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An analysis of the current situation for Polish ferry operators in a transitional environment

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Abstract

This paper begins with an analysis of the situation in Polish ferry shipping as it enters the new millennium and faces increasing tension caused by the extended process of transition. It goes on to present a SWOT analysis conducted amongst experts within the sector to identify the strengths, weaknesses, opportunities and threats that face the sector. This reveals the severity of problems that exist and which in particular are faced by the state operator Polferries. Discussion then follows of the proposed strategy for the industry from the Polish government before looking at the role of price in particular. Finally conclusions are drawn from the analysis.

Keywords: Ferry; Shipping; Poland; Baltic; Transition.

1. Introduction

This paper has a number of objectives which are all centred upon the Polish ferry sector during the period of transition from the state controlled Communist era to the current market led environment:

- To examine the current situation in the Polish Baltic Sea ferry market and in particular the condition and prospects of the Polish owned industry;
- To present the results of research into the market for Polish ferries through the use of a SWOT analysis;
- To examine the role of pricing in the Polish ferry market.
- To provide a broad interpretation of the Polish Baltic Sea ferry industry, its prospects in the immediate future and the role that domestic operators can hope to play.

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The paper begins with an assessment of the current background to the industry and then goes on to examine the results of a SWOT analysis carried out on the sector at the turn of the millennium. The role of pricing in particular is then discussed. The paper concludes with suggestions for future strategy and a discussion of the prospects for the sector.

2. Background to the Polish ferry situation

The Baltic Sea contains one of the largest concentrations of ferry lines in the world. In 2005, around 270 ferries of different types operated on more than 130 lines across the Baltic Sea. Ferry carriage amounted to 25% of the world market of passenger loadings, over 40% of cars and over 25% of trucks in 2001.[1] The biggest ferry movement takes place in countries located in the West and North of the Baltic Sea. This results on the one hand, from the shape of the coastline and the natural conditions of the sea and on the other, as a consequence of the level of economic development in a number of Baltic countries that creates intensive trade exchange and passenger movements.

The largest flows are generated by the countries of Denmark, Germany, Norway and Sweden characterised by:[2]

- A relatively high level of standard of living (defined by GNP);
- A high level of motorization;
- A high level of mobility of citizens;
- A tendency towards export orientation of production.

In contrast the countries of Central and Eastern Europe have a much lower standard of living. These countries are characterized by smaller ferry carriers (if any) resulting from lower mobility of citizens accompanied by lower international trade exchange.[3]

Baltic ferry shipping is characterised by a limited number of carriers servicing specific ferry routes. Each operator varies by size, capitalisation, vessel tonnage, organization and competition in quality of services and prices.

One characteristic feature of ferry shipping in general is the lack of cartelisation and shipping conferences the result of which is an increase in competition between operators on each route. Ultimately access to the market becomes difficult particularly if the dominant ferry operators offer complex services of high standard and undertake intense marketing activity. This commonly now involves cooperation with travel agencies, railway, ports, banks etc.

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[1] ShipPax Statistics 01. *The Yearbook for Passenger Shipping Traffic Figures*. Halmstad, Sweden 2001, p.150.

[2] *Encyclopedia of Polish Publishers of Science in Three Volumes. Volume 1.* D. Kalisiewicz (ed.), Polish Publishers of Science, Warsaw 1999, p. 424 and *Investiguide 2001-2002. Project opportunities and contacts for the CEI Region*. United Nation. Economic Commission for Europe, pp. 52 and 54.

[3] An exception is Tallinn-Helsinki. Intensive movements of citizens of Finland occur looking for cheap shopping balanced by intensive movement of inhabitants from Estonia traveling to Scandinavian countries to work. [ShipPax Statistics 01. *The Yearbook for Passenger Shipping Traffic Figures*. Halmstad, Sweden 2001, p. 148-150.]

The biggest ferry operators in the Baltic Sea have emerged from consolidation of a number of smaller firms. They carry the largest number of passengers on the lines they operate and usually they are too competitive for the remaining smaller carriers. Examples are Silja Line and Viking Line offering on the Baltic Sea some of the largest and most modern ferries in the world reflected in their shares in the market.

Table 1: Comparison of ferry carriage from Poland 1990 and 2000 [000].

