (35% on through rail freight and 25% via truck shuttles). 65% of non-containerised freight to/from the Republic of Ireland and 55% to/from Northern Ireland would also use the tunnel (in both

cases, 5% moves by through rail and the remainder by truck shuttle). Given a series of fare and market growth assumptions, and assuming 25% public sector funding, the project is shown to be financially viable.

Davies estimates that the project would take at least 12 years from inception of a feasibility study to start of operation (1 year for study, 2 for scheme development, 3 for the legislative process and 6 for construction), making the earliest possible opening year 2010. Since no action has been taken on the matter of a feasibility study up to the time of writing (early 2002), 2015 would now be more realistic, even assuming no political or technical delays.

B.5.2 Performance

A rail-based fixed link would carry several different types of service. The pattern of services using the Channel Tunnel is probably broadly representative of how a similar link to Ireland would operate. Services would broadly divide into shuttles, through passenger trains and through freight trains.

Shuttle trains carry road vehicles between terminals close to the portals of the tunnel (it is unlikely that a bridge link would incorporate a shuttle service, direct provision of road infrastructure being more probable). The Channel Tunnel provides two types of shuttle train, one for cars and coaches and a second for freight vehicles. Few vehicle types (other than those conveying certain hazardous substances or exceptionally large loads) cannot be carried. Services operate on a continuous-loop basis at headways of 10 to 30 minutes and speeds of 140km/h. The initial service involved hourly passenger vehicle shuttles and half-hourly freight vehicle shuttles during the day, with lower frequencies at night (Bertrand and Hacquart 1995). It is likely that the shuttle service through any notional Irish Sea tunnel would be very similar in concept and operation.

In the case of the Channel Tunnel, through passenger trains operate on two principal routes, London-Paris and London-Brussels, using 20-car train sets (self-propelled, the outer two vehicles being power units) of similar configuration to French TGV high-speed trains. A few other services are operated, mainly on a seasonal basis. Plans for overnight

services and through day trains to and from locations north of London have been abandoned for the time being.

For an Irish Sea fixed link, the Dublin-London route is likely to be- given the scale of demand for air services between the cities- the most important. If the link was via the Northern Corridor, this route would involve either a connecting train between Belfast and Dublin or gauge-changing at Belfast. Belfast-London (for a link via the Central or Southern Corridors, the same gauge-changing considerations apply), Dublin/Belfast-Northwest England, Dublin/Belfast-Birmingham and (for the Northern Corridor) Belfast-Scotland are likely to be the other principal routes. Through services to/from England east of the Pennines are limited by the extent of electrification. A limited service from Dublin to Paris and Brussels could well be viable. If an economic case for overnight services existed- doubtful at present- then Dublin-Paris/Brussels and Belfast/Cork-London (the latter with gauge changing and a change-over from diesel to electric traction en route) would be the routes likely to be of greatest interest. Passenger trains conveying accompanied cars over long distances ("Motorail") could theoretically be operated, but their potential must remain somewhat dubious, since no attempt has so far been made to provide this service on the Channel fixed link.

Through freight trains would convey a variety of types of freight rolling stock, similar in general to that in use at present in most European countries. Unitised freight could be carried in enclosed rail wagons, trailers on piggyback trains, containers- or swapbodies- on flat wagons or even by a longer-distance version of the freight shuttle train, carrying accompanied trucks ("rolling motorway"). It must be noted that either the latter solution or piggyback traffic would involve significant clearance-enlargement works on any existing British or Irish railway lines to be used for such services. The only significant restriction on commodities would be the exclusion (for a tunnel, at least) of hazardous goods.

All non-hazardous bulk commodities suitable for rail transport would be potential candidates for rail conveyance via a fixed link. However, because bulk transport often takes place over much longer distances than that of unitised commodities, and because the suppliers and immediate consumers of bulk commodities are frequently located in close proximity to ports, the potential of a fixed link in this area is restricted. Experience with the Channel Tunnel appears to bear this out.

In the case of the Channel Tunnel, freight trains are marshalled at locations immediately adjacent to the shuttle train terminals at either end of the tunnel and proceed through hauled by the electric locomotives dedicated to this duty. The locomotives can also haul such trains over electrified lines in Britain, but not continental Europe. It is reasonable to expect that an Irish Sea tunnel would follow a similar approach. One important difference is that an intermodal freight terminal would probably be located near the Irish portal to allow direct transhipment of freight from trucks to trains without the need to change gauge. It is nevertheless likely that a number of freight trains would- as envisaged by Davies (1998)- operate directly to/from destinations in Ireland remote from the tunnel portal by means of gauge changing.

If a road-based fixed link were implemented, its characteristics would be broadly similar to any other part of the highway system, and it would carry a similar mixture of private cars, coaches and freight vehicles. For safety reasons, a relatively low speed limit would probably be applied on the link. Some form of access metering would be likely, in order to minimise congestion.

B.5.3 Costs

The most obvious financial characteristic of a fixed link, and the principal reason for the absence of significant progress towards providing one between Ireland and Britain, is the very high capital cost involved. The Channel Tunnel is one of the examples most commonly referred to in this respect; in that case (an underwater twin bored rail tunnel 50km long) the final capital cost of construction amounted to € 10 billion in 1999 prices, significantly in excess of the original estimate.

Clearly, bored tunnels have extremely high capital costs. There are also considerable uncertainties involved in their construction, since it is extensively controlled by site-specific factors, making prediction of costs in advance somewhat difficult (particularly for a long, deep underwater tunnel in unfavourable geological conditions, such as would be involved in a link to Ireland).

Immersed tube tunnels appear to have an advantage over bored tunnels in terms of capital cost. The fact that the tunnel sections are constructed on land, probably (for a project on

this scale) indoors under assembly-line conditions, reduces the uncertainty involved. There is naturally some degree of risk involved in the prediction of seabed conditions, critical to the planning of dredging works and tunnel placement. Weather also affects immersed tube construction, since dredging and precision placement of tunnel units require suitable sea conditions to ensure safety and accuracy. By comparison, weather effects on bored tunnel construction are minimal, essentially being limited to exposure of coastal working sites and possibly disruption to marine spoil disposal operations in poor weather conditions.

Evidence on the capital costs of submerged floating tunnels is scant but would appear to suggest that they do not- except at extreme depths- offer any advantage relative to immersed tubes in this respect. Conditions economically favourable to this type of construction are only likely to occur in the Northern Corridor.

Savings could be made, if a rail tunnel scheme were to be chosen, by constructing a single-track tunnel initially, with the possibility of upgrading later. This would appear only to be possible in the case of a bored tunnel; the idea was proposed in the past for the Channel Tunnel (Hunt 1994, pp. 153-156). Such a scheme would preclude an effective vehicle shuttle service; in essence, only through trains could operate. The cost of terminals and shuttle trains (and the environmental impact of the terminals and their associated road traffic flows) would be avoided (in addition to the savings in tunnelling), but overall demand would be adversely affected. In view of the limited potential for through trains offered by the small size and non-standard track gauge of the Irish railway network, this course of action would not, in the author's view, be appropriate. In the unlikely event of both road and rail links being provided, however, it is possible that only a single rail track would be required.

The systems associated with tunnels (ventilation, cooling, signalling, power supply, drainage etc.) are a further major contributor to capital costs.

Much of the evidence indicates that bridges, at the considerable lengths and in the exposed conditions considered here, may well prove more costly than tunnels. Technological risks involved in constructing a bridge at least 30km long, and quite possibly much longer, would be daunting. Construction work would also be highly exposed to the weather.

If a rail-based fixed link were constructed, the capital costs of dedicated rolling stock for services on the link would have to be considered. Assuming this link to take the form of a rail-only tunnel, rolling stock for vehicle shuttle services, through passenger trains and (to a certain extent) through freight trains would be necessary. The possible patterns of services are described in greater detail above. It is likely that most rolling stock would have to be acquired new, as only stock designed for the Channel Tunnel would meet the relevant safety requirements, and little of the latter is available second-hand. Some existing freight rolling stock in Britain could possibly be utilised.

Terminals would constitute a further important element of total capital costs for a fixed link. Land would have to be acquired, roads and/or railways, as well as structures (e.g. bridges at a road/rail terminal, service buildings, control rooms) constructed and systems (power, lighting, drainage, communications) installed. Extensive landscaping would probably also be involved.

A vitally important aspect of any fixed link scheme is the provision of adequate road and/or rail, as appropriate, access to the terminals. The costs involved in this area may be quite considerable, as is indicated below.

Operating costs for long fixed links are not an area in which much information exists. However, it does appear that energy is a very significant component, in the case of tunnels at least. Ventilation, cooling, lighting, drainage and terminal operation, along with traction itself, would seem to be the major contributors to this cost. Apropos of the Channel Tunnel, Bertrand and Hacquart (1995) state that "Capital charges swallow the bulk of the revenue, and energy costs are high: more than 20% of the total, compared to 6% on a typical railway". Bridges would presumably require less energy but might well incur higher maintenance costs.

The author has assumed that the "tolls" proposed by Davies (1998) apply to a rail fixed link across the Irish Sea. These are additional charges imposed over and above the running costs of the relevant rail service in order to cover link-specific costs. The level of charge is assumed to approximate €3.25/t for rail freight and €14/t for piggyback freight, €100/passenger for car shuttle traffic and €10/passenger for through rail travel.

B.5.4 Environmental impact

The term "fixed link" covers a multitude of different technologies, each with its own particular set of environmental effects. The most appropriate course of action is probably to examine each technology separately before proceeding to common issues such as energy consumption and terminals.

A bored tunnel would have no direct effect on the marine environment, a significant point in its favour, since it would be constructed entirely through the rock below the seabed. However, considerable quantities of spoil would be produced- typically about 200,000t/km for a tunnel similar to the Channel Tunnel (i.e. 2 no. 7.6m diameter running tunnels, 1 no. 4.8m diameter service tunnel) or, for a Central Corridor route, something of the order of 20 million tonnes. The removal of this material would be a massive operation and the determination of a suitable disposal location extremely difficult (in the case of the Channel Tunnel, spoil was used to reclaim land from the sea and to infill a dry valley).

An immersed tube tunnel would generate far less spoil, but would cause greater disruption to the marine ecosystem in the process. Disturbance to the seabed could potentially affect marine life; given that parts of the Irish Sea are heavily polluted, with some areas having been used as dumping grounds for toxic material, and that hazardous substances have been released by previous seabed work such as pipeline construction, there would appear to be special risks involved in this particular case.

Land Use Consultants (1986, 5.10.5) were of the opinion that an immersed tube tunnel under the English Channel would lead to "direct destruction of...marine organisms living along the construction line and over the area where the spoil is side-cast...increased quantities of suspended sediments...would increase turbidity, reducing visibility and light penetration. These effects could extend up to 24km either side of the trench...". There would also (Land Use Consultants 1986, 5.10.7) be impacts on tidal flows due to the change in the topography of the seabed. Molenaar (1993) states that some projects have been implemented as bored tunnels rather than immersed tubes purely because of the perceived environmental impacts of dredging work.

Since no submerged floating tunnels have been constructed to date, there is some difficulty in judging the environmental impacts of such a scheme. Compared to immersed tube

tunnels, they would cause less disturbance to the seabed (although some would be inevitable due to the anchorage points for the tunnel). They would retain and, indeed, improve upon the environmental advantages of immersed tubes over bored tunnels in the matter of spoil disposal. However, interference with currents due to the structure and its anchorages (as in the case of bridges; see below) is an area of some doubt. A further environmental advantage claimed for this tunnel type is reduced energy consumption due to gentler gradients.

The visual impact of a bridge would be its most noticeable effect. Land Use Consultants (1986, 5.8.6), in a study of various options for an English Channel fixed link, contended that "A quite different order [from tunnels] of landscape and visual impact would occur in the case of bridge proposals...the scale and balance of the cliffs [at the English landfall] in relation to their setting would be seriously compromised...the structure would dominate the view and create a new scale and grandeur of its own". The fact that some would find the impact positive was conceded; indeed, the study was of the opinion that the structure "would become a major tourist attraction".

Bridge pier construction was anticipated to have similar environmental impacts to dredging for an immersed tube tunnel. Once complete, the piers would also lead to changes in tidal velocities with consequent effects on sedimentation and fish spawning grounds. Artificial islands for a combined bridge/tunnel scheme would have a considerably more serious impact.

The terminal facilities necessary, in some form, for any fixed link (see also B.5.5 below) would have their own environmental impacts. These might be expected to include land-use change and severance, loss of buildings, flora and fauna on the site, visual intrusion by day and night, noise, surface water drainage problems and road traffic congestion.

It is assumed for the purposes of assessing energy use and emissions that the mode operating on the fixed link is either road or electric rail. In the former case, passengers would be carried (in the main) by a mixture of private cars and coaches. In the latter, high-speed passenger trains would carry the majority of "through" rail passengers, with car and coach users travelling on shuttle trains. Freight would be carried by truck on a road-based link and by through freight train or truck on shuttle on a rail link.

It is not proposed to cover the energy use and emissions of road and rail transport in detail here; more information on this matter is provided below. It is sufficient to note that cars almost invariably (at typical loadings) use more energy than trains, and trains more than buses.

Calculations were made of the likely emissions resulting from ancillary power use (e.g. for ventilation and lighting) of the tunnel, but excluding energy used in the terminal facilities (for the sake of consistency, since port and airport energy use are not calculated). The basis for this was Channel Tunnel Group (1985). It is assumed that the Irish Sea tunnel is approximately twice as long as the Channel Tunnel and that the 2020 traffic level approximates to one half of the originally-predicted 2003 traffic level for the Channel Tunnel. Thus, twice as much energy is require for ventilation, lighting and drainage, but approximately the same amount for cooling (half the cooling demand over twice the length). A total annual energy demand of 56GWh can be tentatively derived for the Irish Sea tunnel's ancillary functions. The INRETS (1999) electric power generation emission figures for 2020 are then applied to derive the data given below.

Table B.11 Emissions from Tunnel Ancillary Equipment 2020

Pollutant	Tunnel ancillary emissions 2020 (t)
CO_2	16
NO_x	33
SO_2	74
VOC	51
CO	3
PM_{10}	7

B.5.5 Terminal requirements

Any fixed link- including road-based examples- would require some form of land-based terminal facility. For all types of fixed link, toll collection, security/immigration checks, and control of access would be necessary, along with, in all probability, service and amenity facilities (service stations, restaurants etc.), at the ends of the link. Accommodation for control, security and maintenance activities would also have to be

provided. For a rail-based link, the terminals would also have to incorporate facilities for the loading of road vehicles onto trains, along with maintenance facilities for shuttle trains.

Terminal location is an important and sensitive issue, especially for a rail-based scheme, where the terminals can be comparable in scale to airports. The smaller of the two Channel Tunnel terminals covers 140ha and the complex is 5km long from end to end. The English Channel fixed link proposals cited by Land Use Consultants (1986) required terminal areas (at the British end) of between 100ha and 200ha, with the "drive-through" road schemes towards the lower end of this range and the rail/shuttle scheme the upper end.

Access to the terminals by road and/or rail is, as stated previously in this chapter, of vital importance. It is worth considering the access implications of the different fixed link corridors identified. Table B.12 indicates the scale of works likely to be required in each case. It is assumed that rail links to the terminals are 225km/h electrified lines and road links are of motorway or near-motorway standard; therefore, upgrading work is required where existing routes do not meet these standards.

Northern Corridor rail links are assumed to terminate in the Belfast area and all others in the Dublin area. In Britain, rail upgrading is assumed as far as an appropriate point on the West Coast Main Line from London to Glasgow (electrified and proposed for upgrading to 225km/h) and road upgrading as far as an appropriate point on the motorway network.

It can be clearly seen that any fixed link across the Irish Sea would involve- quite apart from the expense of constructing the link itself- massive expenditure on road and rail access. In particular, it will immediately be seen that options N-1, N-3 and S-1 would be likely to involve prohibitive capital costs for the purposes of access to the terminals. Furthermore, option C-2 appears likely to be considerably more costly in this respect than C-1, and it can safely be said that the modest savings on actual link cost which it offers would be insufficient to counteract this. Hence, only options N-2 and C-1 emerge from this part of the analysis as feasible.

Table B.12 Access Implications of Fixed Link Corridors

Option	Irish terminal	British terminal	Length of new railway (km)	Length of significantly upgraded railway (km)	Length of new road (km)	Length of significantly upgraded road (km)
N-1	Bally-mena	Helens-burgh	180	55	30	10
N-2	Larne	Stranraer	130	50	25	240
N-3	Ardglass	Barrow	105	0	75	0
C-1	Swords	Valley	45	200	45	120
C-2	Brittas Bay	Caern-arfon	155	170	50	135
S-1	Rosslare	Haver-fordwest	140	565	90	55

B.6 BUOYANT AIR TRANSPORT

B.6.1 Scope and background

Buoyant air transport is here defined as any air-based system where the vehicle is supported (at least while empty of payload) principally by static lift, i.e. lift arising from buoyancy. In practice this implies that the vehicle must weigh less than the air it displaces; thus, its hull must be filled with a gas lighter than the ambient air, invariably helium in present-day applications.

A fully buoyant aircraft has the majority (though not necessarily all) of its weight supported by static lift even when fully loaded. In essence, this is what is generally known as an airship. A small amount of dynamic lift is provided, typically by the lift generated by the craft's hull itself (sometimes with a contribution from varying the angle of engine thrust) to compensate for small changes in weight due to temperature variations, fuel consumption etc.

The conventional classification of such craft is by structural form. Non-rigid airships (blimps) have their structure supported entirely by internal gas pressure and account for virtually all the craft in service today; however, there are serious negative scaling problems with constructing them in exceptionally large sizes. Semi-rigid airships consist of a pressure-supported hull with localised rigid stiffening elements (e.g. a keel). This type of structure is used in some current large airship projects, since it is cheaper and lighter than a

full rigid structure but allows larger hull volumes than non-rigid. Finally, the traditional rigid structure was used in most of the well-known large airships of the period 1900-1939; it involves a complex load-bearing structure of rings and longitudinal members cross-braced and covered with non-load-bearing fabric, within which (also non-load-bearing) gas cells are contained. Although well suited to large sizes, the rigid structure is complex to construct and maintain; some suggestions have been made for its substitution by one where a hard outer shell bears the bulk of the load ("semi-monocoque"), but this introduces new problems (particularly with weight). Despite these difficulties, a few projects based on the traditional rigid structure have been proposed in recent times.

Hull shape may also vary- amongst the many forms that have been proposed, typically promising advantages in construction, control and mooring, and occasionally flown, are lenticular "flying saucers", multiple-hull designs and "flattened" versions of the traditional form- but none appears to have proved its superiority to the classical form.

Partially buoyant aircraft utilise static lift to support most of their empty weight, but dynamic lift for the payload (and a small proportion of the empty weight, such that the craft remains "heavy"- and thus more easily handled- while stationary and empty of load on the ground). Such craft are sometimes termed "hybrid airships". They can be divided (Mowforth 1991, pp. 39-40) into two categories. "Dynastats" use wing-generated lift, either through attaching wings to a gas-filled hull or by shaping the hull itself to generate lift (a lifting body). "Rotastats" have hulls with rotor blades, similar to those of helicopters, attached; the rotor blades are used to generate the dynamic lift, while forward propulsion may be via either the blades or separate propellers. Dynastats are STOL aircraft and rotastats VTOL.

In structural terms, all the variants listed above are represented in the range of past and present hybrid designs. In the case of dynastats, the hull form is often radically different from that of the fully-buoyant airship, because of the aforementioned requirement to maximise the dynamic lift generated.

Buoyant aircraft as a mode of transport preceded non-buoyant aircraft by many years; the origin of this mode can be traced to early experiments with (unpowered) balloons in the 18th century, followed by the successful application of propulsion and control systems- turning the balloon into an airship, and rendering buoyant aircraft a viable transport mode-

in the mid-to-late 19th century. In the early years of the 20th century, the technology was applied to non-scheduled passenger services with modest success (long before such services were operated by aeroplanes). Significant technological advances resulted from World War I, after which the emphasis shifted to building larger airships for scheduled intercontinental transport (Hartcup 1974, Payne 1991). For a variety of reasons, including accidents, economic problems, the onset of World War II and fierce competition for available funding from the aeroplane industry, practical experience in this respect was somewhat more limited than might have been desired. After World War II, the great technological progress that had been made with long-range aeroplanes during the hostilities stymied any hope of an early return to airship development (Mowforth 1991, pp.14-15). Military interest in airships diminished after World War I, but they remained important in some such roles until the 1960s.

By the 1960s, interest in airships as a practical transport mode began to grow again. Particular areas of interest were the carriage of exceptionally heavy or large loads (e.g. for the construction, forestry and aerospace industries) and the use of the airship as a relatively fast, low-cost, low-energy, infrastructure-independent unitised freight transporter. In the latter field, some saw the optimal goal as a comprehensive, possibly Europe-wide, airship network (e.g. Rynish 1971) whereas others believed that the freight airship would be of principal use in serving regions where there were natural barriers to conventional surface transport, such as sea crossings (Coughlin 1973, Mowforth 1974).

The idea of using airships for short-to-medium range scheduled passenger services also gained some currency around this time, partly in response to noise and other problems arising with then-existing passenger helicopter services. As with the latter, much initial interest tended to focus on airport feeder and inter-airport routes.

None of the more ambitious projects from this era came to fruition, although progress was made in enhancing and enlarging smaller craft. The mid-to-late 1990s saw a second revival of interest in buoyant aircraft. A wide variety of proposals were put forward and, although some again failed, others continue at the time of writing. It is, however, undeniable that much remains to be done, and that considerable uncertainty must continue to characterise any review of the future potential of this mode. Table B.13 summarises some current or recent projects. It also outlines the notional craft design used for analysis in the field of passenger transport, the characteristics of which have been projected on the basis of a

previous study (Goodyear Aerospace Corporation 1976). The design described in Table B.13 is rather larger and slower than that in the original study, but more appropriate for the type of service envisaged. Further details of the concept's derivation are given at B.6.3 below.

Table B.13 Selected Current Buoyant Aircraft Projects

Manufacturer	Zeppelin	CargoLifter	ATG	ATG	ATG	n/a
Model	N 07	CL160	SkyCat 20	SkyCat 200	SkyCat 1000	Notional passenger dynastat design
Structure	Semi-rigid	Semi-rigid	Non-rigid	Non-rigid	Non-rigid	Rigid and non-rigid options possible
Buoyancy	Full	Full	Partial	Partial	Partial	Partial
Helium volume (m^3)	8,225	550,000	32,000	457,500	2,000,000	40,000
Length overall (m)	75	260	81	185	307	108
Cruise speed (km/h)	115	100	130	139	185	211
Max speed (km/h)	130	140	148	167	204	Not calculated
Range (km)	?	10,000	2,266	5,966	7,400	800
Max payload (t)	1.9	160	20	200	1,000	20
Passenger seats	12	n/a	c.100	1,000?	n/a	198
Engines	3×149kW petrol	4×1,425kW diesel, plus thrusters	4×450kW diesel	4×6,000kW gas turbine	6×11,250 kW gas turbine	4×5,445kW gas turbine
First flight	1997	2004	2003?	2005?	2007?	n/a
Service entry	In service	Post-2005	?	?	?	n/a
Capital cost (€ million)	6.8	51	?	?	170	35

Sources: Jackson (1998), Nayler (1998), ATG (2000), ATG website (http://www.airship.com), author's own analysis.

The Zeppelin N 07 (Figure B.11) is one of the first of the recent attempts to produce a modern airship, and is now in regular sightseeing service. It is likely to prove too small for scheduled transport, but outline plans exist for larger craft, up to 84 passenger seats.

The CargoLifter CL160 (Figure B.12) is a very large (larger than any other built to date) airship design optimised for the movement of heavy and outsize consignments, and partly funded by major German manufacturing firms. At the time of writing, construction work on the first full-size prototype was beginning, with a first flight possibly taking place in 2004. A longer-term objective is the construction of an airship with a payload of 400-500t. Some possibilities are foreseen in unitised freight transport, but at present the company appears to be concentrating exclusively on the "heavy lift" market.

The ATG SkyCat series (Figure B.13) is a range of dynastats having a non-rigid structure and a form similar to two conventional airship hulls merged into a "flying wing". An air-cushion landing gear system allows operation from water or rough surfaces, and can provide suction to hold down the craft during ground operations. Present versions have 20t, 200t and 1,000t payloads. The prime markets are seen as being unitised freight transport (at varying ranges) for civilian users and strategic long-range military airlifting. Smaller craft are also seen as having applications in passenger transport and surveillance. A remotely-piloted prototype craft has been flown, and the first SkyCat 20 and SkyCat 200 are now under construction.

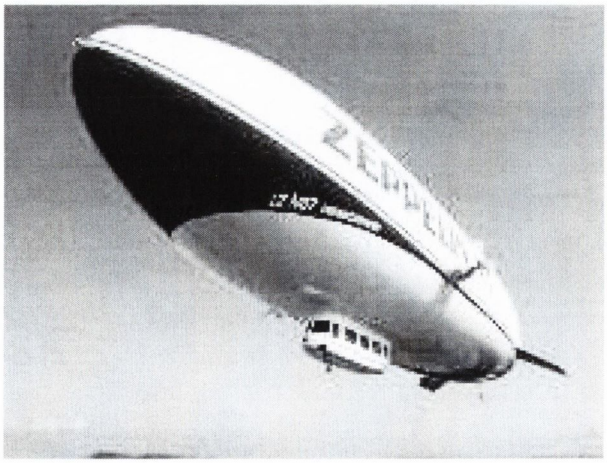


Figure B.11 Zeppelin N07 airship (© Zeppelin Luftschifftechnik GmbH)



Figure B.12 CargoLifter CL160 airship: artist's impression (© CargoLifter AG)



Figure B.13 ATG SkyCat 200 dynastat: artist's impression (© Advanced Technologies Group plc)

B 6.2 Performance

One notable characteristic of the buoyant aircraft is that it is a relatively slow mode by aviation standards. Typically, a fully-buoyant airship will cruise somewhere between 100 and 140km/h; the economic limit would appear to lie in the region of 160km/h, although faster airships have been projected from time to time. This is clearly considerably slower than the typical aircraft, although quite respectable in comparison with surface modes, particularly when account is taken of the buoyant aircraft's ability to use more direct routings than road or rail. It must be noted that a scheduled point-to-point speed must take

account of the possibility of encountering headwinds, which are relatively more significant than for heavier-than-air vehicles owing to the lower cruising speed. Hillsdon (1999) implies that, because of this, "the characteristics of an airship do not support scheduled passenger carriage ...[except] in niche markets...". In practice, airspeed can be increased above cruising speed to the maximum possible for short periods to mitigate wind effects, with the lower airspeed in the opposite direction compensating for additional fuel costs on a round-trip operation (Netherclift 1993, p.30). Mowforth (1979) suggests that 80% of cruise speed is an appropriate value to assume for average flight speed in passenger shuttle operations. This would imply a point-to-point average of 90-95km/h for typical present-day craft. Therefore, although the wind factor affects the possible average speed, it does not, on balance, do so sufficiently to rule passenger airships out entirely. However, the low average speed attainable suggests that fully-buoyant airships may be of questionable utility in scheduled passenger markets except where distances are short or airline competition weak.

Dynastats are characterised by a higher cruising speed than the pure airship, typically 200-300km/h. The factor of increase in cruising speed relative to the fully-buoyant airship is similar to that offered by high speed vessels relative to conventional ferries, but- as with ferries- there may be an operating cost penalty to be paid. Rotastats were mainly designed for short-range heavy lift operations, where speed was not generally considered critical. Hence, they did not tend to offer any significant speed advantage over the conventional airship.

The airship has always been renowned for its long-range capability (with the associated possibility of long endurance at very low speeds for civilian and military surveillance duties), although this is of comparatively little relevance to the present field of study. It does, of course, reflect a relatively frugal energy demand, which is further discussed below in relation to the mode's environmental characteristics.

In terms of individual vehicle size, the conventional airship offers significant economies of scale, principally due to the "square-cube law" (analogous to that previously outlined for ships) whereby the surface area (and thus structure weight and air resistance) rises as the square of linear size but volume (and thus payload) rises as the cube. Material properties must theoretically impose a limiting size, but this would appear to be very large indeed, in excess of 500t payload and probably around 1,000t. Most proposals for modern freight-

carrying airships have postulated a craft somewhere between 300t and 600t payload. The relevant factors for a dynastat-type hybrid are different, since the lift generated is partially dynamic (scaling as the square of size) and partially static (scaling as the cube). However, several dynastat proposals- the current ATG SkyCat being a relevant example- have envisaged payloads in the region of 500-1,000t. Furthermore, a dynastat can be built smaller than a fully-buoyant aircraft for a given payload, since only roughly half the volume of lifting gas is required. This is due to the payload plus part of the structure weight being dynamically supported; the total structure weight will generally be similar to or slightly in excess of that of the payload.

Operation of a conventional airship is subject to a number of problems which lessen the potential advantages of the mode and partly explain why it has failed to achieve general acceptance.

- Equilibrium in flight: a pure airship must remain in equilibrium (total disposable load + empty weight = lift) at all times. However, fuel consumption and temperature rises tend to "lighten" the craft, which must be compensated by reducing lift (i.e. releasing gas- uneconomic with helium) or adding ballast (not generally practical during flight). A solution applied to the fuel weight problem in the past, and proposed for present-day designs such as the CargoLifter CL160, is the use of condensing equipment to recover water from the engine exhaust. The use of alternative fuels may also offer a solution. Vectored thrust (directing a component of engine thrust up or down) is also widely used to cope with small weight and buoyancy changes. Dynamic lift (using the airship's hull to generate lift in a similar manner to a wing) may also contribute (e.g. by lifting off "heavy" with dynamic assistance and lessening the dynamic lift as fuel is consumed).
- Ground handling: the classical airship form is optimised for low air resistance in flight, but vulnerable to crosswinds on the ground, so that it must be allowed to swing with the wind while moored by the nose to some form of mast structure. This increases the amount of space required and complicates ground operations.
- Loading/unloading: again, the total weight of payload, ballast and fuel must remain constant at all times. This implies that either a new payload or an equivalent ballast weight, or possibly a combination, must be substituted for the freight being unloaded. The airship must be held in position during the operation, while remaining able to fly away in case of emergency. The difficulty of this process- particularly in the case of a

heavy lift operation, where the payload will often be a single indivisible unit and the unloading site generally unprepared- cannot be underestimated. CargoLifter AG have adopted a solution developed for the Airfloat HL heavy lift airship design in the 1970s (Mowforth 1991, pp.58-68) with some modifications. The payload module is held in a loading frame, which is suspended, from a hoist on the airship (about which the craft can rotate with changing wind direction) and tethered to the ground by four cables. The frame also contains ballast and fuel tanks which can be filled as the payload is unloaded.

- Low-speed control: Take-off and landing are carried out at low or zero forward speed, when conventional control surfaces are ineffective, so that an alternative means of inducing control forces must be found. Traditionally this involved large (and now uneconomic) ground crews; modern approaches generally make use of control thrusters on the airship and automated mooring systems.

More exotic solutions to the problem of buoyancy control and load exchange have often been proposed. These include manipulation of the temperature or pressure of the helium and the use of compressed air as ballast. No such systems have, to date, proved practicable. In addition, alternative fuels have been suggested as a means of mitigating the buoyancy control problem; this point is discussed below. Hybrid airships avoid most of these problems by using readily-controllable dynamic lift to support the payload, but suffer increased costs and various technical problems as a result.

Another important transport characteristic of the buoyant aircraft (as with all modes) is the type of payload transportable. Mention has already been made of the possibilities for large indivisible loads, although this is of only peripheral relevance to the present area of study. Containerisation is also a possibility, although opinions have differed sharply over the past thirty years on the merits of such an approach, which its critics would see as an attempt to compete with the best-developed element of the existing freight transport system, where the potential of a new mode may be more limited. In the Irish access context, there is the further problem that lo-lo is seen as a slow, cheap mode; the buoyant aircraft would probably compete more effectively on cost and speed with ro-ro freight. Ro-ro loading of airships, usually involving some form of a separate module which is loaded before attachment to the craft and unloaded subsequent to detachment, has been proposed several times in the past (Mowforth 1991, pp. 64-65, 71).

Mowforth (1991, pp.54-55) classifies methods of handling airships as :

- Field loading: handling at an unprepared site using mobile facilities (as generally practised for present-day airships).
- Base loading: operating from fixed terminal facilities.
- Air loading: airship remains in flight and transfers payload to and from the surface via either an auxiliary aircraft or a hoist ("flying crane") system.

Field loading is likely to be irrelevant to freight transport activity in the Irish market, because of the severe limitations on airship size. Base loading is unlikely for (fully buoyant) freight airships of a sufficient size for economic viability; if it were implemented, it would probably involve the provision of lifting gear on board the craft for the handling of individual freight units, or possibly a module-handling facility (see below) at the terminal.

In the case of air loading, the aircraft-based option can probably be safely ignored (given its considerable practical problems) in favour of the "flying crane" system. This would imply a modular operation, with an incoming module being exchanged for an outgoing module at the terminal, the modules being loaded and unloaded away from the actual hoisting point. Lo-lo or ro-ro loading of the module is possible. The author would suggest the latter, on the grounds of greater suitability for the airship's likely market niche (see above) and the potential flexibility offered; a ro-ro module could convey unaccompanied trailers, accompanied trucks, trade (import/export) vehicles, unaccompanied containers on air cushions or palletised freight. However, unaccompanied trailers would be the most appropriate mode for the core system, because of the weight saving through not having to transport tractors, the absence of difficulties in safety certification arising from the carriage of passengers in the airship, and the suitability of trailers for the low-density freight that appears the most promising field of application for the buoyant aircraft. In order to provide speed and reliability commensurate with accompanied ro-ro freight, the system would require tight control; it is suggested that the airship operator (or approved independent franchisees) could provide the road haulage service. This would effectively involve a total door-to-door service along the lines of that offered by integrators, but catering for much larger consignments. Such a system would also have the potential to simplify the security processing of freight, which could (assuming the application of existing air freight regulations) be an area of difficulty if numerous independent operators were involved. A

custom-built fleet of trailers, with large volume to cater for low-density commodities and low weight to maximise payload, could ultimately be provided.

Passenger handling methods are considered, with an emphasis on base loading, at B.6.5 below; the only area worth examining at this point relates to the possible merits of modularised approaches to passenger handling (either base or air loading). The use of modules would allow rapid turn-rounds of airships (as passenger loading/unloading, galley servicing, waste removal etc. would all be independent of the craft), and the fact that passengers could board the module before the arrival of the vehicle itself would reduce the requirement for ground terminal facilities. However, difficulties would arise with public acceptance of such a system.

Modular passenger handling would also facilitate the carriage of accompanied ro-ro passenger vehicles. This possibility has been considered several times in the past (Mowforth 1991, pp.64-65, 71). However, its value in the context of competition from high-speed sea transport is uncertain. It would appear to make more sense for the airship to concentrate on city-to-city routes, which sea transport cannot generally serve effectively, and demand for accompanied vehicle services on such routes would probably be negligible.

As discussed below, hybrid airships of the dynastat type would have ground handling requirements broadly similar to those of aeroplanes or (if capable of VTOL) tiltrotors. If a runway was required, its length would probably be comparable to that of existing STOL facilities, i.e. somewhere in the region of 800m. These characteristics would facilitate near-city terminals, and this, along with the relatively high speeds such vehicles are capable of, makes the mode eminently suitable for the short/medium-range passenger market, providing it can demonstrate favourable economics. The value of the speed advantage in freight operations (other than long-range) is more questionable. However, this study has assumed a dynastat of the ATG SkyCat 1000 design for freight transport purposes, primarily because it appears to be the most suitable of current buoyant aircraft proposals for unitised freight. Ro-ro loading and unloading are assumed, as described above for modular operations; in the case of the SkyCat the craft is designed specifically for ro-ro operation.

B.6.3 Costs

The principal problem in attempting to assess the financial and economic performance of the airship is the general dearth of real-world experience relating to the mode. Current airship operations are mainly in the field of advertising and television camerawork, with some diversifications into areas such as sightseeing and scientific, police or military observation. The craft used are small and often relatively low-technology (e.g. ground handling by large crews rather than exploiting the full potential for mechanisation, simple structural design, few complex navigational systems) but generally perfectly adequate for the task. However, the applicability of any experience gained to the operation of relatively large and sophisticated craft on scheduled passenger and freight routes must necessarily be limited.

Nevertheless, a considerable amount of research has been directed towards the quantification of the airship's operating economics, particularly with regard to freight transport. Table B.14 indicates some past estimates of freight airship operating costs, brought to common price and currency values. The payload, operating speed and range of the airship are given in each case, since these are significant determinants of operating cost. The table bears this out; operating costs decrease with size and increase with speed. The high values quoted by Howe do not have an obvious explanation. It is likely that a combination of the long range (i.e. more fuel weight at the expense of payload) projected and the arbitrary assumptions made regarding the relationship between direct and indirect costs (which result in a higher indirect cost level than Coughlin's more fully developed figures) account for the majority of this. Otherwise, there is a remarkable degree of agreement between sources within the same size and speed range.

Coughlin (1973) supplies the most detailed treatment of the matter, and the only systematic comparison of airship operating costs with those of existing freight modes. The latter indicates that the airship is cheaper than road transport from around 700km to the limit of the short-haul ranges considered (roughly 1,500km) and cheaper than a road/sea combination, air or rail over the entire 400-1,500km range. The cost saving over road haulage amounts to about 18% of the road freight charge at 1,000km or 23% at 1,300km; relative to road and sea, the saving is 20% at 640km, 25% at 1,000km and 19% at

1,300km. It should, of course, be remembered that this assessment is based on data now approximately thirty years old.

The aircraft used as a basis for the freight transport system modelled in this project is the ATG SkyCat 1000, having a payload of 1,000t. Discussions with Advanced Technologies Group confirmed that detailed operating cost estimates did not exist as yet. However, the SkyCat series appeared the most realistic buoyant aircraft design for general freight purposes, of those current at the time of writing, and the SkyCat 1000, as the fastest and highest-capacity of the range, offers distinct advantages. Therefore, it was considered that the design should be used as a basis for operating cost calculations.

A variety of operating cost models for freight airships are available in the literature (although all, of course, suffer from the absence of practical experience for validation purposes). The final decision was to use those presented by Ausrotas (1974), Smith and Ardema (1974) and Huang and Dalton (1976). These were adjusted to allow for the differences between the parameters (e.g. capital cost, engine power, hull volume) of the SkyCat 1000 and those of the airships assumed in the respective studies.

The results obtained were €0.124/t-km from Ausrotas, €0.07/t-km from Smith and Ardema, and €0.05/t-km from Huang and Dalton. A figure of €0.08/t-km was assumed to be representative. Terminal cost functions for buoyant aircraft freight operations are assumed to be half those for ro-ro ships.

Table B.14 Freight Airship Operating Cost Estimates

Source	Payload (t)	Operating speed (km/h)	Range (km)	Cost (€/t-km, mid-1999)
Howe (1971)	300	191	8000	0.49[7]
Howe (1971)	300	171	8,000	0.53[7]
Howe (1971)	316	166	8,000	0.47[7]
Coughlin (1973)	319	186	1,600	0.16
Ausrotas (1974)	60	160	3,200	0.25
Madden/ Bloetscher (1974)	101	160	2,400	0.17
Smith/Ardema (1974)	156	185	5,000	0.13
Nayler (1979)	400	145	2,000	0.09
Nayler (1979)	100	140	1,000	0.17
Nayler (1979)	100	145	1,000	0.15
Nayler (1979)	100	145	1,000	0.17
Nayler (1979)	30	145	600	0.29
Nayler (1979)	7	140	400	0.56
Nayler (1981)	75	139	1,850	0.20
CargoLifter AG (1997)	160	100	10,000	0.15[8]

The economics of passenger-carrying airships, particularly in scheduled point-to-point service, are a less well-researched area. Comparatively little information has been located. Timmermans (1998) supplied the following information to the author, for a nominal Dublin-London service:

Capital cost of 200-seat airship:	€ 22.7 million
Book life:	5 years
⇒ Depreciation p.a.:	€ 4.5 million
Interest p.a.	€ 680,000
Marketing/insurance/overheads p.a.:	€ 680,000
Operating cost per hour:	€ 908
Operating hours p.a.:	6,500

[7] Original values were for 65% load factor. Corrected to 100% for comparability with others.
[8] Based on a per-day figure; assumes 2000km/day with 160t payload.

⇒Operating cost p.a.:	€ 5.9 million
⇒Total cost p.a.	€ 11.8 million
Flying days p.a.	330
One-way flights/day:	4
⇒ One-way flights p.a.:	1320
⇒ Cost/seat/one-way flight:	€ 44.5

This gives a fare level of €0.09/p-km. Assuming profit margins over and above cost price and a 65% load factor tend to increase the price; on the other hand, the assumed vehicle life of 5 years is conservative (15 years is the aim of some current projects, and Coughlin (1973) suggested 10 years) and increased life would reduce depreciation and hence overall costs. It is apparent that airship services may charge somewhat higher fares than existing low-cost airlines, and this might negatively affect their viability if travel time were not airline-competitive.