Line	*Passengers*		*Cars*		*Trucks*		*Rail Wagons*	
	1990	2000	1990	2000	1990	2000	1990	2000
Swinoujscie-Ystad	354	324.4	101.7	73.7	52.6	94.8	32.4	18.8
Swinoujscie-Copenhagen	86.7	101.3	99.9	13.3	5.3	7.0	-	-
Swinoujscie-Rønne	-	10.7	-	1.4	0.06	0.003	-	-
Swinoujscie-Sassnitz	-	69.7	-	-	-	-	-	-
Swinoujscie-Malmö	-	57.7	-	13.8	8.9	1.6	-	-
TOTAL FROM SWINOUJSCIE	440.7	563. 9	201.6	102.2	66.9	103.5	32. 3	18.8
Gdansk-Nynäshamn	-	130.6	-	25.1	1.8	4.0	-	-
Gdansk-Öxelosund	50.0	-	9.1	-	0.3	-	-	-
Gdansk-Helsinki	34.6	-	5.1	-	3.2	-	-	-
TOTAL FROM GDANSK	84.6	130.6	14.1	25.1	5. 3	4.0	0	0
Gdynia-Karlskrona	-	267.0	-	36.2	-	16.8	-	-
Seasonal lines	38.2	-	8.0	-	-	-	-	-
TOTAL	563.5	961.6	133.7	163. 5	98. 6	124.2	32. 3	18.8

Sources: O. Dębicka, *Ferry Shipping on the Baltic Sea, Polish Case. Transit chains in the Baltic Sea Region*, J. Vainio, Turku 1996, p. 55-53 and *ShipPax Statistics 01. The Yearbook for Passenger Shipping Traffic Figures*. Halmstad, Sweden 2001, s. 86 and 122.

3. The Potential of the Polish ferry industry

Polish ferry shipping, summarised in Table 1, possesses potential for development evidenced by a number of trends. The forecasts of national and international tourism in Poland are now highly optimistic. It is predicted that the number of arrivals of foreigners in Poland and departures of Polish citizens abroad will grow on average about 2.5% a year for at least the next ten years. Passenger travel between Poland and Scandinavia and Denmark is also expected to grow substantially. The indication is that until 2010, the increase of passenger movements will be 2-3 million for Poland-Denmark and 1.3 million for Poland-Sweden and the existing capacity of Polish ferry operators can accommodate this growth (Table 2). At present, Polish ferries carry less than 20% of this potential and in comparison with carriers from Scandinavian countries it represents a relatively small figure.

Forecasts for the Polish market indicate a number of trends which will have a positive influence for the growth of tourist movement of Polish citizens:[4]

- increase in the number of women, singles, citizens of larger cities, persons earning middle and higher salaries and the better educated particularly aged between 25 and 40 years;

[4] Ibidem

- a general ageing of European inhabitants and growth in the number of people aged over 65;
- growth of package holidays;
- increased demand for short-stay trips and weekend cruises;
- growth in event cruising (e.g. party and conference trips);
- growth of internet sales and consequential market extension.

Table 2: Potential of the Polish ferry fleet (2000).

Ferry operator	*Ferry*	*Line*	*Beds*	*Departures*	*Annual Potential [000]*	*Pax Carried [000]*	*Utilised potential [%]*
Polferries	Pomerania	Copenhagen - Rønne-Swinoujscie	1000	540	540.0	112.0	20.75
	Nieborow	Swinoujscie-Ystad	1100	721	793.1	104.2	13.14
	Rogalin	Gdansk-	984				
	Silesia	Nynäshamn	984	451	443.8	130.6	29.43
Stena Line	Stena Europe	Gdynia-Karsklona	2076	616	1 278.8	267.0	20.88
Unity Line	Polonia	Swinoujscie-Ystad	1000	2 106	2 106.0	220.2	10.46
Total			7144	4 434	5 161.7	834.1	16.16

Source: E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market*. Technical University of Gdansk, Gdansk 2003, p. 127.

Meanwhile, before the period of transition commenced in 1989, cargo carriage between Eastern and Central Europe and Scandinavian countries and Denmark was small. In recent years, significant growth of trade exchange between these countries has taken place. In the case of Sweden the share of trade with Central and Eastern Europe is now about 17%, with exports increased by 55% and imports 88% between 1996 and 2000. The share of Polish trade with Sweden is small at 1.6% of total Swedish exports and 1.78 % of imports. However there is evidence of growth which is likely to accelerate following Poland's entry to the EU. Exports from Sweden to Poland have increased 3 times and imports 5 times since 1993 (Tables 3 and 4).

Other than Germany, Denmark is now the most important partner in trade for Poland amongst the Baltic countries and marine transport plays the biggest role in international trade of these countries accounting for 90%, of Polish exports but only 48% of imports implying a considerable potential for intensification of trade exchange by sea.

Another significant potential market for Poland is Norway as up to now, Poland has had no ferry connection with the Norwegian market. Norway is one of the countries with the highest level of economic development in the world and is characterized by considerable movement of its citizens, who like to travel to South Europe. Many from the continent travel to Norway for tourism, too.

However, Poland still has very little trade exchange with Norway. In 2000 the share was just 0.83% of the total international trade exchange of Norway.[5] However amongst Central and Eastern European countries Poland is the most important partner for Norway for exports and the second – after Russia (2%) - for imports. There is thus some potential for opening a new line from Poland to Norway.

[5] B. Jeliński, *Norway. More and more important partner. Foreign markets,* 8-11 April 2003 nr 41-42, p. 4.

Table 3: Sweden foreign trade (1996 and 2000).