It was ultimately decided to apply a hybrid (dynastat) solution for passenger transport, in the hope that it might be a more effective competitor to airlines than the (slow, unreliable and potentially difficult to handle) pure airship. Detailed technical and economic models for a hybrid passenger-carrying design (originally intended for short-range city-to-airport flights, and never realised) were available in Goodyear Aerospace Corporation (1976). These were utilised as a basis for the cost projections in this study.

Since the design proposed would utilise a tiltrotor-type system for propulsion and for dynamic lift at low or zero forward speed, it was considered that the propulsion system could be assumed to be based on that of the notional CTR2000 tiltrotor aircraft design (CTRDAC 1995). Two such systems would be required (as the airship has four engines and propellers versus the two on the CTR2000).

The parametric models used in the Goodyear study were applied in order to develop a notional airship design around the CTR2000 propulsion systems, then project its capital and operating costs.

As an initial step, it was assumed that the resulting vehicle would have a capacity of 200 passengers. The weights of the various components were then calculated by applying

appropriate expansion factors (e.g. hull weight proportional to payload to the power of two-thirds, since volume is directly proportional to payload and weight directly proportional to surface area) to the Goodyear weight data.

Allowing for the dynamic lift from the rotors, the necessary buoyant lift to support the craft's total weight was then calculated. This allowed a new value to be derived for hull weight, and the process was iterated to convergence. Cruising power was assumed to be in the same proportion to maximum power as in the original Goodyear study. Once cruising power and volume were known, the cruising speed was derived by assuming that the non-dimensional performance coefficient[9] of the design remained constant at the increased size. This gave a cruising speed of 114 knots (211km/h).

A unit capital cost of approximately €35 million was derived from the Goodyear data, making reasonable assumptions as to the relationship of weight and dimensions to cost for individual sub-assemblies. The relevant depreciation costs are assumed included in indirect operating costs, which have not been calculated in detail but rather on the typical assumption that they approximately equal direct operating costs.

The Goodyear equations for the various direct operating cost components were applied, making the further assumptions of an 80-aircraft fleet size, 15-year depreciation period and 4,500 annual hours per aircraft. The resulting operating cost (total direct and indirect) was (in 1999 prices) €0.17/p-km. Inclusive of a profit margin, a fare level of €0.18/p-km is assumed.

B.6.4 Environmental impact

The airship has acquired a reputation as a relatively environmentally benign means of transport (e.g. White 1978 pp. 101-102). On the whole, this appears to be justified, although it is contingent upon relatively low speeds and certain other conditions.

The energy usage of the airship, at speeds below about 140km/h, is certainly relatively low. For instance, the CargoLifter CL160 is projected to consume 4.5 litres of fuel per km

[9] The performance coefficient K_p (Mowforth 1991, Figure 17) is defined as $K_p = \rho Q^{(2/3)} V^3 / P$, where ρ air density, Q helium volume of craft, V maximum airspeed of craft, P engine power.

(CargoLifter AG 1997). With a 160t payload, this translates into 1.1MJ/t-km. Past figures for freight airship energy use (Howe 1971, Coughlin 1973, Mowforth 1979,1991) range between 1.41 and 28.8 MJ/t-km (the latter for a very small- by freight airship standards-vehicle of 10t payload). However, many of these assume higher cruising speeds than CargoLifter's.

The figures for passenger transport also compare well with other modes. In an extreme case, a notional passenger version of the CL160 could carry around 600 passengers , giving 0.44MJ/p-km at 65% load factor. These values are not entirely realistic, in that a craft of this scale would find comparatively little application in short-distance passenger markets and considerable practical difficulties with handling would arise; however, they illustrate the boundary of what is possible. ATG (2000) projected a SkyCat 15 design (now replaced by the larger SkyCat 20) which would cruise on 628kW of power at 139km/h, with engines having a specific fuel consumption of 0.22kg/kWh. For the proposed 80-seat passenger layout at 65% load factor, this implies 0.79MJ/p-km in cruising operation, still quite an impressive figure.

There have been numerous proposals for alternative power sources for airships. Even nuclear propulsion (Morse 1966) has been suggested in the past, though it would be very unlikely to be practicable in present-day circumstances. Solar propulsion has been the subject of considerable research, although no full-size solar airships are known to have been flown to date and solar power could not be relied upon entirely in northern Europe, even in daylight. Khoury (1999b) presents a very full review of the area. Gaseous fuels have been used successfully and safely for airship propulsion on more than one occasion in the past. One primary objective in all these alternative systems (apart from energy conservation or emission reduction) is ensuring that weight remains constant (as with nuclear or solar power, or a mixture of two gaseous fuels, or a gaseous and a liquid fuel, such that the net fuel density is equal to that of air) or increases (as with a lighter-than-air gaseous fuel) as fuel is burned. This avoids the equilibrium problems referred to at B.6.2 above, which arise due to loss of weight as a conventional fuel is consumed. However, no current airship projects are designed to use alternative forms of propulsion.

The dynastat hybrid airship has energy requirements somewhat greater than the fully-buoyant craft. This is due to the fact that a partially-buoyant aircraft generates at least half of its lift dynamically, meaning that engine power is utilised to produce lift (by driving the

vehicle forward) as well as for propulsion. However, there is a definite advantage in terms of speed. Khoury (1999a) presents evidence (in the form of the von Karman- Gabrielli power-speed plot) which suggests that the dynastat becomes more energy-efficient than a fully-buoyant aircraft around 160km/h and is feasible up to 320km/h, being more energy-efficient than the helicopter within this speed range. Over parts of the range, the technology also competes with the hovercraft, the conventional aeroplane and the fully-buoyant airship itself. The dynastat has lower power requirements than any of these, excepting the case of the airship at speeds below about 185km/h.

The emissions data for passenger-carrying buoyant aircraft actually used in this study are extrapolated from the V/STOL data on the assumption that the buoyant aircraft is propelled by two Civil Tilt Rotor propulsion systems and carries a maximum of 200 passengers.

The freight buoyant aircraft data are based on the ATG SkyCat 1000 design. This craft has six gas turbine engines, each having a maximum continuous power rating of 9,000 kW. Only four of these engines (i.e. 36,000kW) are used in cruising flight. Therefore, it has been assumed that (allowing for the additional power utilised in take-off and landing), a power demand of 40,000 kW may be assumed at a cruising speed of 185km/h (as per manufacturer's specification). Assuming a 550t average net (i.e. excluding the weight of ro-ro trailers) payload, this implies 0.393 kWh/t-km. A specific fuel consumption of 375g/kWh, similar to the Seabus (see above) is assumed for the gas turbines. Therefore, the fuel consumption is 147×10^{-6} t/t-km, and the emission levels can be derived from INRETS (1999) data for marine gas turbines.

Table B.15 2020 Buoyant Air Transport Emissions

Pollutant	Passenger buoyant air 2020 (g/p-km)	Freight buoyant air 2020 (g/t-km)
CO_2	71.2	223
NO_x	0.208	0.652
SO_2	0.2	0.627
VOC	0.028	0.088
CO	0.044	0.138
PM	0.148	0.389

Airship noise emissions are also generally lower than for heavier-than-air craft. The power requirements are reduced by the availability of static lift and the speed and power values typical of the mode tend to favour large, slow-turning propellers, which minimise noise.

Propellers on airships are also sometimes surrounded by noise-reducing ducts (as in the cases of the current Zeppelin and ATG designs). Against this, the lower speed of the airship does mean that noise exposure takes place over a longer period than for aeroplanes.

Land take for terminals is relatively low; this point is further discussed below.

The airship itself has a considerable visual impact; indeed, this is an important factor in its use as an advertising platform. It is difficult to come to a judgement about the acceptability or otherwise of the visual effects of very large craft. Careful siting of terminals, to avoid very low-altitude flight over populated areas, and design of routes to minimise visual impact, would be prudent measures.

B.6.5 Terminal requirements

The main parameters of terminal installations for airships are defined by the method of ground handling and load exchange chosen. The classification of methods into field, base and air loading has been described already (see B.6.2 above). It is likely that any large-scale scheduled passenger or freight airship operation, such as might play a part in Irish access transport, would utilise either base loading or air loading.

In the base loading case, the terminal facility would consist of a mooring mast along with sufficient space for the airship to rotate about the mast while moored to it by the nose (plus an allowance for safety purposes), accompanied by the relevant supporting facilities. Masts are of two types. "High masts" keep the airship well clear of the ground at all times, all access being via a lift to the top of the mast and a gangway through the nose of the airship. "Stub masts" keep the airship very close to ground level, with the tail (in the case of larger craft) moored to a vehicle which is free to move on a circular track around the mast. Access from the ground is then possible.

High masts are clearly unsuitable for freight handling; they are also inappropriate for non-rigid airships (because such craft have no structure to support the nose gangway). They are, however, sometimes claimed to have advantages in minimising the possibility of damage to the airship. It may also be possible to develop city-centre high masts on top of tall

buildings. However, there would appear to be considerable problems with this approach, including structural modifications to the building, providing for more than one mast at a given location without duplication of support facilities, and the need to ensure an obstacle-free approach.

Stub masts in one form or another are in general use for present-day airship operations. The examples currently in use are extremely simple in design and often readily portable (to facilitate typical advertising operations, which involve frequent changes of base). Large ground crews are normally employed; the cost of such an approach could become prohibitive for a craft of a size suitable for scheduled transport.

Air loading is the most appropriate mode of handling for the transport of large indivisible loads, since a "door-to-door" capability is highly desirable in this market. In general freight operations, air loading also offers advantages, since it renders terminals much simpler (and therefore less costly) than if the airship had to be brought to earth and moored for every turn-around. Coughlin (1973) showed that terminal costs are one of the most critical areas for the economics of freight transport by airship. The CargoLifter system exemplifies the air loading philosophy as applied to freight operations. The most basic form of terminal facility projected for this system consists of a clear area approximately 45m × 45m (i.e. much smaller than the craft itself) with mooring hooks at its corners. Two more sophisticated forms of terminal are also proposed; the type required as a base for regular freight operations demands a 400m×400m space, generally with supporting facilities such as warehousing. The largest base type is the maintenance base, only one or two of which would be needed for the Irish access market. This requires a clear circle of 800m diameter for the airship to swing about a mast and space for a hangar, approximately 400m×200m in plan, to house two airships.

Dynastat-type hybrid airships would require a terminal similar to an airport; however, the runway would be considerably shorter, but runways, taxiways and parking areas would need to accommodate the large dimensions of the craft. If a vehicle with VTOL capability were used, the terminal would probably resemble a vertiport (as used for conventional V/STOL aircraft) but scaled up to allow for the larger dimensions of the aircraft using it. It could potentially be smaller than an equivalent facility for fully-buoyant airships, because of the absence of a need for the craft to swing about a mast. In some cases, mixed dynastat/aeroplane operation at existing airports, where they have spare capacity, might be

possible. There would also appear to be potential in handling tiltrotor V/STOL aircraft and VTOL partially-buoyant aircraft at common facilities.

In terms of terminal location, the low noise levels of airships, along with the general absence of any requirement for a runway, theoretically permit the use of city-centre sites. However, this is subject to the availability of land (assuming that a building-mounted high mast is not practicable). Dockland areas and other very large urban renewal sites appear to offer the best prospects of a suitable location close to central business districts; cf. Nayler's (1981) description of a proposal for an airship terminal (intended, initially at least, for sightseeing flights) in the London docklands. It is unlikely that inner-city sites would prove particularly attractive for freight transport; in this sector of the market, edge-of-city sites, close to more recent industrial and warehousing development, would appear superior.

B.7 ACCESS TO TERMINALS

B.7.1 Scope and background

The objective of this section is to examine the characteristics and prospects of the modes used by passengers and freight to gain access to the terminals (ports, airports etc.) of the actual access transport services. In practice, there is a considerable overlap with the internal transport systems of Ireland, Britain and the European mainland; road and rail services are rarely dedicated specifically to access traffic.

In modal terms, this chapter covers principally road and rail. Domestic aviation is considered briefly only insofar as it acts as a feeder to external air routes. It does not appear that coastal shipping is used to any extent to feed freight to access shipping; the relatively short distances involved in the latter would seem to favour direct shipment from origin to destination, and the geography of Ireland does not facilitate economical coastal trade.

Inland waterways are an important mode for the transfer of freight traffic between ports and inland locations in certain parts of Europe, but not in Ireland nor (on any great scale) in Britain. Parts of the European inland waterway network may be of importance to the flows of freight between Ireland and the rest of Europe, but the mode is not likely to be a major

contributor or to possess much potential as a policy element. Accordingly, it will not be further considered here, although a limited inland waterway network is applied in the demand prediction work.

The importance of the interaction between access transport services and their attendant "inland" links has long been recognised in Ireland. The canals of the 18th century, and even more so the railways of the 19th, were frequently planned to link the interior of the country with ports. They thus performed an important function in the access system in parallel with (and perhaps even dominating in some instances) that of internal transport. It appears that the railways, in particular, had a significant impact on access transport; they were frequently used in conjunction with another new transport technology of the time, the steamship, and railway companies often formed their own shipping subsidiaries and constructed ports.

Road transport grew, in parallel with aviation, throughout the 20th century. A gradual shift from rail to road in the transport of freight and passengers to and from ports culminated in the introduction of ro-ro ships by the end of the 1960s; these in turn brought about further shifts away from rail. Airports were generally served only by road links in their earliest years; even today, rail connections are not comprehensive in Britain and still almost non-existent on the island of Ireland.

By the 1970s, the provision of high-quality links to ports and airports had become a priority in highway planning. This has been an important focus of transport policy ever since.

Future development in this field is likely to be concentrated on the existing road and rail modes. Consideration has been given to the prospects for new forms of guided transport, pipelines, and air and water transport, but none of them appear likely to take a major role, though pipelines could be important on a localised level (not considered here) in port areas.

In the case of road transport, various improvements in both infrastructure and vehicles are likely. In the Republic of Ireland, the National Road Needs Study (O'Sullivan and Scetauroute 1998) aimed at achieving an average speed of 80km/h (level of service D in the US Highway Capacity Manual) on all major interurban links. The study used 2019 as its design year, but most improvements to the key routes are scheduled for completion by

2014. The routes of greatest national importance were defined as a series of corridors (a modified version of those used in the 1994-1999 National development Plan):

- North/South: Border-Dundalk-Dublin-Rosslare-Waterford-Cork, with connecting route Cork-Tralee.
- Southwest: Dublin-Portlaoise-Cork/Limerick, with connecting route Limerick-Tralee.
- East/West: Dublin-Kinnegad-Sligo/Galway, with continuation from Sligo into Northern Ireland and connecting routes Longford-Westport and Sligo-Letterkenny.
- Western: Sligo-Galway-Limerick-Waterford-Rosslare, with connecting route Limerick-Cork.

These corridors encompass most of the road links likely to be of importance in the context of this study, and connect with most ports and airports.

The 2000-2006 National Development Plan provides for upgrading of the Dublin-Dundalk/Galway/Limerick/Cork/Waterford routes (i.e. the northern portion of the North-South Corridor, the entire Southwest Corridor, the Galway branch of the Western Corridor; the route to Waterford has not yet been determined). It is intended that motorway or dual carriageway should be provided over the entire length of these routes. Beyond 2006, the opportunities for road upgrading on an interregional level may be expected to diminish somewhat. The only obvious gap remaining in the radial network will be the Dublin-Northwest corridor (Dublin-Sligo/Donegal/Derry). This would appear to be a promising candidate for upgrading, assuming that the National Spatial Strategy directed significant amounts of population and investment to these areas (which is considered relatively likely). Some rationalisation of the route structure may be necessary: it is unlikely that more than two of the three main roads from Dublin to the northwest could be improved to such a standard.

Apart from radial routes centred on Dublin, there may also be scope for similar upgrading of cross-radial routes, notably the Western Corridor. A possible scheme in this corridor would involve the provision of dual carriageway from Galway to Rosslare; extension to Sligo might be considered, depending on the level of development in the northwest. This would provide much of the BMW region with high-quality access to the ports of Waterford

and Rosslare as well as Shannon Airport, potentially relieving congestion in the Dublin area.

In Northern Ireland, the draft "Shaping our Future" regional strategy (DoENI 1998a) identifies five "key transport corridors". These are:

- Eastern Seaboard: Larne-Belfast-Lisburn-Craigavon/Banbridge-Newry and on to join the Republic's North/South Corridor.
- Belfast Metropolitan Area-Derry/Londonderry: Belfast-Antrim-Magherafelt-Maghera-Dungiven-Derry.
- Northern: Belfast-Antrim-Ballymena-Ballymoney-Coleraine-Limavady-Derry.
- Western: Derry-Strabane-Omagh-Ballygawley and onwards to connect with the Republic's East/West Corridor.
- South Western: Belfast-Craigavon-Dungannon-Ballygawley-Enniskillen, again continuing to connect with the East/West Corridor.

Although these corridors are not mode-specific, only the Eastern Seaboard and Northern corridors are served by rail.

The links to the access transport system's terminals will themselves be upgraded, as in the case of the Dublin Port Tunnel already mentioned in this report. Airport access roads are likely candidates for further improvement in some areas. A further major road-based port access scheme, at present being considered in outline form (and assumed as part of the 2020 do-minimum network), is a southern access road to Dublin Port, completing the M50 motorway ring around the city.

Rail transport, too, will undergo some improvement, although a very large-scale investment programme for the mode was incorporated into the 1994-1999 Operational Programme for Transport and is now nearing completion. The mainline rail improvements in the 2000-2006 Programme are likely to concentrate on lines excluded from the previous package. Beyond this period, it is possible to foresee some improvements to passenger rail service in terms of enhanced frequency and minor increases in speed, along with, perhaps, certain enhancements to network capacity. It is not considered likely that speeds will rise above 160-175km/h or that main lines will be electrified (although the Dublin-Belfast corridor is a possible exception). In the access transport context, these changes will be very

minor. However, investment in rail access to airports is likely, and already planned for Dublin. The possibility of a link to Shannon exists in the longer term (see below), and Belfast (Aldergrove/ International) may have similar potential. Other airports in Ireland appear to have inadequate passenger volume for, or (as in Cork's case) topographical barriers to, the provision of a rail link. In Britain and Continental Europe, existing airport links will probably continue to be enhanced and new ones inaugurated. No major change in the provision of rail services to ports is likely. However, there may be some scope for improvement, e.g. the frequently-suggested electrification of the Crewe-Holyhead railway. It is considered that an electrification and upgrading (to provide for 225km/h passenger trains and possibly for piggyback freight) scheme for this latter route should be evaluated in the context of this project (it would, in any case, be necessary for a Central Corridor fixed link option).

Away from the access terminals themselves, improvement of rail services in a number of British corridors (WCML, trans-Pennine etc.) of interest in the context of Irish access movements is likely to continue.

A rail upgrading package in the Western Corridor may also be an attractive option. As in the case of road transport, this route has for long been neglected in investment terms due to the higher traffic levels on the radial Dublin-based corridors. Existing (very restricted) passenger rail services operate over the section of the corridor between Ennis and Rosslare; these could, without incurring excessive costs, be enhanced and extended to Galway. Extension to Castlebar or Ballina would be possible on existing tracks; an extant but long-disused railway could be used to continue the service to Sligo. A link to Shannon Airport (which has so far been considered mainly in the context of Limerick commuter demand) could also facilitate interregional traffic, particularly from Galway (and potentially points north thereof) to Shannon. Rail freight from the existing rail-linked lo-lo terminal at Waterford could make use of this corridor.

Before continuing with any discussion of rail freight, it should be observed that the Joint Committee on Public Enterprise and Transport (1999, 2.23-2.29) found in relation to the Irish rail freight business that "the inescapable conclusion...is that [it] is a business in long-term decline, despite the substantial economic growth...". It was concluded that "any sizeable investment...[should] be accompanied by a strategic analysis of the freight sector in Ireland." Furthermore "the wisdom of investing in freight modes suitable...for low

value, high volume primary products when current development policy emphasises the knowledge economy must be questioned." In practice, this could lead to a complete abandonment of rail freight services, or, more likely, of unitised facilities. Since 1999, there has been a significant decline in rail freight within Ireland. However, at the time of writing (early 2002) it does not appear likely that freight services will be abandoned completely.

Rail freight offers some potential for technological change, predominantly in the introduction of new forms of intermodal handling. At present, containerisation dominates the rail transport of access freight traffic in Ireland, with the exception of certain bulk commodities. The other principal forms of intermodal handling are piggyback, swap-body and bi-modal vehicles.