Specification	*Export*					*Import*				
	1996		2000			1996		2000		
	ml SEK	share [%]	ml SEK	share [%]	change 02/96	ml SEK	share [%]	ml SEK	share [%]	change [%]
Countries of EU (before 1st of May 2004)	325.2	57.1	424.8	54.0	30.63	315.7	70.4	429.2	66.8	35.95
Other European countries	88.4	15.5	136.3	17.3	54.18	61.2	13.6	108.9	16.9	77.94
Africa	9.1	1.6	12.3	1.6	35.16	2.9	0.6	2.4	0.4	-17.24
North and South America	64.5	11.3	116.7	14.8	80.93	32.7	7.3	42.6	6.6	30.28
Asia	73.4	12.9	89.1	11.3	21.39	34.6	7.7	57.2	8.9	65.32
Oceania	8.6	1.5	9.6	1.2	11.63	1.6	0.4	2.4	0.4	50
Total	569.2	100.0	786.6	100.0	38.19	448.7	100.0	642.7	100.0	43.24

Source: Ministry of Foreign Affairs, Sweden.

Table 4: Share of Poland in Swedish trade of Sweden (1994-2002) [ml SEK].

Specification	1994	1995	1996	1997	1998	1999	2000	2001	2002	*change [%]*
POLAND										
Export	4 589	6 602	7 159	10 126	10 660	12 682	13 234	12 800	12 627	175.17
Import	3 575	4 201	3 968	4 902	5 751	5 900	7 926	9 583	11 474	220.93
Balance	1 014	2 401	3 190	5 224	4 909	6 782	5 308	3 217	1 153	
CENTRAL AND EAST EUROPE										
Export	13 569	17 659	18 909	25 405	28 471	30 795	35 684	35 534	37 140	173.72
Import	12 089	12 390	11 461	14 834	18 721	20 448	28 327	28 712	32 813	171.42
Balance	1 480	5 268	7 448	10 572	9 751	10 346	7 357	6 822	4 327	
TOTAL										
Export	472 000	568 000	569 000	633 000	675 000	701 000	797 000	787 000	787 000	66.8
Import	399 000	461 000	449 000	501 000	545 000	567 000	667 000	655 000	643 000	61.02
Balance	72 000	107 000	120 000	132 000	130 000	134 000	130 000	133 000	144 000	

Source: Ministry of Foreign Affairs, Sweden.

Possibilities also exist in the return of Polish ferries on lines to Finland. The most serious threat to this route is the newly developing services from St. Petersburg, Riga and Tallinn and from existing services from the ports of Finland to Western Europe (rail ferries from Helsinki to Travemünde, Lubeck and Kilonia and from Kotka to Rostock). However Poland possesses a strategic advantage compared with the location of German ports, because of the shorter distances across the Baltic and by land connection across Poland to South Europe.

The Czech and Slovak Republics and Hungary play only a small role in the international trade of Scandinavia and Denmark. Their trade lies between 0.15 and 2% of the total for Sweden, Denmark, Finland and Norway together. However, they are countries which following entry to the EU, have enormous potential for economic development and increased trade exchange. Poland would benefit through increased freight transit and passenger movement.

Polish trade and consequently opportunities for the ferry industry have increased after entry to the European Union. Economic and political changes across the rest of Central and Eastern Europe along with the reunification of Germany have already increased tourism links across the Baltic Sea with Scandinavia and growth in international trade between these countries and the number of ferry connections.

The rapidly increasing number of cars in Poland creates positive conditions for the future of ferry shipping as well and Polish citizens have greater possibilities of travel abroad by car. In the case of travel to Scandinavia, ferries provide the only means of transport.

However, not all is good and a number of different barriers will also influence the functioning of ferry shipping in Poland:

- internal competition between Polferries and Unity Line and competition from foreign ferry operators acting in Poland;
- permanent rail and road connections across the Danish straits;
- competition from others forms of marine transport;
- the need for capital;
- strong competition from German ferry operators.

One of the biggest barriers for Polish ferry operators noted above is the strong competition of existing foreign based, large and experienced ferry operators. Unlike Polish operators, these companies can afford to sustain losses for considerable periods of time from other profitable markets.

In terms of the macro-environment for Polish ferry shipping the following conditions exist:

- *geographical;*
  - location of Poland on the Baltic Sea on major communication routes;
- *economic and social;*
  - level and rate of economic development;
  - increasing standard of living of citizens;
  - intensification of international trade by sea between Baltic countries;
- *political;*
  - economic policy of Poland towards marine transport;
  - entering the European Union;
  - adapting Baltic Sea ferries to international rules concerning safety on the sea and protection of the environment;
- *technical and technological;*
  - technical progress in shipbuilding facilitating bigger units;
  - technical progress in organization of loading, shortening time in port;
  - development of railway infrastructure;
  - urgent need for development of road infrastructure;
- *demographic;*
  - population size, age structure and education.

The strategic geographical location of Poland, across transit routes of Europe, is one of the most important conditions determining the development of ferry shipping in Poland. According to experts from the EU Transport Commission and the United Nations, transit through Poland east-west will increase by 60 % and north-south 30% by

2015.[6] However, the location of Poland, away from the shorter sea connections across the Baltic, may well be a barrier to development of the ferry sector. Despite this, there are possibilities of exploiting middle distance and longer routes.

The Swedish and Finnish markets have clear potential. Silja Line and Viking Line, operating between Turku-Stockholm and Helsinki-Stockholm together carry over 9.5 million passengers a year, mainly for tourist purposes. (Table 5).

Table 5: Passenger market share Finland and Sweden ferry services – 2000.

Ferry Operator	*% Share*
Silja Line	45
Viking Line	39
Eckero Linien	7
Birka Line	7
Anedin Linien	2
SeaWind Line	1.15

Source: Authors

However Poland is characterised by a lower level of economic development than the countries of south-west and the north Baltic Sea. The GNP per person of Poland is several times lower than in the Scandinavian countries and Denmark. This has a negative influence on the quantity of travel to these countries simply because of financial reasons. However, increases in economic development in Poland are occurring rapidly and will improve this situation.

The corollary of this is that prices for Swedish, Finnish, Norwegian and Danish travellers are much lower in Poland and thus there is considerable potential for marine tourism in this direction. Scandinavian tourists are exacting costumers and in order to satisfy there needs, modern ferries will have to be provided as they are in the northern Baltic Sea. Intensification of this market is possible thanks to the relatively short distances and the exploitation of fast ferries. The example of the Tallinn-Helsinki route is evidence of this carrying almost 6 million passengers annually.

An important factor in the development of ferry shipping belongs to political conditions including those of international trade. Before Poland joined the EU, development of Polish ferry shipping was limited by extensive border rules and custom duties encouraging passenger and drivers to avoid Poland and transit between Scandinavia and south Europe by German ports. Liberalisation of international trade is a positive move in the development of international exchange for Poland.

Amongst the conditions that determine development of ferry shipping in Poland are international regulations concerning safety and protection of the environment. Ferry enterprises have to fulfil all present rules of the International Convention concerning safety on sea (SOLAS) as well as the Stockholm Convention annex, the ISM Code and MARPOL, the latter relating to marine pollution. In many cases – especially in the case of older ships – it necessitates rebuilding. For Polferries this presents severe problems and one vessel - *Nieborow* - was too old for modernisation and was sold.

The economic policies of Poland also influence the condition and operation of ferry shipping. At present, a difficult situation is worsened by existing fiscal, monetary and credit policies and the lack of indirect help by the government to the industry. Examples

[6] K. Klimek, Motorways in Poland – opportunity for success or threat ... , in *Competitiveness of Marine Transport of Poland*. Science Exercises of The University of Gdansk, Economics of Marine Transport, Gdansk 1999, s. 130.

of policy support used elsewhere in the EU include tax reduction, state investment, government guarantees for credits for tonnage investments, zero VAT for marine services and exemption from VAT for ship construction in domestic shipyards. None of these are available in Poland.

One very important condition for the development of ferry shipping is adequate transport infrastructure. The ports of the Baltic Sea that possess the most positive conditions for ferry shipping are Frederikshaven, Rostock, Malmö, Helsinki, Turku and Copenhagen largely thanks to their well developed network of roads and motorways and connections between ferry terminals and their hinterland.

However, in Poland the existing infrastructure is a major barrier to development. The present problems of Polish transport systems are a result of limited financial resources for modernisation and building new lines for car, truck and rail movements and this situation has a poor influence upon the international exchange and development of tourism. The Polish road infrastructure is far worse than in West European countries. Poland has just 300km of motorways compared with Germany's 11,000 km. Virtually all other Polish roads need modernization.

The key role for Polish ferries is building motorways, especially the A1 motorway (running south from the Gdansk/Gdynia region) which is a major section of the international north-south route. Even though it is more than 30 years since the initiation of the idea to build the A1, the project has not been finished. Transit cargo more than anything else is likely to be affected by this situation with severe competition not only from ferry services in Germany but increasingly from Russia, Lithuania, Latvia and Estonia. Polish ferry ports also suffer from inadequate investment with facilities developed under Communist times which fail to compare with ports in Germany, Denmark, Sweden, Finland or even Estonia and Lithuania reflected in port traffic elsewhere (Table 6).

Poland's entry to the European Union in 2004 is a major stimulus for the ferry sector. One of the aims of the EU is integration of the transport network, introducing new technologies for multimodal transport (including ferries) and the creation of European transport corridors which will encourage an increase in transit movements between Scandinavia and the European continent in particular the north-south motorway link.

Central and Eastern European ports exhibit countries with much lower levels of demand (Table 7) with the only exception the Tallinn-Helsinki route.

Technical progress in shipbuilding and in the organization of loading will also play an important role in the Polish ferry shipping industry. These include an increase in the size of ferries, the speed of conventional ships, an increase in vessel quality for passengers, shorter stays in ports, modern technology for vessel loading and improvements in the standards of safety.