Piggyback transport involves the placing of a road freight vehicle (usually a trailer) on a rail chassis. This can be carried out by ro-ro or lo-lo methods; if loading is ro-ro, the tractor unit may sometimes be conveyed on the train, possibly accompanied by the driver (as in the case of the Alpine "rolling motorways" and the Channel Tunnel freight shuttle trains). In Ireland, piggyback trains could link the principal ro-ro ports with terminals in the west and south-west of the island, reducing truck traffic on the roads leading to the ports. Unfortunately, major alterations to the rail system, principally involving the rebuilding of structures, would be involved in order to provide sufficient clearance for piggyback traffic.

In Britain, such considerations have led to a reappraisal of the proposal to upgrade the West Coast Main Line (WCML) for piggyback freight. A proposal (the Central Railway project, see http://www.central-railway.co.uk/) also exists for the construction of a new railway (partially on disused rights-of-way or parallel to existing tracks) from the Channel Tunnel to Liverpool, with clearances sufficient for piggyback trains and priority given to freight. Shuttle services would link various points in England (including the port of Liverpool) with a terminal near Lille in northern France. This proposal is obviously ambitious and involves certain risks, but would appear to be of interest. Upgrading of the Crewe-Holyhead line to cater for piggyback traffic could be considered in conjunction with either the WCML upgrade or Central Railway; if an Irish Sea rail fixed link were to be constructed with its landfall near Holyhead, this upgrade could prove extremely useful.

In any scenario involving the operation of piggyback services, routes direct to mainland Europe via the Channel Tunnel would be of greatest interest, although services to south-eastern England could also have potential. The sphere of operation could be rather wider if a fixed link across the Irish Sea were to be constructed.

On balance, it is considered likely that a Channel Tunnel-northwest England piggyback corridor, linked to the port of Liverpool, will be provided in any event by 2020. This might take the form of the Central Railway project or of an upgraded WCML. For the purposes of this project, it is not considered necessary to assume which option is chosen.

Swap-bodies are, in essence, containers which dispense with the ability to stack the units and the standardisation of dimensions in return for greater payload weight (due to lower structure weight) and volume (due to larger dimensions). They are generally conveyed by rail or road; very few ships capable of handling swap-bodies *per se* exist. Swap-bodies can, of course, be carried on trailers aboard a ro-ro ship or rail wagons aboard a train ferry.

In the Irish context, it is possible to envisage a rail service carrying swap-bodies from one or more British ports on the Irish Sea (e.g. Holyhead, Liverpool, Stranraer) to continental European destinations. Indeed, such a concept was studied in the late 1980s and considered worthwhile. The swap-bodies would cross the Irish Sea on road trailers; it would therefore be unlikely that there would exist any significant potential for transporting them by rail within Ireland, given the additional handling necessary.

Bi-modal vehicles can be mounted on rail bogies by simple retraction of their road wheels; they do not, therefore, require a rail chassis or a road trailer. However, the concept is largely unproved in Europe. The possible application of the idea in the Irish access market would probably be very similar to that outlined above for swap-bodies.

Before leaving the subject of rail freight intermodality, mention should be made of the possibilities for small-container traffic. This is a continuum rather than a single type of unit; the main potential is likely to be at the lower end of the size range, in terms of containers of a size appropriate to air transport. These could be conveyed to and from airports via dedicated trains operating at similar speeds to passenger trains, thus enabling air freight traffic to bypass road congestion around airports. They might also find applications in conjunction with certain types of high-speed sea transport technology.

Construction of rail-linked freight terminals at airports and acquisition of new rolling stock would seem necessary. All in all, this concept seems relatively unlikely to find favour in the Irish access market, given the high capital costs and considerable risks of setting up an entirely new system. However, it is already being used to distribute freight from airports in mainland Europe, and some Irish exports and imports might therefore make use of it.

It is likely that domestic air transport in Ireland will continue in a similar mode of operation to its present one. There will probably be some enhancements to services, particularly on the subsidised routes, and the Essential Air Services Programme (subsidy scheme) may well be extended somewhat. Against this, improvements to surface transport, both road and rail, will continue and may undermine the airlines' position on some routes or lead to the termination of subsidy contracts. Improved rail access to Dublin airport could make rail more competitive with domestic aviation for "feeder" travel from more remote regions to connect with British or European flights. There does not seem to be any evidence that domestic airlines could increase their share of the freight market.

Airline services within Britain and Europe will follow a similar trend. The replacement of domestic flights with high-speed rail services connecting directly to airports is likely to continue, because of the benefits it offers in terms of point-to-point journey time, airport decongestion and reduced energy use.

B.7.2 Performance

Road and rail are the two principal modes considered in this chapter. Their basic characteristics are well-known; rail is distinguished from road by being limited to a fixed guideway; this gives benefits in safety, capacity (including the ability to form vehicles into trains) and reliability, but means that passenger or freight movements frequently involve intermodal chains.

Road passenger vehicles may be (simplifying enormously to give a broad outline of the types of greatest relevance to this study) private cars carrying around 5 passengers at average speeds of 60-80km/h (with a legal upper limit of 100-120km/h) or coaches carrying 50-70 people at scheduled speeds of 50-70km/h with an upper limit of 100km/h.

Road freight vehicles (trucks) used in international trade appear to be mainly articulated, consisting of a tractor and trailer with 4-6 axles in total. The overall weight of the combination is limited by law to a value in the region of 40-44t, the precise figure varying between countries.

Rail passenger trains in Ireland typically have a capacity of around 400-500 passengers and operate at scheduled speeds of 60-120km/h. Scheduled train speeds in Britain and mainland Europe are higher- 160km/h is common in Britain and 200km/h or more elsewhere. Freight trains, on the other hand, generally operate at around 40km/h on average, including stops (SINTEF et al., 1998).

B.7.3 Costs

The economics of the private car constitute an extremely complex area of study, since the driver's perception of cost is more important for the purposes of most decisions than the actual value. Once the vehicle has been purchased, the perceived marginal cost of additional mileage is very low, and may be limited to the cost of fuel. The perceived marginal cost of carrying additional passengers is effectively zero. These factors make it difficult for collective transport modes to compete with a high-occupancy car on cost alone.

Gibbons (1998) quotes car operating costs of €0.2578-0.4276/vehicle-km in Irish conditions. However, fuel only accounts for €0.04-0.05/vehicle-km; this is effectively the perceived marginal cost of mileage, as discussed above. Vehicle-kilometre figures must be divided by the average number of passengers per car to convert to passenger-kilometres. Thus, if two passengers per car is assumed to be a typical occupancy rate for interregional travel, then an operating cost in the region of €0.12-0.21/p-km and perceived marginal cost of €0.02-0.03/p-km are indicated.

Coach travel is generally the cheapest mode of collective passenger transport. The data available at the time of writing appears to bear this out (e.g. a return fare of €50 Dublin-London or €105 Dublin-Paris), the general pattern of fares appearing to correspond to a rate of about €0.05-0.1/p-km.

The costs of road freight transport are slightly better defined. However, the multitude of operators, of varying sizes and with varying structures, adds to their complexity. A major study carried out in the Republic of Ireland (Indecon et al. 1999) indicates that small businesses dominate the sector and that costs are in the region of IR£ 0.24/t-km (€0.31/t-km) on average. This value, however, seems rather high. SINTEF et al. (1998) suggest that €0.039-0.045/t-km is more appropriate, at least for food products and fertiliser. It is possible that the Indecon value is distorted by the large number of different types of haulage operation grouped together in the survey; furthermore, it should be observed that the SINTEF figures are exclusive of intermodal transfer costs (elements of which may be incorporated into hauliers' charges).

Rail is generally perceived in Britain and Ireland as a more costly mode of transport than road, both for passengers and unitised freight. This is probably true in the case of passenger transport, but not necessarily for the line-haul cost of freight, which is generally lower by rail. However, over shorter distances, the costs of road/rail transfers can radically alter the picture with respect to total point-to-point cost, as described in greater detail below.

Rail passenger fares in Ireland were in the region of IR£0.07-0.11 per mile in 1993 (Joint Committee on Commercial State-Sponsored Bodies 1995, 4.9). Since then, there has been a general 10% increase, suggesting current values of €0.06-0.1/p-km.

Actual line-haul charges for rail freight are low. Data given by Nautical Enterprise Centre (1998) indicate that typical rates for containerised freight are in the region of €0.03/t-km. SINTEF et al. (1998) quote €0.011-0.018/t-km, but these are (as in the case of all the figures from this source) link costs for the STAN model which exclude intermodal transfers. Rail-road transfers are estimated by the same source to cost €7.2-12.1/t. This cost element clearly has a serious effect on the viability of rail freight over short distances such as those found in Ireland.

For the purposes of this study, costs of €0.174/p-km for car, €0.075/p-km for coach and €0.08/p-km for conventional rail services have been assumed. Costs for freight transport are assumed to be €0.03/t-km for trucks and €0.012/t-km for rail transport. Piggyback rail services are assumed to cost €0.019/t-km for truck-carrying services and €0.002/p-km for car-carrying operations, exclusive of link-specific charges on fixed links. These figures are

projected from those for rail freight. High-speed trains are assumed to have a fare level of €0.09/p-km, which is generally in line with high-speed rail fares in France but does not include additional charges for fixed links; these would increase the fare level to €0.11-0.14/p-km on typical routes between Britain and Ireland.

B.7.4 Environmental impact

Road transport tends to be characterised as a high-impact mode in environmental terms and rail as comparatively low-impact. As a general rule, this is true. However, in terms of emissions, it may be noted that road coaches (but not cars) often produce lower emission levels than trains (but at a lower speed) and road haulage may be more efficient than rail for the transport of certain types of low-density freight.

In interregional applications, a car will typically require 0.7-0.8MJ/seat-km of energy (Waters 1992, CE 1997). Two people (compare the 1.5-person average for urban travel) constitute a normal occupancy level (i.e. 40% occupancy in a 5-seat vehicle). Thus, car energy consumption is in the range 1.4-1.6 MJ/p-km. In practice, the size of the car and the choice of a petrol or diesel engine also affect the fuel consumption, but the values remain broadly similar in the context of a comparison between modes. A coach has an energy consumption of around 0.2-0.3MJ/seat-km and typically operates at 65% occupancy, giving a value of 0.3-0.5MJ/p-km.

The amount of energy required for road haulage depends on the commodity as well as the vehicle technology. Waters (1992, Table B.6) presents an indicative range of energy consumption levels. Bulk (tanker or tipper) operations, container haulage and the movement of semi-finished goods lie at the bottom of the range, around 0.7MJ/t-km. Finished goods require around 0.8MJ/t-km and parcels 0.9. Export/import traffic consumes 1.0MJ/t-km and short-distance waste tipping (rather than long-distance bulk tipper traffic) 1.2. The very highest values are for consumer product haulage (1.6) and components delivery to factories (2.0). SINTEF et al. (1998) cite an emission level of 1.4kg CO_2/km for an articulated truck, corresponding (for 25t payload) to roughly 0.73MJ/t-km.

In respect of rail passenger transport, in the Irish context a typical diesel locomotive used on both passenger and freight trains has an energy consumption of 1 gallon/mile, or approximately 106.6MJ/km. Hauling a passenger train with around 400 seats, this would correspond to 0.27MJ/p-km at 100% occupancy or 0.67 at the more realistic 40%. High-speed diesel trains used in Britain achieve approximately 0.9MJ/p-km at a 45% load factor. Electric high-speed trains consume 0.7-1.2MJ/p-km at 45-50% load factors.

As in the case of road freight, rail freight's energy demands vary with the commodity carried. Waters (1992, Table B.8) quotes a figure of 0.6MJ/t-km for bulk traffic, 0.7 for single-consignment point-to-point trainloads, 1.0 for wagonload traffic (i.e. individual wagons are picked up and dropped off at multiple points) and 0.9 for container trunk haulage. These figures would appear to indicate that rail freight only possesses a conclusive advantage over road in terms of energy consumption for bulk haulage and trainload freight. It must, however, be taken into account that the road figures are for fully loaded vehicles whereas the rail data is an average. Furthermore, Irish figures based on the locomotive fuel consumption data referred to above (Nautical Enterprise Centre, 1998) would suggest that, at the average payload cited by the same source of 400t/train, a value of 0.27MJ/t-km is attained. This is more in line with other past evaluations of rail freight energy use. SINTEF et al. (1998) claim a figure of 0.5kg CO_2/40 foot unit-km, equivalent to about 0.32MJ/t-km.

The emission figures utilised for appraisal purposes are given in Tables B.16 and B.17 below. Mid-range energy consumption figures from the data described above are used in conjunction with the information on emissions characteristics from INRETS (1999) for road transport.

Rail transport data assume that passenger trains are carry an average of 160 people at a speed of 150km/h with 2,400kW of installed power (i.e. 0.1kWh/p-km), and freight trains to carry 400t at 80km/h for a similar installed power (0.075kWh/t-km). The INRETS splits between diesel and electric traction (65% electric in 1995, 80% in 2020) are used and emissions assigned accordingly. For fixed-link services (i.e. the final three columns of Table B.17), 100% electric traction has been assumed and freight-train data adjusted by weight to represent vehicle shuttle trains. Passenger high-speed trains are assumed to have a power requirement of about 12,000kW at 250km/h (similar to Eurostar).

Table B.16 Road Transport Emissions

Pollutant	Private car 1995 (g/p-km)	Coach 1995 (g/p-km)	Truck 1995 (g/t-km)	Private car 2020 (g/p-km)	Coach 2020 (g/p-km)	Truck 2020 (g/t-km)
CO_2	105	20	102	105	20	102
NO_x	0.24	0.29	1.827	0.029	0.07	0.438
SO_2	0.025	0.01	0.641	0.025	0.01	0.641
VOC	0.04	0.02	0.077	0.006	0.005	0.018
CO	0.243	0.046	0.237	0.049	0.02	0.104
PM	0.039	0.008	0.038	0.039	0.001	0.006

Table B.17 Rail Transport Emissions

Poll-utant	Passenger train 1995 (g/p-km)	Freight train 1995 (g/t-km)	Passenger train 2020 (g/p-km)	Freight train 2020 (g/t-km)	Passenger shuttle train 2020 (g/p-km)	Freight piggyback train 2020 (g/t-km)	Passenger high-speed train 2020 (g/p-km)
CO_2	67.6	50.7	67.6	50.7	101.4	81.12	70
NO_x	0.498	0.374	0.498	0.374	0.748	0.598	0.043
SO_2	0.211	0.158	0.065	0.049	0.098	0.078	0.098
VOC	0.107	0.08	0.054	0.04	0.08	0.064	0.068
CO	0.145	0.109	0.013	0.010	0.02	0.016	0.005
PM	0.180	0.135	0.07	0.053	0.106	0.085	0.009

Road traffic noise is another contentious issue in many countries. However, it is generally difficult to segregate out the contribution which Irish access transport makes to the problem. There are a number of localised exceptions, such as truck traffic in the vicinity of ports (e.g. Dublin's inner city).

Rail noise is, in general, considered less of a concern than road noise, partly due to its intermittent nature. The areas affected are also naturally more limited. However, noise remains an essential factor for consideration in planning any new rail scheme or the greatly increased utilisation of existing tracks, especially where heavy freight traffic is involved.

Roads also require considerable amounts of land, particularly in the case of motorways. In addition to the effects of land use changes, visual intrusion and loss of buildings, vegetation etc., they generally create considerable community severance impacts.

While railways also have severance and land take effects, the land requirement for a given capacity tends to be smaller than for a road. Furthermore, they are more readily placed in tunnel where this is necessary to mitigate severance or visual impacts. There also appears to be (at least in Ireland) greater spare capacity on the existing rail network than the national road system, although this should not be taken to imply that no shortages of rail capacity exist.

Because road transport dominates all other modes in most countries in terms of the generation of emissions and other negative environmental impacts, a far greater volume of research work has been conducted on its effects. As a consequence, a very large number of impacts, beyond the previously-determined areas of emissions, land take/severance, visual effects, noise and certain others, have been identified. It is not proposed to list them in detail. Dust emissions from braking and vehicle motion, and water pollution from road run-off, are just two examples. The energy used in the construction of vehicles and roads has also been the object of considerable attention, but is excluded from consideration for the purposes of this project.

Road safety has also to be considered in any assessment of the mode's environmental impact, although it affects the human environment to a greater extent than the natural environment. Safety has not been considered in the assessment of other modes because there is little or no evidence of significant differences between them in this respect.

However, road safety is a difficult aspect to ignore, particularly where it relates directly to access traffic, as in the case of heavy truck traffic in certain areas.

B.8 CONCLUSIONS

B.8.1 Identifying measures for further investigation

Following the completion of the preliminary technological analysis, the measures considered of possible value for further analysis were identified on a mode-by-mode basis. They are summarised in Table B.18 below, which divides them into service and infrastructure measures (though the two may be interrelated in some cases).

A preliminary analysis enabled the following measures to be ruled out.

- Train ferries and associated port provisions. Excluded because the future of the technology was very uncertain and because of problems posed by the small Irish rail network and the location of many importers and exporters relatively close to ports.
- Freight-carrying wing-in-ground-effect craft. Excluded because it appeared to offer comparatively few advantages, and because of inadequate background data.

It was also identified at an early stage that a choice had to be made between conventional fully-buoyant airships and hybrid dynastats for both the passenger and freight components of any notional buoyant air transport system. Preliminary analysis indicated that the cost/speed combination offered by fully-buoyant airships would not be an effective competitor to airlines, so that dynastats were favoured in this respect. However, it initially appeared that dynastats would not offer sufficient advantages relative to airships in the freight market to justify their higher costs. This latter position was subsequently modified in the light of the emergence of the ATG SkyCat design, with particular reference to the 1,000t payload model which appeared to offer significant potential operating cost savings over smaller craft. It was considered possible that these savings would compensate for additional costs resulting from the partial use of dynamic lift, and this appears to be borne out by the operating cost calculations subsequently made. Hence, it was decided that

Table B.18 Preliminary Identification of Possible Measures

Mode	Service measures	Infrastructure measures
Conventional air	• Tiltrotor V/STOL city centre-city centre, feeder airport-city centre, regional airport-city centre • Dedicated high-capacity freight service	• Vertiport system • Second Dublin airport • Additional regional airports
Conventional sea	• New routes • Train ferry services	• Second Dublin port (ro-ro freight only) • Train ferry facilities at ports
High-speed sea	• High-speed freight ferries • Large high-speed passenger/freight ferries • Passenger-carrying wing-in-ground-effect craft • Freight-carrying wing-in-ground-effect craft • New fast ferry routes	• Terminal/access facilities for wing-in-ground-effect craft
Fixed links	• Passenger/freight rail services, Dublin-GB/Europe. • Road vehicle shuttle services through tunnel	• Immersed tube rail tunnel Dublin-Holyhead • Associated road/rail construction/upgrading package
Buoyant air	• Passenger airship system • Freight airship system • Passenger dynastat system • Freight dynastat system	• Passenger and freight terminals as appropriate for airships or dynastats
Access to terminals	• Rail service improvements	• Enhanced rail freight access to ports • Airport rail links • Road upgrading

dynastat-type craft rather than airships were favoured for both passenger and freight operations.

The remaining possible measures were taken forward in the analysis, and chapter 4 of the thesis describes how further development was carried out on them. Chapter 5 outlines the

process of developing these individual elements into a set of coherent strategies for input to the modelling and appraisal processes.

B.8.2 Summary of characteristics

Having identified the measures worthy of further investigation, the data from this Appendix were gathered into summary table form. The information was then presented as two tables, relating respectively to qualitative and quantitative issues. These form Tables 3.7 and 3.8 of the thesis and are not reproduced here.

Specific attention was also given to identification of the external costs for each mode. The cost figures detailed in sub-section 7.6.3 of the thesis formed the basis for this work. The emission data identified in this Appendix were used to calculate emission costs; accident and pavement damage costs for road transport were based on those already identified in chapter 7. The various costs were combined for each mode and are indicated in Table B.19 below.

Table B.19 Estimates of external costs for various transport modes in 2020

Mode	External cost per p-or t-km (€)
Car	0.033
Passenger train	0.019
High-speed passenger train	0.005
Passenger/car shuttle train	0.029
Coach	0.003
Mainline/low-cost airline	0.045
Regional airline	0.076
V/STOL	0.077
Passenger buoyant air	0.031
Ferry (passenger)	0.008
Fast ferry (passenger)	0.038
Ultra-high-speed ferry (passenger)	0.056
Truck	0.016
Freight train	0.014
Freight piggyback rail	0.023
Air freight	0.365
Buoyant air freight	0.084
Ferry (ro-ro freight)	0.044
Fast ferry (ro-ro freight)	0.073
Bulk ship/inland waterway	0.008
Lo-lo ship	0.007
Fast freighter	0.113

APPENDIX C APPRAISAL CRITERIA IN PAST STUDIES

C.1 COST-BENEFIT

C.1.1 Roskill Commission (Third London Airport)

(Source: Flowerdew 1972)

Airport construction
Extension of Luton airport
Airport services
Meteorology
Airspace movements
Passenger user costs
Freight user costs
Road capital
Rail capital
Air safety
Defence
Public scientific establishments
Private airfields
Residential conditions (noise, off-site)
Residential conditions (on site)
Luton noise costs
Schools, hospitals and public authority buildings (including noise)
Agriculture
Commerce and industry (including noise)
Recreation (including noise)

C.1.2 Channel Tunnel: 1963

(Source: Minister of Transport 1963)

Tunnel/bridge capital costs
Tunnel/bridge operating costs
Passenger aircraft total costs
Vehicle ferry aircraft capital costs
Vehicle ferry aircraft operating costs
Ferry ship capital costs
Ferry ship operating costs
General cargo ship total costs
Ferry port/ airport capital costs

C.1.3 Channel Tunnel: 1973

(Source: Coopers & Lybrand 1973)

Tunnel capital costs
Tunnel revenue
Tunnel operating cost
Rail capital costs
Rail revenue
Rail operating costs
Airline revenue
Airline costs
Shipping capital costs
Shipping revenue
Shipping operating costs
Port capital costs
Port revenues
Port operating costs
Road capital costs
Road hauliers' revenue
Road hauliers' operating costs
User benefits:
- Fares
- Time costs
- Freight charges
- Freight time savings

C.1.4 Channel Tunnel: 1975

(Source: Channel Tunnel Advisory Group 1975)

Tunnel capital costs
Ship capital costs
Port capital costs
Tunnel operating costs
Ship capital costs
Port capital costs
Tunnel revenue
Shipping revenue
Port revenue
Tunnel fares
Ship fares
Time savings:
- Car-accompanied
- Classic (i.e. rail + sea or through rail)
- Freight

C.1.5 Dublin Transportation Initiative

(Source: DTI 1993)

Car user time savings
HGV time savings
Public transport time savings
Car operating cost savings
HGV operating cost savings
Accident cost savings
Capital costs
Operating costs

C.1.6 EU freight nodal centres

(Source: Gruppo CLAS/Systema 1996)

Owners/operators:	Loan repayment costs
	Taxes (direct)
	Real estate acquisition costs
	Engineering costs
	Equipment costs
	Maintenance/renewal
	Operating/administrative/monitoring costs
	Revenue from sale of services
	Rent revenue
	Grants/loans
Users:	Cost of services
	Rental costs
	Transport time
Players in the macro-/ socio- economic context:	Loans
	Grants
	Taxes
	Loan repayment income
	Safety/environmental impacts

C.1.7 EU passenger nodal centres

(Source: ISIS et al. 1996)

Travellers:	Changes in travel time
	Other changes in travel disutility
Suppliers/Operators:	Operating cost change
	Capital costs

Community Effects: Environmental
Secondary employment

C.2 MULTICRITERIA

C.2.1 Dublin Transportation Initiative

Table C.1 Dublin Transportation Initiative Objectives/Criteria (Source: DTI 1993)

Objective	Criterion	Author's classification
Employment and the Regional Economy	Encourage economic development and regeneration	Competitiveness
	Consolidate existing business and industry	Competitiveness
	Attract new investment and stimulate growth in tourism	Competitiveness
	Improve physical access to all job opportunities for unemployed	Equity
Quality of Life	Improve reliability and comfort of travel	Equity/Sustainability
	Improve personal safety and security on-street and in transit	Equity/Sustainability
	Reduce traffic accident levels	Sustainability
	Reduce direct environmental effects from transport: noise, air pollution, energy consumption	Sustainability
	Improve access to leisure and cultural facilities	Equity
International and National Context	Achieve consistency with EC and National Government plans and policies	Feasibility
	Improve access to international markets via ports and airports	Competitiveness
	Improve access to and from the sub-region	Competitiveness
	Help foster sustainable development	Sustainability

(continued over)

Table C.1 continued

Objective	Criterion	Author's classification
Development of the City and the Region	Maintain the relative advantage of the City Centre in terms of accessibility for all	Competitiveness/Equity
	Provide the framework for a satisfactory pattern of new town/suburban development	Sustainability
	Achieve coherence with development plans including those of adjacent areas (Kildare, Meath, Wicklow)	Feasibility
	Conserve and enhance physical and cultural heritage	Sustainability
Efficiency in Implementation	Contain finance needs within available levels (National Government, European)	Competitiveness/ Feasibility
	Optimise use of existing infrastructure and facilities	Feasibility
	Timescale; full implementation this century (finance not a constraint)	Feasibility
	Capacity for self enforcement	Feasibility
	Additional legislation/administrative structures required	Feasibility
	Provide a framework for financial health of transport operating companies	Competitiveness
	Disruption during construction/ implementation	Feasibility/ Competitiveness

C.2.2 Strategic Planning Guidelines for the Greater Dublin Area

Table C.2 SPGGDA Objectives/Criteria (source: Brady Shipman Martin et al., 1999)

Objective	Criterion	Author's classification
Facilitation of Public Transport	-	Sustainability
Balance of Public and Private Transport	-	Sustainability
Reduction in the Need to Travel	Employment	Sustainability/Equity
	Shopping and social facilities	Sustainability/Equity
Utilisation of Existing Capacity	Zoned Land	Feasibility
	Sanitary Services	Feasibility
	Transport	Feasibility
Use of Under-Utilised Land	Brownfield site	Sustainability/Feasibility
	Low-density residential areas	Sustainability/Feasibility
Facilitation of Economic Activities	-	Competitiveness
Facilitation of Higher Residential Densities	-	Sustainability
Facilitation of Mixed Uses	-	Sustainability
Equity and Affordability	Integration	Equity
	Affordability	Equity
Urban/Rural Demarcation	-	Sustainability
Conservation of High Quality Agricultural Land	-	Sustainability
Protection of Heritage and Amenity	-	Sustainability
Regional Balance	-	Equity
Relative Cost	-	Feasibility/ Competitiveness

C.2.3 NATA (original AST)

Table C.3 NATA Objectives/Criteria (source: DETR 1998b)

Objective	Criterion	Author's classification
Environmental Impact	Noise	Sustainability
	Local air quality	Sustainability
	Landscape	Sustainability
	Biodiversity	Sustainability
	Heritage	Sustainability
	Water	Sustainability
Safety		Sustainability
Accessibility	Public transport	Equity/Sustainability
	Severance	Sustainability
	Pedestrians and others	Equity/Sustainability
Integration		Feasibility/Sustainability

C.2.4 GOMMMS (revised AST)

Table C.4 GOMMMS Objectives/Criteria (source: DETR 2000c)

Objective	Criterion	Author's classification
Environment	Noise	Sustainability
	Local air quality	Sustainability
	Greenhouse Gases	Sustainability
	Landscape	Sustainability
	Townscape	Sustainability
	Heritage of Historic Resources	Sustainability
	Biodiversity	Sustainability
	Water Environment	Sustainability
	Physical Fitness	Sustainability
	Journey Ambience	Equity/Sustainability
Safety	Accidents	Sustainability
	Security	Equity/Sustainability
Economy	Transport Economic Efficiency	Competitiveness/ Feasibility
	Reliability	Competitiveness
	Wider Economic Impacts	Competitiveness
Accessibility	Option values	Equity
	Severance	Sustainability
	Access to the Transport System	Equity
Integration	Transport Interchange	Feasibility/Sustainability
	Land-Use Policy	Feasibility/Sustainability
	Other Government Policies	Feasibility

C.2.5 Regional Eurostar study (modified AST)

Table C.5 Regional Eurostar Objectives/Criteria (source: Little 1999)

Objective	Criterion	Author's classification
Environment	Noise	Sustainability
	Local air quality	Sustainability
	Climate change	Sustainability
	Journey Ambience	Equity/Sustainability
Safety	Accidents	Sustainability
	Security	Equity/Sustainability
Economy	Efficiency: users	Competitiveness
	Efficiency: operators	Competitiveness
	Reliability	Competitiveness
	Wider economic impact	Competitiveness

C.2.6 South East Airports Appraisal Framework (modified AST)

Table C.6 SEEAAF Objectives/Criteria (source: DETR 2000b)

Objective	Criterion	Author's classification
Safety	Air Safety: population at risk	Sustainability
	Accidents on Road and Rail Networks	Sustainability
Economy	Air passenger benefits	Competitiveness
	Cargo user benefits	Competitiveness
	Transport provider benefits	Competitiveness
	Government	Competitiveness/ Feasibility
	Benefits to non air transport users	Competitiveness/Equity
	Regeneration and redistribution of economic activity	Competitiveness/Equity
	Productivity growth across the economy	Competitiveness
	Foreign direct investment and trade	Competitiveness
	Benefits to particular industries	Competitiveness
Environment	Noise	Sustainability
	Local air quality	Sustainability
	Climate change	Sustainability
	Landscape	Sustainability
	Townscape	Sustainability
	Biodiversity	Sustainability
	Heritage	Sustainability
	Water	Sustainability

(continued over)

Table C.6 continued

Objective	Criterion	Author's classification
Accessibility	Accessibility to the air transport system by public transport	Equity/Sustainability
	Accessibility to the air transport system by private transport	Equity
Integration	Airport strategy	Equity/Feasibility
	Spatial strategy	Equity/Feasibility
	Strategic transport network	Feasibility
	Economic regeneration	Equity/Competitiveness
	Environmental regeneration	Sustainability
	Green belt	Sustainability
	Previously used land	Sustainability
Further considerations	Commercial viability	Feasibility
	Operational considerations	Feasibility

C.2.7 EU passenger nodal centres

Table C.7 EU passenger nodal centre objectives/criteria (source: ISIS et al. 1996)

Objective	Criterion	Author's classification
Travellers	Changes in travel time	Competitiveness
	Other changes in travel disutility	Competitiveness
Suppliers/Operators	Operating cost change	Competitiveness
	Capital costs	Competitiveness/ Feasibility
European Effects	Connectedness	Equity/Competitiveness
	Local Access	Equity
	Compliance with established European standards	Feasibility
Community Effects	Environmental	Sustainability
	Employment- direct & indirect	Competitiveness

APPENDIX D POLICY OBJECTIVES

D.1 NATIONAL SPATIAL STRATEGY

Table D.1 "Guiding Principles for the National Spatial Strategy" (source: Department of the Environment and Local Government 2001, Box 2)

Objective	Author's classification
To provide an integrated spatial framework for policies progressing economic and social development and enhancing quality of life	Competitiveness/Equity/Sustainability
To optimise and sustain the overall economic performance of the country by affording all areas of the country the opportunity to develop to their potential	Competitiveness/Equity
To facilitate and underpin the development of an island economy in the island of Ireland and accompanying social and human interaction, in the interests of yielding benefits for the whole island	Equity
To manage our natural environment and cultural heritage in a sustainable manner	Sustainability
To emphasis[e] the special and distinctive attributes of rural society and ensure the vitality of rural areas	Equity/Sustainability
To seek to create new development opportunities in the BMW region and the structurally weaker areas of the S&E region	Equity
To counteract the population drift to the Greater Dublin Area by promoting appropriate employment opportunities in other parts of the country as well	Equity
To consolidate and enhance the international competitiveness of Dublin and the other main cities	Competitiveness
To prepare [for] and respond to the likely structural economic and social changes developing from the information society	Competitiveness/Equity
To ensure that the NSS is capable of effective and realistic implementation at national, regional and local levels	Feasibility

D.2 NATIONAL DEVELOPMENT PLANS

D.2.1 1994-1999 OPT Economic Objectives

Table D.2 Economic Objectives in 1994-1999 Operational Programme for Transport (source: Government of Ireland 1994)

Objective	Author's classification
Reduction of export transport costs	Competitiveness
Improved access to markets	Competitiveness
Improved access to tourist areas	Competitiveness
Support for agriculture/natural resources development and local/border area economic development	Equity
Indirect support for job creation	Equity
Promotion of cohesion and integration of peripheral regions into the EU	Equity

D.2.2 1994-1999 OPT Transport Objectives

Table D.3 Transport Objectives in 1994-1999 OPT (source: Government of Ireland 1994)

Objective	Author's classification
Integrated improvement programme for internal and access systems to reduce costs	Competitiveness
improved reliability through decongestion and speed increases	Competitiveness

D.2.3 1994-1999 "principles to be followed in implementation"

Table D.4 1994-1999 "principles to be followed in implementation of OPT" (source: Government of Ireland 1994)

Objective	Author's classification
Environmental sustainability	Sustainability
Regional development	Equity
Providing for the needs of the disadvantaged and mobility impaired	Equity
Optimising use of existing infrastructure	Feasibility
Safety improvement	Sustainability

D.2.4 2000-2006 NDP Transport Objectives

Table D.5 Transport Objectives in 2000-2006 National Development Plan (source: Government of Ireland 1999)

Objective	Author's classification
Improving the reliability of the road transport system	Competitiveness
Improving road infrastructure to facilitate competitiveness and balanced regional development	Competitiveness/Equity
Better access to ports and airports, to counter "the negative effects of peripherality"	Equity
Contributing to sustainable transport policies	Sustainability
Improving road safety	Sustainability
Improving rail safety	Sustainability
Increasing rail passenger capacity	Sustainability/Competitiveness
Improving the quality, speed and reliability of rail services	Sustainability/Competitiveness

D.3 REPUBLIC OF IRELAND: SUSTAINABLE DEVELOPMENT STRATEGY

Table D.6 Transport-related objectives in National Sustainable Development Strategy (source: Department of the Environment 1997)

Objective	Author's classification
Making transport more efficient	Sustainability/Competitiveness
Reducing the environmental impact and intensity of transport	Sustainability
Support for moves towards the internalisation of external costs	Sustainability/Equity

D.4 REPUBLIC OF IRELAND: GENERAL TRANSPORT POLICY

D.4.1 Department of Public Enterprise strategy statement

Table D.7 Selected air transport-related objectives from Department of Public Enterprise strategy statement (Department of Public Enterprise 1998)

Objective	Author's classification
To ensure that the standards, safety and security of aviation continue to inspire confidence in the use of Irish airspace and technical infrastructure	Competitiveness
To facilitate and encourage a wide range of reliable, regular and competitive commercial air services for Irish tourism, trade and industry	Competitiveness
To seek to maintain at least one domestically based and financially viable airline of sufficient scale to provide air services between Ireland and all our main export markets on a year round basis	Competitiveness
To ensure that Irish airports are cost competitive and have appropriate infrastructure to meet the current and prospective needs of the international airline industry	Competitiveness

D.4.2 Department of the Marine strategy statement

Table D.8 Objectives relevant to access transport from Department of the Marine and Natural Resources strategy statement (Department of the Marine and Natural Resources 1998)

Objective	Author's classification
To facilitate the co-ordination and integration of maritime transport within the total transport chain	Competitiveness
To ensure competitive port services	Competitiveness
To ensure adequate infrastructure at ports so as to facilitate competitive shipping services	Competitiveness
To facilitate the restructuring of the roles of declining sub-regional ports	Equity

D.5 MAJOR PREVIOUS STUDIES

D.5.1 Dublin Transportation Initiative Vision Statement

Table D.9 Objectives in DTI Vision Statement (source: DTI 1993)

Objective	Author's classification
Dublin as a leading European City: Competing and co-operating successfully, civilised, literate and vibrant	Competitiveness
The National Capital: Proud of its history and heritage, its unique character conserved, a fit setting for Government and National Centres of Excellence	Sustainability/Competitiveness
A Metropolitan Region with a strong, growing and diverse city, town and rural economy, based on a skilled and adaptable workforce	Competitiveness
A Living City-Region on a human scale, accessible to all: at its heart, a city to serve its people and communities and to meet their aspirations for an improving quality of life	Equity

D.5.2 Fitzpatrick studies:BMW region

(From a pre-National Development Plan study on development strategies for the region; the corresponding S&E region study is described below.)

Table D.10 Fitzpatrick BMW region objectives (source: Fitzpatrick et al. 1999b)

Objective	Author's classification
Maintain the pace of unemployment reduction, especially long-term unemployment	Equity
Reduce social exclusion, including rural smallholder and non-farm exclusion	Equity
Contribute to regional and national progress by developing the region as National counterweight to the Eastern and Southern cities	Equity
Promote spatial balance of development within the region, including integrated rural development	Equity
Address the specific problems of remote rural communities	Equity
Build on the region's distinct strengths and attributes	Feasibility
Introduce good spatial planning into regional development policy	Sustainability
Increase regional competitiveness, at international, EU and national level	Competitiveness
Facilitate the presence in the region of the key drivers of modern enterprise growth-high quality infrastructure and services, a highly skilled workforce, and a good environment	Competitiveness/Sustainability
Promote cross-border trade, business and other links	Equity
Increase the regional base of high productivity, high income generating enterprises	Competitiveness
Give regional expression to the National Development Plan	Feasibility
Develop appropriate strategies for the major enterprise sectors in the Region	Competitiveness

D.5.3 Fitzpatrick studies: S&E region

Table D.11 Fitzpatrick S&E region objectives (source: Fitzpatrick et al. 1999a)

Objective	Author's classification
Maintain and improve the quality of life, in a sustainable manner, for all who wish to live and work in the region	Sustainability
Consolidate and build on the region's recent economic performance, especially regarding reductions in employment and long-term unemployment	Equity/Competitiveness
Develop Cork, Limerick and Waterford, and other urban centres, as a means of alleviating further congestion in Dublin	Equity
Distribute economic growth and its benefits throughout the region	Equity
Address emerging issues of sustainability and bottlenecks to growth including infrastructure and skilled labour provision	Sustainability/Feasibility
Target social exclusion in urban and rural deprived areas	Equity
Maintain a strong, vibrant, economically viable rural economy and a sustainable rural environment	Equity/Sustainability
Maintain the region's position as the "powerhouse of national economic development" while contributing to the national objective of more spatially balanced economic activity in Ireland	Competitiveness/Equity
Promote North-South co-operation	Equity

D.6 NORTHERN IRELAND: TRANSPORT POLICY

D.6.1 1998 Transport Policy Statement

(Note: these objectives are identified only in terms of their relevance to the "integrated transport" concept.)