Internal conditions also play an important role in the functioning of Polish ferry shipping. These conditions concern the specific activities of ferry operators. They include: the quality of the ferry fleets; its number and technical level; the quantity and level of professional education and experience of staff; the structure of prices and management processes including marketing and research and development. [7]

[7] S. Marciniak (ed.), *Macro and Micro Economics. Basic Problems.* Polish National Publishers, Warsaw 1998, p. 234.

Table 6: Passengers, cars and trucks movements, major Baltic Sea terminals (2000).

Ferry Terminal	Passengers	Market share [%]	***Cars***	Market share [%]	***Trucks***	Market share [%]
Helsinborg	14 425 255	9.20	2 235 072	4.48	392 776	7.40
Stockholm	8 612 368	5.50	557 256	1.12	195 580	3.68
Helsinki	8 000 149	5.10	292 768	0.59	129 762	2.44
Göteborg	4 337 029	2.78	724 615	1.45	260 102	4.90
Copenhagen	4 130 092	2.64	101 651	0.20	15 438	0.29
Malmö	3 308 909	2.11	0	0	165 055	3.11
Trelleborg	1 341 222	0.86	251 607	0.50	266 630	5.02
Travemunde	742 135	0.47	119 573	0.24	229 510	4.32

Source: ShipPax Statistics 01. *The yearbook for passenger shipping traffic figures*. Halmstad, Sweden 2001.

Table 7: Passengers, cars and trucks Central-Eastern European ports (2000)

Ferry Terminal	Passengers	*Market Share [%]*	*Cars*	*Market Share [%]*	*Trucks*	*Market Share [%]*
Tallinn	6 353 156	4.05	214 462	0.43	114 775	2.16
Gdynia	181 858	0.11	25 672	0.05	16 117	0.30
Gdansk	96 832	0.06	17 408	0.03	1 786	0.03
Klajpeda	53 779	0.03	13 292	0.03	75 380	1.42
Riga	52 054	0.03	3 321	0.007	2 289	0.04
Liepaja	0	0	730	0.001	9 000	0.17

Source: ShipPax Statistics 01. *The Yearbook for passenger shipping traffic figures*. Halmstad, Sweden 2001.

In terms of Polish ferry operators, Polferries faces the greatest difficulties. Its financial condition does not allow for new tonnage investment and the quality of services is not good despite its long history and experience. In much better condition is Unity line, which as a young ferry operator, employing young and well educated personnel, functions reasonably efficiently in the market.

4. The strengths and weaknesses of Polish ferry operators

The position of the Polish ferry shipping industry is poor in the context of competition in the Baltic Sea market. Polish ferry operators occupy a small place in Baltic Sea operations serving just 1 % of passenger movement and 5 % of cargo carriage.[8] In this section we shall use a SWOT analysis in an attempt to better understand the causes of this. Following the transition of Poland from a planned to a competitive economy from 1989 the company was suddenly deprived of half its market share by new entries to the Polish market. In recent years the carriage of passengers, cars and trucks by the main

[8] Poland has more than 3% of cargo market share thanks to railway carriage on ferries belonging to Unity Line [ShipPax Statistics 01. *The Yearbook for Passenger Shipping Traffic Figures*. Halmstad, Sweden 2001, s. 86, 122 and 150].

state-owned Polferries has decreased by 30%.[9] The greatest problems have been felt on the Swinoujscie-Ystad route, where Polferries competes directly with the Polish privately owned Unity Line which entered the market in 1994.

In assessing the marketing environment for Polish ferry operators on the Baltic Sea, a number of issues were considered: political and economic, technical, organisational and social conditions, capacity of the market, forecasts of market change, and analysis of customer behaviour. A SWOT analysis was carried out in 2003 by one of the authors for the two major Polish ferry operators Unity Line and Polferries based on the opinions of experts in the region. These two operators dominate the Polish owned ferry industry and were selected for the SWOT analysis for this reason. Senior managers from a range of companies with interests in the ferry sector (hauliers, travel agents, port managers, freight forwarders, policy-makers) were asked to rate their agreement or otherwise to the strengths, weaknesses, opportunities and threats presented in the following sections and average points scores were calculated to indicate their opinions overall.

Table 8: Strengths and Weaknesses of unity line

	Strengths (S)	***Points***
S1	Servicing a line that meets natural land transport corridors	5
S2	Young and qualified staff	5
S3	Possessing one of the most modern ferries on the Baltic Sea	4
S4	High quality of services	4
S5	Systematic market research into the structure of customers and their needs	4
S6	Ability to transport railway wagons	3
	Weaknesses (W)	**Points**
W1	Servicing only one line	-5
W2	Possessing two old cargo units, unadapted to the needs of the market	-5
W3	Low frequency of departures	-4
W4	Insufficient promotion	-4
W5	Insufficient sales network	-4

Source: E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market.* Technical University of Gdansk, Gdansk 2003, p. 185.