Table D.12 1998 NI Transport Policy Statement Objectives (source: Department of the Environment for Northern Ireland 1998b)

Objective	Author's classification
Integration within and between different types of transport- so that each contributes its full potential and people can move easily between them	Feasibility/Sustainability
Integration with the environment- so that transport choices support a better environment	Sustainability
Integration with land use planning- at national, regional and local level so that transport and planning work together to support more sustainable transport choices and reduce the need to travel	Sustainability
Integration with policies for education, health and wealth creation- so that transport helps to make a fairer, more inclusive, healthier and more prosperous society	Equity/Competitiveness

D.6.2 2002 Proposed Regional Transportation Strategy

Table D.13 Selected elements of NI 10-year "Transportation Vision" (Department of Regional Development 2002)

Objective	Author's classification
Exploiting the latest technology, innovative practices and communication techniques to ensure that best use is made of the transportation network and services	Feasibility/Sustainability
A high quality strategic transport network constructed, operated and maintained to ensure rapid and predictable journey times for public transport ...goods vehicles and cars	Competitiveness
[Integration of transport] with land use planning ... contributing to a healthy and environmentally aware society choosing to walk, cycle and use public transport for many journeys	Sustainability
Modern and innovative public transport services planned, managed, operated and regulated to meet the needs of travellers' regular journeys, thereby providing a realistic alternative to ... the car and making a major contribution to the mass movement of people...	Sustainability
An extensive, customer-orientated public transport system fully integrated with all modes of travel...	Sustainability
Efficient and affordable forms of public transport operated to regulated service standards...	Sustainability
Rural areas served by different types of accessible public transport...	Sustainability
All infrastructure and services used responsibly and managed, operated and maintained to [high] standards of safety	Sustainability
A safe environment for pedestrians in general and older people and children in particular...	Sustainability
Contributing to the creation of attractive central areas in cities and towns for living, working and leisure...	Sustainability
Safe and extensive walking and cycling networks...	Sustainability

D.7 NORTHERN IRELAND: SPATIAL STRATEGY

Table D.14 Selected "Guiding Principles" of the "Shaping Our Future" Strategy (Department of the Environment for Northern Ireland 1998a)

Objective	Author's classification
A people and community focused approach...	Equity
A sustainable approach to development-based on: -Social progress that meets the needs of everyone -Effective protection of the environment -Prudent use of natural resources -Maintenance of high and stable levels of economic growth and employment	Sustainability
Achieving a more cohesive society...based on: -equality of opportunity and equity of treatment... -spatial equity and complementarity... -a partnership approach... -strengthening community cohesion... -a...more sustainable approach to transport... -an outward looking perspective...	Equity/Sustainability
Achieving competitiveness based on: -investing in intelligence... -improving accessibility and communications to and within the Region... -reconciling growth with quality of life...	Competitiveness/Sustainability
An integrated approach based on: -strengthening interconnections between all aspects of Government... -building on the many strengths of the regional institutions in Northern Ireland...	Feasibility

D.8 UK TRANSPORT POLICY

D.8.1 "Integrated Transport White Paper"

Table D.15 UK Integrated Transport White Paper Objectives (source: Department of the Environment, Transport and the Regions [DETR] 1998c)

Category	Objective	Author's classification
Better health	Reduce pollution from transport	Sustainability
	Improve air quality	Sustainability
	Encourage healthy lifestyles by reducing reliance on cars...	Sustainability
	Reduce noise and vibration from transport	Sustainability
	Improve transport safety for users, those who work in the industry and the general public	Sustainability
More jobs and a strong economy	Improve reliability for journeys in all modes...	Competitiveness
	Improve links with international markets	Competitiveness
	Support regeneration and the vitality of urban and rural areas	Equity
	Make more efficient use of the transport system	Feasibility/Sustainability
	Promote more sustainable UK transport industries	Sustainability

(continued over)

Table D.15 continued

Category	Objective	Author's classification
A better environment	Reduce road traffic growth	Sustainability
	Respond to the challenge of climate change	Sustainability
	Minimise transport's demand for land, protect habitats and maintain the variety of wildlife	Sustainability
	Limit the visual intrusion caused by transport	Sustainability
	Reduce use of non-renewable materials/energy sources	Sustainability
	Ensure that environmental impacts are taken fully into account in investment decisions and in the price of transport	Sustainability
	Enhance public awareness of transport and environmental issues	Sustainability
A fairer, more inclusive society	Produce better public transport and easier access to workplaces [etc.]...especially [for] people on low incomes	Equity
	Reduce community severance caused by transport	
	Reduce the need to travel through better planning and technology	Sustainability
	Promote better transport choice for disabled people	
	Reduce the fear of, and level of, crime on the transport system	
	Promote better conditions for those working in transport	
A modern, integrated transport system	Build a framework which retains competition...but provides for intervention... in the public interest...	Competitiveness/Feasibility
	Make increasing use of economic instruments such as pricing and taxation...;	Sustainability/Feasibility
	Improve the planning framework...	Feasibility

D.8.2 Other documents

Table D.16 Selected relevant objectives from White Paper daughter documents

Document	Objective	Author's classification
Sustainable distribution policy (DETR 1999)	To promote a "Sustainable Market"...[which] must function effectively, openly and fairly - not only...in the UK but at a global scale	Sustainability/ Competitiveness
	To promote integration of the freight transport infrastructure by means of "Strategic Planning"	Sustainability/Feasibility
	to ensure the freight transport industry achieves the Government's social and environmental objectives, by "Raising Standards"	Equity/Sustainability
Shipping policy (DETR 1998d)	Gaining safety and environmental benefit	Sustainability

D.9 EU POLICY

D.9.1 Trans-European Networks

Table D.17 Trans-European Network Objectives (source: Commission of the European Communities 1995)

Objective	Author's classification
Provide business with fast, efficient transport services at competitive costs	Competitiveness
Offer the travelling public a wide choice of...transport alternatives...	Competitiveness
Reduce congestion and pollution by channelling...traffic onto rail, combined transport, short sea shipping and inland waterways	Sustainability
Establish better connections between the regions on the periphery of the Union and those at its centre	Equity
Create stronger transport links with partner countries...	Equity/Competitiveness

D.9.2 2001 White Paper

Table D.18 2001 EU Transport White Paper Objectives (source: Commission of the European Communities 2001)

Objective	Author's classification
Revitalising the railways: Liberalisation of rail freight markets and creation of a dedicated rail network for freight traffic	Sustainability/Competitiveness
Improving quality in the road transport sector [Legal reform and some improvements in safety and employee protection regulations]	Sustainability/Equity
Promoting transport by sea and inland waterway ["Sea motorways" involving "better connections between ports and the rail and inland waterway networks together with improvements in the quality of port services" along with safety improvements and technical harmonisation]	Sustainability
Striking a balance between growth in air transport and the environment [airport improvements and traffic control harmonisation coupled with anti-noise and pollution regulations]	Competitiveness/Sustainability
Turning intermodality into reality [improving interoperability and technical harmonisation between different freight modes]	Competitiveness
Building the trans-European transport network [with particular emphasis on rail]	Competitiveness/Equity
Adopting a policy on effective charging for transport [encouraging internalisation of external costs and harmonisation of fuel taxation]	Sustainability

D.9.3 European Spatial Development Perspective

Table D.19 European Spatial Development Perspective Objectives (source: Commission of the European Communities 1999)

Objective	Author's classification
Better co-ordination of spatial development policy and land use planning with transport and telecommunications planning	Sustainability
Reduction of negative effects in areas subject to high traffic pressure by strengthening environmentally compatible means of transport, levying road tolls and internalising external costs	Sustainability/Equity
Promoting the interconnection of inter-modal junctions for freight transport, in particular for transport on the European corridors, especially regarding shipping and inland navigation	Sustainability/Competitiveness
Co-ordinated and integrated infrastructure planning and management for avoiding inefficient investments... and securing the most efficient use of existing transport infrastructure	Competitiveness/Feasibility

APPENDIX E PROGRAM LISTINGS

E.1 ESTIM.CPP

```
#include <iostream.h>
#include <math.h>
#include <iomanip.h>
#include <fstream.h>
#include <stdlib.h>
// ESTIM
// A program to implement NEA's OD-ESTIM in the Irish access
// market
// Warren J. Whitney 1999

ofstream outFile ("matrix.txt", ios::out);
 float distgdp (const int ds [23][23], const float gd [23],
int r2, int c2)
{
if (ds [r2][c2] !=0)
return ((pow (gd[c2], 0.7))/(pow(ds[r2][c2], 2)));
else
return 0;
}
void printmatrix1 (const float mx1 [23])
{
     for (int x = 0; x< 23; x++)
   {
     cout<<setw (20)<<mx1[x];
    }
}

void printmatrix2 (const float mx2 [23][23])
{
     for (int x1 = 0; x1<23; x1++)
   {
   for (int y1 = 0; y1<23; y1++)
     {
     outFile<<setw (20)<<mx2 [x1][y1];
       }
   outFile<<endl<<endl;
     }
}
float t1 (const int d1 [23][23], const float g1[23])
{
     float top = 0;
     for (int j1 = 0; j1 < 23; j1++) {
          for (int i1 = 0; i1 < 23; i1++)    {
        top+=distgdp (d1, g1, i1, j1);
          }
     }
return top;
}

float b1 (const int d2 [23] [23], const float g2[23], const
int h [23])
{
     float bottom = 0;
```

```
     for (int j2 = 0; j2 <= 23; j2++) {
          for (int i2 =0;i2 <= 23; i2++) {
      if (h[i2]==1 && h[j2]==1)
                    bottom += distgdp (d2, g2, i2, j2) ;
      else
               bottom+=0;
          }
     }
return bottom;
}
float b2 ( const int d3[23][23], const float g3[23],const int
r1)
{
float bottom2 = 0;
for (int c1 = 0; c1<23; c1++){
   bottom2+= distgdp(d3, g3, r1, c1);
   }
return bottom2;
}
float area (const int d [23] [23], const float g[23], const
int h1 [23])
{
return (t1(d,g)/b1(d,g,h1));
}

  main (char c)
{
 if(!outFile){
     cerr<<"File could not be opened"<<endl;
   exit(1);
   }
float  nbtripgen  [23]=  {0},  btripgen  [23]=  {0},  nbtrips
[23][23] = {0}, btrips
[23][23]={0};
  int dist [23] [23] = {{0, 20, 125, 250, 80, 200, 175, 75,
150, 370, 225,
 350, 325, 335, 400, 450, 325, 280, 220,1150, 775, 910, 425},
{20, 0, 110, 235, 100, 175, 160, 75, 150, 370, 250, 375, 350,
350, 410, 475,
350,300, 225, 1150, 775, 910, 450},
{125, 110, 0, 135, 100, 125, 150, 170, 260, 460,330, 460,
415, 400, 400, 480,
325, 330, 240, 1160, 840, 840, 460},
{250, 235, 135, 0, 175, 85, 160, 260, 350, 580, 460, 585,
525, 525, 550, 600,
425, 460, 375, 1300, 970, 900, 600},
{80, 100, 100, 175, 0, 110, 100, 75, 175, 410, 320, 420, 415,
435, 475, 525,
400, 360, 275, 1220,900, 970, 500},
{200, 175, 125, 85, 110, 0, 70, 175, 275, 510, 425, 550, 510,
510, 550, 610,
460, 450, 350, 1300, 900, 900, 585},
{175, 160, 150, 160, 100, 70, 0, 125, 220, 440, 390, 515,
510, 520, 575, 625,
500, 465, 375, 1400, 960, 1000, 585},
{75, 75, 170, 260, 75, 175, 125, 0,100, 340, 300, 385, 400,
425, 510,
550, 450, 375, 300, 1230, 830, 980, 500},
{150, 150, 260, 350, 175, 275, 220, 100, 0, 240, 275, 315,
350, 410, 510, 550,
```

```
475, 380, 320, 1300, 780, 1020, 485},
{370, 370, 460, 580, 410, 510, 440, 340, 240, 0, 300, 220,
340, 440, 580, 600,
600, 450, 300, 1160, 770, 1080, 500},
{225, 250, 330, 460, 320, 425, 390, 300, 275, 300, 0, 150,
100, 150, 285, 310,
285, 150, 150, 1030, 530, 760, 225},
{350, 375, 460, 585, 420, 550, 515, 385, 315, 220, 150, 0,
125, 240,
390, 400, 425, 275, 300, 900, 520, 900, 290},
{325, 350,415, 525, 415, 510, 510, 400, 350, 340, 100, 125,
0, 125, 250, 275,
300, 150, 200, 900,500, 700, 165},
{335, 350, 400, 525, 435, 510, 520, 425, 410, 440, 150, 240,
125, 0, 150, 160,
200, 65, 160, 840, 390, 640, 75},
{400, 410, 400, 550, 475, 550, 575, 510, 510, 580, 285, 390,
250, 150, 0, 60,
 110, 150, 215, 830, 370, 450, 140},
{450, 475, 480, 600, 525, 610, 625, 550, 550, 600, 310, 400,
275, 160,
  60, 0, 175, 175, 260, 770, 325, 455, 125},
{325, 350, 325, 425, 400, 460, 500, 450, 475, 600, 285, 425,
300, 200,
 110, 175, 0, 150, 150, 900, 455, 515, 225},
{280, 300, 330, 460, 360, 450, 465, 375, 380, 450, 150, 275,
150, 65, 150, 175,
150, 0, 100, 900, 450, 645, 140},
{220, 225, 240, 375, 275, 350, 375, 300, 320, 300, 150, 300,
200, 160, 215, 260,
 150, 100, 0, 1020, 550, 710, 225},
 {1150, 1150, 1160, 1300, 1220, 1300, 1400, 1230, 1300, 1160,
1030, 900, 900,
 840, 830, 770, 900, 900, 1020, 0, 480, 645,775},
  {775, 775, 840, 970, 900, 900, 960, 830, 780, 770, 530,
520, 500, 390, 370,
  325, 455,    450, 550, 480, 0, 385, 325},
  {910, 910, 840, 900, 970, 900, 1000, 980, 1020, 1080, 760,
900, 700, 640, 450,
   455, 515, 645, 710, 645, 385, 0, 580},
   {425, 450, 460, 600, 500, 585, 585, 500, 485, 500, 225,
290, 165, 75, 140,
   125, 225, 140, 225, 775, 325, 580, 0}}; //distances
between zones

 float GDP [23] = {17700, 4000, 4900, 8100, 1900, 4000, 3600,
4400, 21400, 80400,
99100, 34700, 71300, 61800, 143100, 138100, 72600, 78700,
38400, 1854400, 531600
,1211400, 91100};
//GDP of zones

 float hh [23] = {343205, 102041, 118924, 168903, 61629,
97218, 106789,
124709,582000, 2136000, 2817000, 1081000, 2077000, 1691000,
3229000, 2999000,
 2012000, 2132000, 1174000, 37300000, 11044225, 24467917,
2169000};
//no. households by zone
```

```
 int home [23] = {1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0,
 0, 0, 0, 0};        // indicates whether zone in Ireland
for (int i = 0; i<23; i++)
      {
      nbtripgen [i] = (hh[i]*area(dist, GDP, home)*33.61);
      btripgen [i] = (hh[i]*area(dist, GDP, home)*16.05);
      if (nbtripgen [i] < 0)
    nbtripgen [i] = (btripgen [i]*(33.61/16.05));
    if (btripgen [i] < 0)
    btripgen [i] = (nbtripgen [i]*(16.05/33.61));
    if ((nbtripgen [i] < 0) || (btripgen [i] <0))
      {cerr<< "Error- origins < 0"<<endl<<endl;
       exit(1);}
      }
cout<< "Non-business origins"<<endl<<endl;
printmatrix1(nbtripgen);
cout<<endl;
cout<< endl<<"Business origins"<<endl<<endl;
printmatrix1(btripgen);
cout<<endl;

    for (int j3 = 0; j3<23; j3++){
      for (int i3=0; i3<23; i3++)
      {
       if (dist[i3][j3]!=0) {
           nbtrips  [i3][j3]  =  nbtripgen[i3]*(distgdp  (dist,
GDP, i3, j3)/
          b2 (dist, GDP, i3));
           btrips [i3][j3] = btripgen[i3]*(distgdp (dist, GDP,
i3, j3)/
          b2(dist, GDP, i3));
          }
       else {
           nbtrips [i3][j3] =0;
          btrips [i3][j3] =0;
          }
       }
       }
outFile<< "Non-business matrix"<<endl<<endl;
printmatrix2(nbtrips);
outFile<< "Business matrix"<<endl<<endl;
printmatrix2(btrips);
cout<<endl<<"Enter x to exit"<<endl;
cin >>c;
if (c == 'x')return 0; //exit condition
}
```

E.2 ESTIMFR.CPP

```
//ESTIMFR
// An implementation of the freight elements of NEA's OD-  //
ESTIM for Irish access conditions
// Warren J. Whitney 1999

#include<iostream.h>
#include<math.h>
#include<iomanip.h>
//#include<fstream.h>

class Commodity //class definition
{
public:
Commodity ();
void setprsec (int);
void setatsec (int);
void setalpha1 (float);
void setalpha2 (float);
void setbeta1 (float);
void setbeta2 (float);
void setaGDP (int, float [3][23]);
void setpGDP (int, float [3][23]);
void generate (int origin);
void attract (int dest);
float rprn (int rp);
float ratn (int ra);
private:
float prn [23];
float attn [23];
float pGDP [23];
float aGDP [23];  //GDP by zone for production and attraction
sectors of
                                  //commodity
float od [23][23];
int prsec, atsec; //identifiers of production and attraction
sectors for a
                                  // commodity
float beta1, alpha1, beta2, alpha2;
};
Commodity::Commodity() //constructor
{
float prn[23]={0};
float attn [23]={0};
float pGDP [23]={0};
float aGDP [23]={0};
float od [23][23]={0};
beta1=0;
beta2=0;
alpha1=0;
alpha2=0;
}
void Commodity::setprsec (int x5)
{
prsec=x5;
}
void Commodity::setatsec (int x6)
```

```
{
atsec=x6;
}
void Commodity ::setalpha1 (float a1)
{
alpha1= a1;
}
void Commodity ::setalpha2 (float a2)
{
alpha2= a2;
}
void Commodity ::setbeta1 (float b1)
{
beta1= b1;
}
void Commodity ::setbeta2 (float b2)
{
beta2= b2;
}
void Commodity::setpGDP(int p, float G [3][23])
{
for (int x1=0; x1<23; x1++)
     {
     pGDP[x1]=G[p][x1];
     }
}
void Commodity::setaGDP(int a, float G1 [3][23])
{
for (int x3=0; x3<23; x3++)
     {
     pGDP[x3]=G1[a][x3];
     }
}

void Commodity ::generate (int origin)
{
prn[origin]= (alpha1 + (alpha2*pGDP[origin]));
}
void Commodity ::attract (int dest)
{
attn[dest]= (beta1 + (beta2*aGDP[dest]));
}
float Commodity::rprn(int rp)
{
return prn[rp];
}
float Commodity::ratn (int ra)
{
return attn[ra];
}
void main ()
{
Commodity com [10];
int prsec_array[10] = {0, 1, 0, 0, 0, 1, 0, 1, 1, 1};
int atsec_array[10] = {1, 2, 3, 3, 2, 2, 2, 0, 2, 3};
float alpha1_array[10] ={9.595, 11.734, 7.176, 8.522, 10.498,
10.296, 11.738,
8.905, 8.729, 9.288 };
float alpha2_array [10] ={0.697, 0.463, 0.576, 0.729, 0.267,
0.518, 0.563,
```

```
0.598, 0.753, 0.763 };
float beta1_array [10] ={-2.986, -29.733, 12.759, 38.004,
401.320, 101.408,
19.541, 72.536, 177.784, 22.628};
float beta2_array [10] ={2.221, 2.794, 0.298, 0.360, 0.491,
0.685, 0.345, 0.179,
0.438, 0.848 };
float GDP_array[3][23]= {{100, 200, 400, 600, 200, 300, 300,
400, 1100, 4200,
1700, 600, 2300, 2100,2900, 400, 3700, 1900, 1000, 18500,
12200, 29100, 1900},
{6500, 2200, 2400, 4000, 700, 1800, 1300, 1900, 5300, 22700,
32700, 11400,
22600, 21600, 33700, 22000, 18000, 27700, 13100, 602700,
150400, 328300, 21500},
{13000, 1600, 2000, 3500, 1000, 1900, 2000, 2000, 15000,
53500, 64700, 22600,
46400, 38000, 92700, 115700, 50900, 49100, 24300, 1233200,
371300, 852800,
67800}};
for (int x=0; x<10; x++)
     {
     com[x].setprsec(prsec_array[x]);
     com[x].setatsec(atsec_array[x]);
     com[x].setpGDP(com[x].rprn(x), GDP_array);
     com[x].setaGDP(com[x].ratn(x), GDP_array);
     com[x].setalpha1(alpha1_array[x]);
     com[x].setalpha2(alpha2_array[x]);
     com[x].setbeta1( beta1_array[x]);
     com[x].setbeta2( beta2_array[x]);
     for (int d=0; d<23; d++)
          {
          com[x].generate(d);
          com[x].attract (d);
          }
   cout<<endl<<endl;
     cout<< "Productions- commodity class "<<x<<endl;
     for (int x2 = 0; x2< 23; x2++)
     {
     cout<<setw (20)<<com[x].rprn(x2);
     }
   cout<<endl<<endl;
     cout<< "Attractions-commodity class"<<x<<endl;
     for (int x4 = 0; x4< 23; x4++)
     {
     cout<<setw (20)<<com[x].ratn(x4);
     }
     }
}
```

APPENDIX F COMMODITY DATA

F.1 SITC COMMODITY CLASSIFICATION

0 Food and live animals

1 Beverages and tobacco

2 Crude materials, inedible, except fuels

3 Mineral fuels, lubricants and related materials

4 Animal and vegetable oils, fats and waxes

5 Chemicals and related products

6 Manufactured goods classified chiefly by material

7 Machinery and transport equipment

8 Miscellaneous manufactured articles

9 Commodities and transactions not classified elsewhere

F.2 NSTR COMMODITY CLASSIFICATION

0 Agriculture products and live animals

1 Foodstuffs and animal fodder

2 Solid mineral fuels

3 Petroleum products

4 Ores and metal waste

5 Metal products

6 Crude and manufactured materials, building materials

7 Fertilisers

8 Chemicals

9 Machinery, transport equipment, manufactured articles and miscellaneous articles

10 Trade not classified by commodity

F.3 STEMM COMMODITY CLASSIFICATION

(NB: The commodities are designated by letters in STEMM documentation, but by numbers in the STAN model)

A/1 Food and live animals (identical to SITC 0)

B/2 Beverages and tobacco (identical to SITC 1)

C/3 Crude materials, inedible, except fuels (identical to SITC 2)

D/4 Mineral fuels (= SITC 3 excluding natural gas (SITC 34) and electricity (SITC 35))

E/5 Animal and vegetable oils, fats and waxes (identical to SITC 4)

F/6 Chemicals and related products (identical to SITC 5)

G/7 Paper, paperboard and articles of paper pulp, paper or paperboard (=SITC 64)

H/8 Metal products (=iron/steel (SITC 67) + non-ferrous metals (SITC 68) + manufactures of metals (SITC 69))

I/9 Manufactured goods (= SITC 6 excluding SITC 64, 67, 68, 69 as described above)

J/10 Machinery (= SITC 7 excluding office machines (SITC 75), telecommunications equipment (SITC 76), misc. electrical equipment (SITC 77), misc. transport equipment (SITC 79))

K/11 Miscellaneous manufactured articles (=SITC 8 + SITC 9, excluding professional/scientific apparatus (SITC 87) and photographic equipment (SITC 88))

L/12 Valuable machinery and manufactured articles (=SITC 75 + SITC 76 + SITC 77 + SITC 87 + SITC 88 as described above)

F.4 COST WEIGHTINGS

The STAN model applies a commodity-specific weighting to each of the three components of transport cost (which, in this case, are understood respectively to represent monetary cost, travel time and waiting time). The cost weightings applied to monetary cost represent the different characteristics of the various commodities (fragility, ease of bulk handling etc.) which affect their transport costs. The weightings applied to time correspond to "values of time" (€/hour). For passenger traffic, weightings differ only between business and non-business travel, and only then for values of time. Because of limited data availability, it is assumed that fare levels are identical for all travel purposes. Time values are based on those described in chapter 7 of the thesis.

The weightings of cost components for freight traffic have been taken from VTT (1998). The relative weightings of travel and waiting time have been derived empirically.

Table F.1 below shows the weightings applied.

Table F.1 Cost Weighting Factors

Commodity	Cost component		
	Monetary	Travel time	Waiting time
1	1	1	1.9
2	6	2.5	2.6
3	0.75	0.1	0.7
4	0.25	0.1	0.9
5	4	0.8	0.75
6	1.25	1	1.1
7	1.5	1	2.9
8	1	1	1
9	1.75	2	1.75
10	3.5	8.25	1.8
11	6.25	6.75	1.8
12	6.25	17	2.4
All non-business passengers	1	6.94	6.94
All business passengers	1	28.07	21.053

F.5 SUB-NETWORKS

Each commodity (here counting the subdivisions of passenger traffic by "meta-mode" as different commodities) is assigned to a corresponding sub-network. Table F.2 below lists the modes in the relevant sub-networks; the mode identifiers are explained in Tables G.1 and G.2 of Appendix G. Note that parentheses () around a commodity number or mode indicate that the relevant commodity or mode is not represented in all strategies.

Table F.2 Sub-networks

Commodity number	Commodity	Modes in sub-network
1	Food/animals	l r (p) i f A b a (s) (h) (B)
2	Beverages/tobacco	l r (p) f A a (s) (h) (B)
3	Crude inedibles	l r p i f b a
4	Mineral fuels	l r i b
5	Animal/veg. oils	l r i f b a
6	Chemicals	l r (p) i f A b a (s) (h) (B)
7	Paper/paperboard	l r (p) i f b a (s) (h) (B)
8	Metal products	l r (p) i f A b a (s) (h) (B)
9	Manuf. goods	l r (p) f A a (s) (h) (B)
10	Machinery	l r (p) i f A b a (s) (h) (B)
11	Misc. manuf.	l r (p) f A a (s) (h) (B)
12	Valuable machinery/manuf. goods	l r (p) f A a (s) (h) (B)
(16)	Business new mode	l r D (B) (H)
(17)	Non-business new mode	l r D (B) (H)
20	Business air	l r L A D R (B) (H) (t)
21	Business car-available	l f s (p) (w)
22	Non-business air	l r L A D R (B) (H) (t)
23	Non-business car-available	l f s (p) (w)
24	Non-business classic	r f s C (H) (w)

APPENDIX G STAN FUNCTIONS

G.1 GENERAL REMARKS

Transport costs in STAN consist of three components, representing direct (out-of-pocket) cost, time cost and waiting/delay cost. Each of these components is defined in currency units (in this case, euro) per passenger or tonne for each link and transfer type. There can be more than one link type per mode or more than one transfer type per origin mode-destination mode pair, e.g. to reflect conditions in different parts of the network.

The definition of each cost component is termed a *function*. A *function set* comprises functions defining all three components (different functions can be assigned to different commodities within a function set, but the author has not followed this approach).

Functions are common to all scenarios in the model, so the list of functions defined for this project is common to passenger and freight transport (although each individual function is specific to one or the other). Function sets are scenario-specific. Functions are defined either as link (fl) or transfer (ft).

Demand is defined in terms of *products*. In the present case, as mentioned above, functions are not specifically derived for each product. Instead, a set of weights is associated with a product and applied to the three cost components. These weights are stored under the "user-defined product data" headings up1, up2 and up3 for direct, time and waiting costs respectively. There are twelve products representing freight commodities and seven representing various types of passenger demand.

The STAN model allows each product to be assigned to a sub-network consisting of specified modes; Appendix F.5 indicates which modes each of the nineteen products is assigned to.

As well as product characteristics (up1/up2/up3; see Appendix F) and the length of a link (length), function definitions can include numerous other variables. The author has used

user-defined mode data item 1 (um1) to represent a nominal tax or charge levied on each mode (equal to 0 in the 1995 base case) on a per p-km or t-km basis. User-defined transfer data item 1 (ut1) represents a similar tax on transfers in certain cases, while user-defined link data item 1 (ul1) is used to store the number of services per week on a scheduled route.

Not all functions developed are actually utilised in the present version of the model.

G.2 LINK FUNCTION SETS

Table G.1 Freight link function sets

Freight mode	Identifier	Link type	Function set
Truck	l	General	100
		Motorways	101
		Irish general	102
		Urban	103
Rail	r	General	110
		Fixed links	113
Ferry	f	All	130
Airline	A	General	180
		Subsidised "air bridge"	181
Lo-lo	a	All	120
Bulk ship	b	All	170
Inland waterway	i	All	150
Fast container ship	h	All	190
Fast ferry	s	All	191
Buoyant air	B	All	200
Piggyback rail	p	all	220

Table G.2 Passenger link function sets

Passenger mode	Identifier	Link type	Function set
Car	l	General	100
		Motorways	101
		Irish general	102
		Urban	103
Rail	r	Irish	111
		British	112
		General	110
Low-cost airline	L	All	120
Ferry	f	All	130
Airline	A	All	140
Regional airline	R	All	150
Fast ferry	s	All	160
Coach	C	All	170
Wing-in-ground-effect (Seabus)	w	All	190
Buoyant air	B	All	200
High-speed train	H	All	210
Piggyback rail	p	All	220
V/STOL (tiltrotor)	t	All	230
Dummy [airport] links	D	All except Dublin	180
		Dublin	181

Table G.3 Functions used in freight link function sets

Freight link function set	Direct cost	Time cost	Waiting time cost
100	1	2	3
101	4	5	6
102	7	8	9
103	4	31	6
110	10	11	12
113	84	11	12
120	13	14	15
130	16	17	18
140	19	20	21
150	22	23	24
160	25	26	27
170	28	29	30
180	32	33	34
181	88	33	34
190	80	81	18
191	82	83	18
200	96	97	18
220	85	86	18

Table G.4 Functions used in passenger link function sets

Passenger link function set	Fare	Travel time	Waiting time
100	40	41	42
101	43	44	45
102	46	47	48
103	49	50	51
110	52	53	54
111	55	56	57
112	58	59	60
120	61	62	63
130	64	65	66
140	67	68	69
150	70	71	72
160	73	74	75
170	76	77	78
180	42	42	42
181	79	42	42
190	89	90	75
200	98	99	69
210	93	92	69
220	94	95	69
230	91	62	66

G.3 TRANSFER FUNCTION SETS

The key matrices below identify the function sets pertaining to each transfer by mode of origin and destination. They are followed by a listing of the function sets themselves.

Table G.5 Transfer function set key matrix-Freight (general)

	l	r	a	f	i	b	A	p	h	s	B
l	-	100	101	102	104	121	140	152	150	102	170
r	100	-	106	107	109	122	-	-	150	107	170
a	101	106	-	111	113	123	-	-	-	-	-
f	102	107	111	-	116	124	-	153	-	-	-
i	104	109	113	116	-	126	-	-	-	-	-
b	121	122	123	124	126	-	-	-	-	-	-
A	140	-	-	-	-	-	-	-	-	-	-
p	152	-	-	153	-	-	-	-	-	153	-
h	150	150	-	-	-	-	-	-	-	-	-
s	102	107	-	-	-	-	-	153	-	-	-
B	170	170	-	-	-	-	-	-	-	-	-

(NB: Function set 154 applies to subsidised road/rail transfers)

Table G.6 Transfer function set key matrix-Freight (Dublin/Dún Laoghaire ports)

	l	r	a	f	b	h	s
l	-	-	131	132	133	151	132
r	-	-	134	135	136	151	135
a	131	134	-	-	-	-	-
f	132	135	-	-	-	-	-
b	133	136	-	-	-	-	
h	151	151	-	-	-	-	-
s	132	135	-	-	-	-	-

Table G.7 Transfer function set key matrix-Passenger

	l	r	L	f	A	R	s	C	D	w	t	p	B
l	-	101	102	103	104	105	106	107	134	106	160	131	160
r	101	108	109	110	111	112	113	114	134	113	160	-	160
L	130	130	115	-	116	117	-	130	134	-	117	-	117
f	131	132	-	119	-	-	120	121	-	120	-	-	-
A	130	130	116	-	122	123	-	130	134	-	123	-	123
R	130	130	117	-	123	125	-	130	134	-	125	-	125
s	133	132	-	120	-	-	127	128	-	127	-	-	-
C	107	114	118	121	124	126	128	129	134	128	-	-	-
D	130	130	102	-	104	105	-	130	-	-	105	-	105
w	106	113	-	120	-	-	127	128	-	-	-	-	-
t	160	160	117	-	123	125	-	-	105	-	-	-	-
p	131	-	-	-	-	-	-	-	-	-	-	-	-
B	160	160	117	-	123	125	-	-	105	-	-	-	-

Table G.8 Functions used in passenger transfer function sets

Passenger transfer function set	Transfer cost	Transfer time	Waiting time
100	57	57	57
101	57	70	57
102	57	71	57
103	57	72	57
104	57	73	57
105	57	73	57
106	57	74	57
107	57	75	57
108	57	76	57
109	57	71	57
110	57	77	57
111	57	73	57
112	57	73	57
113	57	78	57
114	57	79	57
115	57	80	57
116	57	80	57
117	57	80	57
118	57	71	57
119	57	81	57
120	57	82	57
121	57	83	57
122	57	84	57
123	57	84	57
124	57	73	57
125	57	84	57
126	57	73	57
127	57	85	57
128	57	83	57
129	57	86	57
130	57	87	57
131	57	88	57
132	57	89	57
133	57	90	57
134	91	71	57
135	91	73	57
136	91	73	57
137	91	71	57
138	91	73	57
139	91	73	57
140	91	87	57
141	91	80	57
142	91	80	57

(continued over)

Table G.8 continued

Passenger transfer function set	Transfer cost	Transfer time	Waiting time
143	91	80	57
144	91	84	57
145	91	84	57
146	91	84	57
147	91	71	57
148	91	73	57
149	91	73	57
160	57	92	57
161	57	93	57

Table G.9 Functions used in freight transfer function sets

Freight transfer function set	Transfer cost	Transfer time	Waiting time
100	1	2	57
101	3	4	57
102	5	6	57
103	7	8	57
104	9	10	57
105	11	12	57
106	13	14	57
107	15	16	57
108	17	18	57
109	19	20	57
110	21	22	57
111	23	24	57
112	25	26	57
113	27	28	57
114	29	30	57
115	31	32	57
116	33	34	57
117	35	36	57
118	37	38	57
119	39	40	57
120	41	42	57
121	43	44	58
122	45	46	58
123	47	48	58
124	49	50	58
125	51	52	58
126	53	54	58

(continued over)

Table G.9 continued

Freight transfer function set	Transfer cost	Transfer time	Waiting time
127	55	56	56
128	57	57	57
129	57	57	57
130	57	57	57
131	59	4	57
132	60	6	57
133	61	44	57
134	62	14	57
135	63	16	57
136	64	46	57
140	65	66	57
150	95	96	57
151	97	96	57
152	98	99	57
153	100	101	57
154	57	2	57
155	103	4	57
156	104	6	57
157	105	44	57
158	106	14	57
159	107	16	57
160	108	46	57
161	109	96	57
170	120	121	57

G.4 FUNCTION DEFINITIONS

Table G.10 Link function definitions

Link function	Formulation
fl1	(um1 + .03) * length * up1
fl2	.003 * length * up2
fl3	0
fl4	up1 * length * (.03 + um1)
fl5	.0026 * length * up2
fl6	0
fl7	up1 * length * (.03 + um1)
fl8	.003 * length * up2
fl9	0
fl10	(.012 + um1) * length * up1
fl11	.005 * length * up2
fl12	0
fl13	(.004 + um1) * length * up1
fl14	.006 * length * up2
fl15	(17.1 / ul1) * up3
fl16	(.068 + um1) * length * up1
fl17	.006 * length * up2
fl18	(17.1 / ul1) * up3
fl19	(.009 + um1) * length * up1
fl20	.006 * length * up2
fl21	0
fl22	(.00068 + um1) * length * up1
fl23	.015 * length * up2
fl24	0
fl25	(.068 + um1) * length * up1
fl26	.006 * length * up2
fl27	(17.1 / ul1) * up3
fl28	(.004 + um1) * length * up1
fl29	.006 * length * up2
fl30	0
fl31	(.00638 * length) * up2
fl32	((.49 * length) + um1) * up1
fl33	.000406 * length * up2
fl34	(17.1 / ul1) * up3
fl40	(.16 + um1) * length * up1
fl41	(length / 80) * up2
fl42	0
fl43	(.16 + um1) * length * up1

(continued over)

Table G.10 continued

Link function	Formulation
fl44	(length / 90) * up2
fl45	0
fl46	(.16 + um1) * length * up1
fl47	(length / 70) * up2
fl48	0
fl49	(.16 + um1) * length * up1
fl50	(length / 30) * up2
fl51	0
fl52	(.08 + um1) * length * up1
fl53	(length / 160) * up2
fl54	0.5 * up3
fl55	(.08 + um1) * length * up1
fl56	(length / 100) * up2
fl57	(84 * up3) / ul1
fl58	.08 + um1) * length * up1
fl59	(length / 140) * up2
fl60	0.5 * up3
fl61	(.07 + um1) * length * up1
fl62	((.001138 * (length + 450)) + .1) * up2
fl63	84 * up3 / ul1
fl64	(.32 + um1) * length *up1
fl65	(length / 30) * up2
fl66	(84 * up3) / ul1
fl67	(.17 + um1) * length * up1
fl68	((.001138 * (length + 450)) + .1) * up2
fl69	84 * up3 / ul1
fl70	(.26 + um1) * length * up1
fl71	((.001138 * (length + 250)) + .1) * up2
fl72	84 * up3 / ul1
fl73	(0.37 + um1) * length * up1
fl74	(length / 60) * up2
fl75	84 * up3 / ul1
fl76	(.075 + um1) * length * up1
fl77	(length / 60) * up2
fl78	84 * up3 / ul1
fl80	(.026 + um1) * length * up1
fl81	(length / 50) * up2
fl82	(.15 + um1) * length * up1
fl83	(length / 70) * up2
fl84	((.012 + um1) * length * up1) + ul2
fl85	((.019 + um1) * length * up1) + ul2
fl86	.0025 * length * up2
fl88	(.25 + um1) * length * up1
fl89	(.24 + um1) * length * up1

(continued over)

Table G.10 continued

fl90	(length / 200) + .25
fl91	(.16 + um1) * length * up1
fl92	(((length – ul3) / 150) + (ul3 / 250)) * up1
fl93	((.09 * length) + 20) * up2
fl94	((.002 + um1) * length * up1) + ul2
fl95	(length / 100) * up2
fl96	(.08 + um1) * length * up1
fl97	(length /185) * up2
fl98	(0.07 + um1) * length
fl99	((.001 * length) + .01) * up2

Table G.11 Transfer function definitions

Transfer function	Formulation
ft1	4.9 * up1
ft2	6.5 * up2
ft3	4.9 * up1
ft4	6.5 * up2
ft5	3.1 * up1
ft6	3.3 * up2
ft7	4.9 * up1
ft8	6.5 * up2
ft9	4.9 * up1
ft10	6.5 * up2
ft11	3.1 * up1
ft12	3.3 * up2
ft13	5.8 * up1
ft14	26.1 * up2
ft15	7.4 * up1
ft16	13.1 * up2
ft17	3.1 * up1
ft18	13.1 * up2
ft19	5.8 * up1
ft20	26.1 * up2
ft21	8.9 * up1
ft22	13.1 * up2
ft23	8 * up1
ft24	9.792 * up2
ft25	8.9 * up1
ft26	39.2 * up2
ft27	5.8 * up1
ft28	26.1 * up2
ft29	8 * up1
ft30	9.792 * up2
ft31	8 * up1

(continued over)

Table G.11 continued

Transfer function	Formulation
ft32	9.792 * up2
ft33	8 * up1
ft34	13.1 * up2
ft35	6.1 * up1
ft36	13.1 * up2
ft37	8.9 * up1
ft38	39.2 * up2
ft39	11.9 * up1
ft40	26.1 * up2
ft41	8 * up1
ft42	13.1 * up2
ft43	6.6 * up1
ft44	13.1 * up2
ft45	7.9 * up1
ft46	26.1 * up2
ft47	11.5 * up1
ft48	19.6 * up2
ft49	9.7 * up1
ft50	16.3 * up2
ft51	10.9 * up1
ft52	39.2 * up2
ft53	11.5 * up1
ft54	19.6 * up2
ft55	9.7 * up1
ft56	16.3 * up2
ft57	0
ft58	34.3 * up3
ft59	(4.9 + ut1) * up1
ft60	(3.1 + ut1) * up1
ft61	(6.6 + ut1) * up1
ft62	(5.8 + ut1) * up1
ft63	(7.4 + ut1) * up1
ft64	(7.9 + ut1) * up1
ft65	1.76 * up1
ft66	1.1 * up2
ft70	.1 * up2
ft71	1.5 * up2
ft72	up2
ft73	.75 * up2
ft74	up2
ft75	.1 * up2
ft76	.5 * up2
ft77	.5 * up2
ft78	.5 * up2

(continued over)

Table G.11 continued

Transfer function	Formulation
ft79	.5 * up2
ft80	2 * up2
ft81	.5 * up2
ft82	.5 * up2
ft83	.75 * up2
ft84	.5 * up2
ft85	.5 * up2
ft86	.5 * up2
ft87	.25 * up2
ft88	.25 * up2
ft89	.25 * up2
ft90	.25 * up2
ft91	ut1 * up1
ft92	.3 * up2
ft93	.5 * up2
ft95	5.25 * up1
ft96	16.4 * up2
ft97	(5.25 + ut1) * up1
ft98	1.6 * up1
ft99	1.6 * up2
ft100	4.7 * up1
ft101	4.8 * up2
ft103	(4.9 – ut1) * up1
ft104	(3.1 – ut1) * up1
ft105	(6.6 – ut1) * up1
ft106	(5.8 – ut1) * up1
ft107	(7.4 – ut1) * up1
ft108	(7.9 – ut1) * up1
ft109	(5.25 – ut1) * up1
ft110	0 - ut1
ft120	1.6 * up1
ft121	1.6 * up2

APPENDIX H TRANSPORT SERVICE PATTERNS

H.1 SHIPPING

Table H.1 Shipping service patterns (Modes: f- ferry, s- fast ferry, a- lo-lo, h- fast freighter, w- Seabus)

From	To	Type	Weekly sailings 1995	Weekly sailings 2020 do-min/ combined strategies	Weekly sailings 2020 air/sea high investment	Weekly sailings 2020 air/sea managed demand	Weekly sailings 2020 fixed link	Weekly sailings 2020 buoyant air
Dublin	Holyhead	f	14	28	14	14	7	
Dublin	Holyhead	s	0	42	42	21	21	
Dublin	Liverpool	a	7	21	21	21	14	
Dublin	Liverpool	f	0	21	14	14	7	
Dublin	Liverpool	s	21	42	0	21		
Dublin	Bristol	h	0	0	14	0		
Dublin	Le Havre	a	1	3	3	3		
Dublin	Le Havre	h	0	0	7	0		
Dublin	Antwerp	a	2	6	6	6		
Dublin	Rotterdam	a	23	63	63	42		
Dublin	Rotterdam	h	0	14	28	7		
Dún Laoghaire	Holyhead	f	13	0	0	0	0	0
Dún Laoghaire	Holyhead	s	21	28	21	21		
Dún Laoghaire	Liverpool	w	0	0	84	0	0	0
Arklow	Holyhead	f	0	0	0	14		
Arklow	Fishguard	f	0	0	0	14		
Rosslare	Fishguard	f	18	21	21	21		

(continued over)