Table 9: Strengths and Weaknesses of Polferries

	Strengths (S)	***Points***
S1	Servicing a line that meets natural land transport corridors	5
S2	Good experience of staff	4
S3	Long tradition of activity in Poland	3
	Weaknesses (W)	**Points**
W1	Poor financial situation	-5
W2	Lack of proper tonnage for needs of market	-5
W3	Complicated organisational structure	-5
W4	Low quality and narrow range of services	-4
W5	Low frequency of departures, which is insufficient for cargo demands	-4
W6	Extended processes of transitional reorganisation and privatisation	-4
W7	Insufficient promotion	-4
W8	Limited range of market research	-4
W9	Insufficient sales network	-4

Source: E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market.* Technical University of Gdansk, Gdansk 2003, p. 185.

[9] ShipPax Statistics 01. *The Yearbook for Passenger Shipping Traffic Figures*. Halmstad, Sweden 2001, p. 112 and 133.

A scale from 1 to 5 points for strengths and opportunities and from –1 to –5 points for weaknesses and threats was used as the basis of the analysis following the work of Kramer (undated).[10] Tables 8 and 9 present the results for the first two stages of the SWOT exercise for Unity Line and Polferries for strengths and weaknesses. Unity Line has positive results overall (+3) but Polferries achieved a very poor negative result (-27). Polferries scored negative results for the majority of categories with positive reaction only to the company's history and tradition and the benefits of their port locations. Of particular concern were the poor scores for quality of service, the paucity of service frequencies, the low level of marketing and utilisation of the wrong sort of tonnage. By comparison Unity Line showed far more strengths which included market analysis, quality of service and marketing knowledge and capabilities. Unity Line is also the only ferry operator in Poland that has passenger, vehicle and railway ferries the latter on contract with Polish National Railway (PKP) and there is market potential particularly for the latter as environmental concerns in the EU increase. However, the company also failed to take issues of promotion and sales seriously enough and were still operating some very old vessels.

In the case of Polferries, the results of the analysis confirm a difficult situation. The most significant weaknesses are the low quantity and quality of tonnage stemming from a poor financial situation including substantial debt and lack of financial resources for modernisation. In turn this leads to insufficient departures and low carriage potential in relation to needs. One of the most serious problems is the extended processes of reorganisation and privatisation combined with poor decisions unrelated to conditions in the market. The prime example was the purchase of the fast ferry (*Boomerang*), which was inappropriate for Polish operating conditions. Services are also characterised by low quality and narrow range lack of strong marketing activity. The firm does not undertake any market research. This difficult situation is intensified by competition from domestic and foreign ferry operators.

5. Opportunities and threats for Polish ferry operators

An analysis of the opportunities and threats for the two companies was conducted in the same way and the results are presented in Tables 10 and 11. Summing the marks for both operators for opportunities and threats the result is overall positive (+4), which means that in the Polish market as a whole there are more opportunities than threats and thus some limited reason for optimism.

In spite of the generally poor situation indicated in the strengths and weaknesses section, opportunities for the development of ferry shipping in Poland do exist. Forecasts of increased demand of passengers and cargo are clearly based on the projected economic development of Poland, increased wealth of citizens and a growing interest in marine tourism. There are also hopes for technical progress, finding expression in the purchase of modern tonnage improving quality in passenger and cargo carriage. This will be determined by the economic and shipping policy of the country and the entry of Poland to the European Union. It is also connected with different means of financial help for shipping enterprises.

[10] T. Kramer, *SWOT analysis as a base of strategic decisions of a firm*. Economic Academy, Katowice, s. 137.

Table 10: Opportunities for Polish ferry operators.

	Opportunities (O)	*Points*
O1	Increased demand for marine tourism	5
O2	Increased demand for short one and two-day cruises	5
O3	Increased demand from passenger carriage	5
O4	Increased demand from transit cargo through Polish ports	5
O5	Anticipated increases in the Polish economy and living standards	5
O6	Liberalisation of international trade following Poland's entry to the EU	5
O7	Tonnage renewal of tonnage, modernisation of ports, development of short sea shipping and cabotage shipping, and additional connections between Poland and other Baltic Sea countries	5
O8	Modernisation of access roads to ferry terminals in Poland	5
O9	New ferry terminal in Gdynia	5
O10	Strategic location of Poland, situated at crossroads of Europe	4
O11	Increased trade exchange with Scandinavian countries and Denmark following Poland's entry to the EU	4
O12	Increased share of trucks in cargo carriage of Polish foreign trade and transit	4
O13	European Union funding support	4
O14	Increased motorisation in Poland	4
O15	Modernisation of railway infrastructure	4
O16	Rebuilding of roads and motorways, particularly Motorways A1 and A3	3
O17	Increased ship size	3
O18	Technological progress in ship loading reducing port time	3
O19	Fast ferries	3

Source: E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market.* Technical University of Gdansk, Gdansk 2003, p. 186.

Table 11: Threats for Polish ferry operators.

	Threats (T)	*Points*
T1	Competition from foreign ferry operators entering the Polish market	5
T2	Intensification of competition from German ferry operators	5
T3	Internal "ferry war" between Polferries and Unity Line between Swinoujscie (Poland)-Ystad (Sweden)	5
T4	Lower level of economic development of Poland compared with countries of South West and North Baltic Sea	5
T5	Difficulties over border rules and custom duties	5
T6	Lack of economic policy for shipping in Poland (fiscal polities, finance and credit policy and lack of forms of indirect help)	5
T7	Lack of financial sources for modernisation and building of roads and motorways	5
T8	Shortage of finance for investment in the modernisation of rail rolling-stock and main communication routes	5
T9	Lack of financial sources for new and reconstruction of ferry terminals	5
T10	Growing concentration of capital	4
T11	Increased competition from land and sea transport systems from Moscow, St. Petersburg, Riga, Tallinn via ports of Finland to ports of West Europe	4
T12	Development of modern rail, road and water connections in Europe that encourages high quality services offered by foreign ferry operators	4
T13	Complex procedures and criteria for EU investment in marine transport	4
T14	Increased costs of investment in marine transport from stricter rules and technical standards	4
T15	Seasonal passenger carriage	3
T16	Growth of competition of other forms of marine transport	3
T17	Growth of competition of land (road and railway) transport including new crossings of the Fehrman Belt, Öresund and Big Belt	3
T18	Decrease of demand for railway ferry carriage	3

Source: E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market.* Technical University of Gdansk, Gdansk 2003, p. 187.

Finance needs to be found for the modernization of roads, railway and port infrastructure connecting ferry terminals with their hinterland. This will enhance connections with Scandinavian countries and South Europe for tourists and freight travelling in the north-south corridor, a market currently dominated by the ports of eastern Germany.

However the threats for the industry are substantial and in particular are faced by Polferries rather than Unity Line. Table 11 indicates the range that exist some of which appear to be intractable in the context of competition from foreign ferry operators. It needs to be re-emphasised that these threats are particularly faced by Polferries who already face a wide range of weaknesses identified above. The prospects do not look good in the long term and particularly when vessels need to be replaced.

6. The marketing environment for Polish ferry operators

Taking Polish ferry shipping as a whole, the mission for the sector stems from the function which ferry shipping plays in the market. This aim is broadly speedy, safe and regular carriage by sea, of people (mainly with cars) and cargo on dedicated and modern ferries, ensuring the highest quality of services and frequency of carriage adapted to the needs of the market.

The following strategies have been identified by the Polish Government:[11]

- increasing the role of Polish ferry shipping in the Baltic market;
- increasing the effectiveness of Polish ferry enterprises;
- increasing the share of Polish ferry shipping both of passenger and truck carriage to 5% by 2010. The present share is small and insufficient in relation to the development needs and economic cooperation between Poland and other Baltic countries.

These strategic aims will require a development strategy - both organisational and in terms of capital. Consolidation will be needed around the existing two Polish ferry operators - Polferries and Unity Line. To achieve this it might well be necessary to encourage collaboration between Polish operators as well as with competitors - for example Stena Line and other enterprises with interests in ferry shipping: railways, shipyards, freight forwarders, travel agencies, banks, insurance offices and others. Only strong and effective ferry operators have a chance of surviving in the Baltic Sea marketplace and somehow an internal war of competition has to be prevented.

The specific aims identified by the Government to achieve a 5% of share in the Baltic marketplace are:

- increasing the market share of Polish citizens traveling to and from the Scandinavian countries and Denmark and transit passengers traveling between North and South Europe;

[11] *Assumption of development strategy of Polish ferry shipping*. Ministry of Transport and Marine Economics, Warsaw, October 1999, p. 17.

- increasing the share of international cargo between Poland and the Scandinavian countries and Denmark and transit cargo between the Nordic countries and countries located along the north-south European transport corridor;
- developing new market segments such as conference passengers;
- entering the Norwegian market;
- returning to the Finnish market.

To achieve this, a new development model will need to be adopted characterized by:

- maximising sector activity through introduction of modern systems of management, logistics and marketing;
- improvement in quality of services;
- reducing and controlling costs.

Taking into consideration the earlier SWOT analysis a series of proposals for Polish ferry operators can be suggested:

- *tasks for Unity Line;*
  - Intensification of ferry services for transit cargo between Scandinavian countries and countries located in the hinterland of ports of the South Baltic.
  - Intensification of passenger carriage of Polish and foreign tourists;
  - Intensification of rail cargo carriage on existing and new markets for example to Finland.

- *tasks for Polferries;*
  - Increasing share of existing markets and intensification of cargo carriage;
  - Intensification of passenger carriage in existing markets and the development of new markets.