Table H.1 continued

From	To	Type	Weekly sailings 1995	Weekly sailings 2020 do-min/ combined strategies	Weekly sailings 2020 air/sea high investment	Weekly sailings 2020 air/sea managed demand	Weekly sailings 2020 fixed link	Weekly sailings 2020 buoyant air
Rosslare	Fishguard	s	21	0	0	21	0	0
Rosslare	Pembroke	f	9	21	21	21		
Rosslare	Bristol	w	0	0	28	0	0	0
Rosslare	Le Havre	f	4	6	6	6		
Rosslare	Cherbourg	f	1	1	1	1		
Rosslare	Roscoff	f	1	1	0	0		
Rosslare	Roscoff	s	0	0	7	7		
Waterford	Rotterdam	a	6	18	18	18	12	
Waterford	Rotterdam	h	0	0	7	7		
Waterford	Le Havre	h	0	0	0	7		
Cork	Swansea	f	5	7	7	7	7	7
Cork	Rotterdam	a	17	51	51	51	34	
Cork	Rotterdam	h	0	0	7	14		
Cork	Antwerp	a	2	6	6	12	4	
Cork	Bristol	w	0	0	28	0	0	0
Cork	Bristol	h	0	0	14	21		
Cork	Roscoff	f	12	12	12	12	12	7
Cork	Le Havre	f	1	1	1	1		
Cork	Le Havre	a	1	1	1	7		
Cork	Cherbourg	f	1	1	1	1		
Derry	Troon	s	0	0	0	14	0	0

(continued over)

Table H.1 continued

From	To	Type	Weekly sailings 1995	Weekly sailings 2020 do-min/ combined strategies	Weekly sailings 2020 air/sea high investment	Weekly sailings 2020 air/sea managed demand	Weekly sailings 2020 fixed link	Weekly sailings 2020 buoyant air
Larne	Cairnryan/ Stranraer	f	84	126	112	112	98	119
Belfast	Troon	s	0	14	0	14		
Belfast	Stranraer	s	28	63	56	56		
Belfast	Heysham	s	0	14	14	14		
Belfast	Greenock	a	1	3	3	3	3	3
Belfast	Glasgow	w	0	0	42	0	0	0
Belfast	Liverpool	f	6	14	14	14		
Belfast	Liverpool	a	7	21	21	21	14	21
Belfast	Liverpool	w	0	0	56	0	0	0
Belfast	Liverpool	h	0	0	14	0	0	0
Belfast	Liverpool	s	0	0	0	14	0	0
Belfast	Rotterdam	a	19	56	56	56		
Belfast	Rotterdam	h	0	0	14	28		
Belfast	Antwerp	a	1	3	3	7	3	3
Belfast	Le Havre	a	1	3	3	7	3	3
Belfast	Le Havre	h	0	0	0	7	0	0
Belfast	Cardiff	a	2	6	6	6	6	6
Belfast	Swansea	a	2	6	6	6		
Drogheda	Liverpool	f	0	0	0	14	0	0
Drogheda	Liverpool	a	0	0	0	7	0	0
Drogheda	Holyhead	s	0	0	0	21	0	0

(continued over)

Table H.1 continued

From	To	Type	Weekly sailings 1995	Weekly sailings 2020 do-min/ combined strategies	Weekly sailings 2020 air/sea high investment	Weekly sailings 2020 air/sea managed demand	Weekly sailings 2020 fixed link	Weekly sailings 2020 buoyant air
Drogheda	Le Havre	a	0	0	0	14	0	0
Drogheda	Rotterdam	a	0	0	0	21	0	0
Loughshinny	Liverpool	f	0	0	7	0	0	0
Loughshinny	Holyhead	f	0	0	14	0	0	0

H.2 CONVENTIONAL AIRLINE

Table H.2 Airline Service Patterns (A- mainline carrier, R- regional carrier, L- low-cost carrier)

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Sligo	London Stansted	R	0	0	0	14	0	0	0
Sligo	Manchester	R	0	0	0	14	0	0	0
Sligo	Birmingham	R	0	0	0	14	0	0	0
Donegal	London Stansted	R	0	0	0	14	0	0	0
Donegal	Manchester	R	0	0	0	14	0	0	0
Donegal	Birmingham	R	6	0	0	14	0	0	0
Donegal	Glasgow	R	5	5	0	14	0	0	5
Dublin	Stockholm	A	6	24	24	22	24	24	24
Dublin	Oslo	A	0	14	14	12	14	14	14
Dublin	Helsinki	A	0	14	14	12	14	14	14
Dublin	Copenhagen	A	14	56	56	50	56	56	56
Dublin	Hamburg	R	0	14	14	12	14	14	14
Dublin	Dusseldorf	A	14	56	56	50	56	56	56
Dublin	Frankfurt	A	20	40	40	36	40	40	40
Dublin	Munich	A	7	28	28	25	28	28	28
Dublin	Berlin	A	0	14	14	12	14	14	14
Dublin	Stuttgart	A	0	14	14	12	14	14	14

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Dublin	Beauvais	L	0	63	0	56	63	63	56
Dublin Baldonnel	Beauvais	L	0	0	98	0	0	0	0
Dublin	Paris	A	22	60	60	56	60	60	56
Dublin	Strasbourg	R	0	14	14	14	14	14	14
Dublin	Nantes	R	0	14	14	14	14	14	14
Dublin	Bordeaux	R	0	14	14	14	14	14	14
Dublin	Lyon	R	0	14	14	14	14	14	14
Dublin	Marseille	R	0	14	14	14	14	14	14
Dublin	Amsterdam	A	18	35	35	30	35	35	32
Dublin	Brussels	A	18	60	60	55	60	60	56
Dublin	Charleroi	L	0	42	0	38	42	42	35
Dublin Baldonnel	Charleroi	L	0	0	63	0	0	0	0
Dublin	Newcastle	R	14	56	56	50	40	40	42
Dublin	Teesside	L	0	14	0	12	10	10	14
Dublin Baldonnel	Teesside	L	0	0	21	0	0	0	0
Dublin	Leeds/ Bradford	R	21	84	84	77	35	50	77
Dublin	Sheffield	R	0	14	14	14	14	14	14
Dublin	Finningley	A	0	14	14	12	10	10	14
Dublin	East Midlands	R	14	56	56	50	39	34	56

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Dublin	London Heathrow	A	144	150	150	135	144	144	120
Dublin	London Gatwick	R	30	0	0	0	0	0	0
Dublin	London Gatwick	L	11	50	0	45	35	30	50
Dublin Baldonnel	London Gatwick	L	0	0	50	0	0	0	0
Dublin	London Gatwick	A	0	50	50	45	35	30	30
Dublin	London Stansted	L	41	100	0	90	63	63	90
Dublin Baldonnel	London Stansted	L	0	0	100	0	0	0	0
Dublin	Luton	L	9	100	0	90	70	60	80
Dublin Baldonnel	Luton	L	0	0	150	0	0	0	0
Dublin	London City	R	30	100	100	90	90	90	90
Dublin	Bristol	R	19	84	84	80	63	56	63
Dublin	Birmingham	R	34	70	70	63	28	42	70
Dublin	Birmingham	L	14	56	84	50	21	32	56
Dublin	Manchester	R	37	150	150	135	45	90	120
Dublin	Manchester	L	12	48	0	44	15	30	36

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Dublin Baldonnel	Manchester	L	0	55	0	0	0	0	55
Dublin	Liverpool	L	10	40	40	35	14	21	40
Dublin	Cardiff	R	7	28	28	25	20	25	28
Dublin	Glasgow	R	28	100	100	90	90	60	90
Dublin	Edinburgh	R	18	72	72	65	65	44	65
Dublin	Prestwick	L	8	32	0	28	28	21	28
Dublin Baldonnel	Prestwick	L	0	0	48	0	0	0	0
Dublin	Madrid	A	8	32	32	28	32	32	32
Dublin	Lisbon	A	0	14	14	14	14	14	14
Dublin	Athens	A	0	14	14	14	14	14	14
Dublin	Bucharest	A	0	14	14	14	14	14	14
Dublin	Prague	A	0	14	14	14	14	14	14
Dublin	Moscow	A	0	14	14	14	14	14	14
Dublin	Warsaw	A	0	14	14	14	14	14	14
Dublin	Zurich	A	20	80	80	70	80	80	80
Dublin	Vienna	A	0	14	14	14	14	14	14
Dublin	Rome	A	5	20	20	18	20	20	20
Dublin	Malta	A	0	14	14	14	14	14	14
Dublin	Budapest	A	0	14	14	14	14	14	14
Midlands	London Stansted	L	0	0	0	21	0	0	0

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Midlands	Manchester	R	0	0	0	14	0	0	0
Midlands	Birmingham	R	0	0	0	14	0	0	0
Midlands	Paris	R	0	0	0	14	0	0	0
Midlands	Brussels	R	0	0	0	14	0	0	0
Shannon	Frankfurt	A	0	0	0	14	0	0	0
Shannon	Paris	A	0	0	0	14	0	0	0
Shannon	Amsterdam	A	0	0	0	14	0	0	0
Shannon	Brussels	A	0	0	0	14	0	0	0
Shannon	London Heathrow	A	33	40	40	30	40	40	35
Shannon	London Gatwick	L	0	21	21	21	17	14	21
Shannon	London Stansted	L	0	42	42	38	35	28	42
Shannon	Birmingham	R	0	7	7	14	7	7	7
Shannon	Manchester	R	7	28	28	28	21	28	28
Shannon	Glasgow	R	0	0	0	14	0	0	0
Waterford	Luton	R	7	0	0	0	0	0	0
Waterford	London Stansted	R	11	35	35	0	35	35	0
Waterford	London Stansted	L	0	0	0	21	0	0	0
Waterford	Manchester	R	0	0	0	14	0	0	0

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Waterford	Birmingham	R	0	0	0	14	0	0	0
Waterford	Paris	R	0	0	0	14	0	0	0
Waterford	Brussels	R	0	0	0	14	0	0	0
Cork	Frankfurt	A	0	0	0	14	0	0	0
Cork	Paris	R	6	14	14	14	14	14	14
Cork	Paris	A	0	14	14	21	14	14	14
Cork	Amsterdam	A	0	7	7	14	7	7	7
Cork	Brussels	A	0	7	7	14	7	7	7
Cork	London Heathrow	A	18	21	18	21	18	18	18
Cork	London Gatwick	R	0	14	14	14	14	14	14
Cork	London Stansted	L	5	42	63	38	38	28	35
Cork	Birmingham	R	13	52	52	46	40	52	52
Cork	Manchester	R	14	56	56	50	44	56	56
Cork	Glasgow	R	0	0	0	14	0	0	0
Kerry	Luton	R	7	0	0	0	0	0	0
Kerry	London Stansted	L	0	21	7	21	7	7	21
Kerry	Manchester	R	0	0	0	14	0	0	0
Kerry	Birmingham	R	0	0	0	14	0	0	0
Kerry	Paris	R	0	0	0	14	0	0	0

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Kerry	Brussels	R	0	0	0	14	0	0	0
Galway	London Stansted	L	0	0	0	14	0	0	0
Galway	Manchester	R	0	0	0	14	0	0	0
Galway	Birmingham	R	0	0	0	14	0	0	0
Galway	Paris	R	0	0	0	14	0	0	0
Galway	Brussels	R	0	0	0	14	0	0	0
Knock	London Stansted	L	7	14	14	14	14	14	14
Knock	Manchester	R	6	6	0	14	14	14	6
Knock	Birmingham	R	0	0	0	14	0	0	0
Knock	Paris	R	0	0	0	14	0	0	0
Knock	Brussels	R	0	0	0	14	0	0	0
Belfast Int	Frankfurt	A	0	0	0	14	0	0	0
Belfast Int	Paris	R	0	0	0	14	0	0	0
Belfast Int	Amsterdam	R	12	50	50	40	50	50	50
Belfast Int	Brussels	R	0	0	0	14	0	0	0
Belfast Int	London Heathrow	A	97	100	100	90	100	100	100
Belfast Int	London Gatwick	R	28	63	63	56	49	49	63

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Belfast Int	London Stansted	L	23	56	84	50	42	42	49
Belfast Int	Luton	L	0	56	84	50	42	42	56
Belfast Int	Birmingham	R	25	100	100	90	75	63	90
Belfast Int	Manchester	R	53	100	100	90	75	63	90
Belfast Int	Glasgow	R	28	56	56	50	56	36	49
Belfast City	Glasgow	R	18	84	84	76	84	63	56
Belfast City	Edinburgh	R	17	84	84	76	84	63	56
Belfast City	Newcastle	R	23	56	56	49	56	56	56
Belfast City	London Stansted	R	25	56	56	49	45	42	49
Belfast City	London Gatwick	R	28	56	56	49	45	42	49
Belfast City	Birmingham	R	24	91	91	80	67	60	77
Belfast City	Cardiff	R	7	28	28	25	28	28	28
Belfast City	East Midlands	R	16	64	64	58	64	64	64
Belfast City	Leeds/ Bradford	R	11	44	44	40	44	44	44
Belfast City	Manchester	R	32	100	100	90	75	63	80
Belfast City	Liverpool	R	14	56	56	50	56	56	56
Belfast City	Southampton	R	7	28	28	25	28	28	28
Derry	Edinburgh	R	12	0	0	0	0	0	0
Derry	Glasgow	R	7	0	0	14	0	0	0

(continued over)

Table H.2 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020 do-min	Weekly flights 2020 air/sea high investment	Weekly flights 2020 air/sea managed demand	Weekly flights 2020 fixed link	Weekly flights 2020 buoyant air	Weekly flights 2020 combined strategies
Derry	Manchester	R	7	0	0	14	0	0	0
Derry	London Stansted	L	0	7	7	21	7	7	7
Derry	Birmingham	R	0	0	0	14	0	0	0
Derry	Paris	R	0	0	0	14	0	0	0
Derry	Brussels	R	0	0	0	14	0	0	0

Table H.3 Connecting air services

From	To	Type	Weekly flights 1995	Weekly flights 2020
London Heathrow	Stockholm	A	62	62
London Heathrow	Oslo	A	46	46
London Heathrow	Helsinki	A	33	33
London Heathrow	Copenhagen	A	57	57
London Heathrow	Hamburg	A	47	47
London Heathrow	Reykjavik	A	7	7
London Heathrow	Lisbon	A	42	42
London Heathrow	Zurich	A	55	55
London Heathrow	Stuttgart	A	34	34
London Heathrow	Strasbourg	R	12	12
London Heathrow	Budapest	A	28	28
London Heathrow	Bucharest	A	15	15
London Heathrow	Warsaw	A	23	23
London Heathrow	Sofia	A	5	5
London Heathrow	Prague	A	18	18
London Heathrow	Bremen	A	11	11
London Heathrow	Hanover	A	28	28
London Heathrow	Berlin	A	48	48
Manchester	Hamburg	R	6	14
Manchester	Hanover	R	7	14
Manchester	Dusseldorf	A	29	29
Manchester	Munich	R	17	17
Manchester	Stuttgart	R	6	14
Manchester	Paris	A	58	58
London Gatwick	Bordeaux	A	21	21
London Gatwick	Amsterdam	A	26	26

(continued over)

Table H.3 continued

From	To	Type	Weekly flights 1995	Weekly flights 2020
London Gatwick	Brussels	A	25	25
London Gatwick	Madrid	A	34	34
London Gatwick	Athens	A	13	13
London Gatwick	Rome	A	22	22
London Gatwick	Vienna	A	18	18
London Gatwick	Malta	A	10	10
Copenhagen	Faeroe Islands	R	14	14
Copenhagen	Vilnius	A	11	11
Copenhagen	Tallinn	A	11	11
Dublin	Cork	R	32	42
Dublin	Shannon	R	32	35
Dublin	Galway	R	14	35
Dublin	Donegal	R	0	21
Dublin	Knock	R	5	21
Dublin	Kerry	R	13	21
Dublin	Sligo	R	7	21
Dublin	Derry	R	14	21
Frankfurt	Kiev	A	13	13
Frankfurt	Dresden	A	39	39
Bucharest	Chisiniau	R	6	6
Prague	Bratislava	R	22	22

H.3 V/STOL

Table H.4 V/STOL services

From	To	Weekly flights (2020 Air/Sea High Investment only)
Dublin city centre	London city centre	315
Dublin city centre	Birmingham city centre	56
Dublin city centre	Manchester city centre	56
Dublin city centre	Glasgow city centre	14
Cork airport	London city centre	56
Shannon airport	London city centre	35
Belfast City airport	London city centre	154
Belfast City airport	Birmingham city centre	35
Belfast City airport	Manchester city centre	21
Belfast City airport	Glasgow city centre	14
Waterford airport	London Heathrow airport	28
Waterford airport	Manchester airport	14
Kerry airport	London Heathrow airport	28
Kerry airport	Manchester airport	14
Galway airport	London Heathrow airport	28
Galway airport	Manchester airport	7
Knock airport	London Heathrow airport	14
Knock airport	Manchester airport	7
Sligo airport	London Heathrow airport	14
Sligo airport	Manchester airport	7
Donegal airport	London Heathrow airport	14
Donegal airport	Manchester airport	14
Donegal airport	Glasgow city centre	7
Derry airport	London Heathrow airport	14
Derry airport	Manchester airport	14
Derry airport	Glasgow city centre	7

H.4 BUOYANT AIR (PASSENGER)

Table H.5 Passenger buoyant air services

From	To	Weekly flights (2020 Buoyant Air only)	Weekly flights (2020 Combined Buoyant Air only)
Dublin city centre	London city centre	350	210
Dublin Baldonnel	London city centre	0	105
Dublin city centre	London Heathrow	0	210
Dublin city centre	Birmingham	63	63
Dublin city centre	Manchester	63	63
Dublin city centre	Glasgow	14	14
Dublin city centre	Edinburgh	14	14
Dublin city centre	Bristol	14	14
Dublin city centre	Leeds	14	14
Dublin city centre	Liverpool	21	21
Dublin city centre	Brussels	0	21
Dublin city centre	Paris	0	21
Dublin city centre	Amsterdam	0	21
Cork	London city centre	70	70
Shannon	London city centre	42	42
Galway	London city centre	14	0

(continued over)

Table H.5 continued

From	To	Weekly flights (2020 Buoyant Air only)	Weekly flights (2020 Combined Buoyant Air only)
Galway	London Heathrow	0	14
Waterford	London Heathrow	0	14
Athlone	London Heathrow	0	14
Belfast	London city centre	175	105
Belfast	London Heathrow	0	70
Belfast	Birmingham	28	28
Belfast	Manchester	28	28
Belfast	Glasgow	14	14

H.5 AIR FREIGHT

Table H.6 Air Freight Services

From	To	Weekly flights (all strategies except 2020 Air/Sea- High Investment)	Weekly flights (2020 Air/Sea- High Investment only)
Dublin	London	1	63
Dublin	Brussels	0	56
Dublin	East Midlands	5	5
Dublin	Frankfurt	1	1
Dublin	Manchester	5	5
Dublin	Liverpool	2	2
Dublin	Paris	4	4
Cork	London	0	21
Cork	Brussels	0	28
Shannon	London	7	21
Shannon	Brussels	5	28
Shannon	East Midlands	5	5
Shannon	Paris	1	1
Knock	London	0	21
Knock	Brussels	0	28
Belfast	London	0	42
Belfast	Brussels	0	42
Belfast	Birmingham	5	5
Belfast	Liverpool	1	1

H.6 BUOYANT AIR (FREIGHT)

Table H.7 Buoyant Air Freight Services

From	To	Weekly flights (2020 Buoyant Air and Combined Buoyant Air only)
Dublin (Baldonnel)	London	21
Dublin (Baldonnel)	Lille	28
Cork	London	21
Cork	Lille	28
Shannon	London	21
Shannon	Lille	14
Knock	London	21
Knock	Lille	14
Belfast	London	21
Belfast	Lille	28

H.7 COACH

Table H.8 Coach Services

From	To	Weekly services (all strategies)
Dublin	London	28
Dublin	Birmingham	28
Galway	London	7
Galway	Birmingham	7
Athlone	London	7
Athlone	Birmingham	7
Sligo	London	7
Sligo	Birmingham	7
Dublin	Manchester	7
Dublin	Leeds	7
Dublin	Glasgow	7
Belfast	London	7
Belfast	Birmingham	7
Belfast	Manchester	7
Belfast	Glasgow	14
Belfast	Newcastle	7

H.8 HIGH-SPEED RAIL

Table H.9 High-Speed Rail Services

From	To	Weekly services (Fixed Link and Combined Fixed Link only)
Dublin	London	224
Dublin	Birmingham	112
Dublin	Manchester	112
Dublin	Liverpool	56
Dublin	Paris	14
Dublin	Brussels	14

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