Table 12 indicates a strategy to realise these aims and suggests that a change of direction and attitude in Polish ferry operators and the introduction of experiences from overseas operators would be beneficial. In particular Stena Line entered the market between Poland and Sweden based on the (so far unrealized) plan for the Polish north-south A1 motorway creating new strategic opportunities for Scandinavian countries. Despite the continued absence of the motorway Stena has been a notable success in competition with Polish ferry operators partly as a consequence of its global strategy including new investments in their fleet. This includes buying up other firms in the Baltic region - Scandlines AB (Trelleborg-Sassnitz and Trelleborg-Rostock) and HH Ferry (Helsingor-Helsinborg).

Clearly the Polish government will play a very important role in developing appropriate conditions for building roads, motorways and ports and possibly helping in the expensive purchase of new tonnage. Meanwhile, the processes of restructuring and privatisation are also necessary to ensure:

- reduction of financial debt;
- growth of income;
- increased competitiveness;
- increased attractiveness of ferry services; and
- improved effectiveness.

One of the most important tasks is the building of a new ferry terminal in Gdynia Port creating new possibilities with modern loading technologies and shaping new logistical solutions for Gdansk/Gdynia in the north-south transport corridor.

Table 12: Formulation and realisation of strategies.

Aim	***Strategy***	***Realisation***
Increase the role of Polish ferry shipping on the Baltic Sea. Increase effectiveness of Polish ferry operators. Increase market share to 5% by 2010	Increase ferry connections.	Capital investment in Polish ferry enterprises concentrated around the existing Polish ferry carriers - Polferries and Unity Line.
Improve competitive position.	Competitive.	Decrease costs. Increase productivity. Look for partners for cooperation. Improve quality.
Increase share in passenger market.	Product development.	Purchase several new modern units of different size and profile. Rebuild and modernise ferries. Improve quality of services. Adapt the frequency of departures to market needs. Develop land tourism and cruise services with hotel facilities. Intensify promotional activities.
Increase share in cargo market.	Product development.	Modernise fleet and improvement of loading technologies. Improve ferries of ro-pax type. Improve service quality. Adapt frequency of departures to market needs. Intensify promotion.
Develop new market segments.	Diversification.	Adapting offers to the new market segment, for example business passengers (conferences). Purchase several new modern units of different size and profile. Improve service quality. Adapt to market needs. Intensify promotion. Develop distribution network.
Enter Norwegian market.	Diversification.	Open new lines to Norway. Improve ferries of ro-pax type. Modernise the fleet and improve loading technologies. Improve service quality. Adapt departures to market needs. Intensify promotion. Develop distribution network.
Return to Finnish market	Diversification.	Open new lines to Finland. Improve ferries of ro-pax type. Improve service quality. Adapt departures to market needs. Intensify promotion. Develop distribution network.

Source*:* E. Kapsa, *Perspectives of ferry shipping in Poland on the base of development of Baltic market*. Technical University of Gdansk, Gdansk 2003, p. 195.

The Polish government has other strategic reasons to become involved in the Baltic ferry sector and provide support for its development. Although now constrained by Poland’s entry into the EU, measures might include:

- the most effective use of natural strengths of the location of Poland on the Baltic Sea in Central Europe;
- the development of Polish ferry operators as modern economic units playing an important role in the economic development of Poland;

- creating an effective transport policy for Poland recognizing ferry shipping as a link in land transport chains ensuring coordinated development;
- improvement in economic policies particularly in the context of competition from German ferry operators;
- creating an effective but controlled framework for competition for ferry operators in Poland to the benefit of operators and the national economy;
- increase income from the export of marine transport.

These tasks should be realised first of all by units of public administration,[12] to which we can include primarily the Ministry of Transport and Marine Economics along with support from municipal administrations from the marine regions.

7. Pricing policy for Polish ferry shipping

The Polish ferry market exhibits all the traditionally accepted price characteristics of ferry shipping around the world. One of characteristic features of pricing in ferry shipping is the integrated package of services offered as one price. Tickets might include carriage, cabin, food and car transport. More and more often hotel accommodation is included as well.

The present situation in the Baltic Sea ferry market for passengers is characterized by strong competition between operators along with modal competition by, road, railway and air and also alternative forms of tourism. The movement of cargo is also characterized by intense competition. Consequently operators have to adapt themselves to market demand and have flexible pricing policies that can react quickly to changes in the environment. The ferry market is additionally characterized by a market that is in many ways optional (e.g. tourism) and seasonal along with substantial fixed costs.[13] Hence price plays a very important role. Price discounts can induce potential customers to use services particularly out of season thereby flattening expensive peaks and troughs in demand.

Price plays different roles on strategic and tactical levels. On a strategic level, price reflects the strategies of the firm, positioning products and creating a service image and reveals to potential customers values concerning quality. Ferry enterprises can use two basic alternative price strategies; penetration and skimming. Penetration focuses on setting prices at a lower level than competition, normally rapidly increasing customer numbers and deterring others entering the market. Skimming is charcterised by high prices, rapidly maximising income and improving image.

In the case of existing ferry services, the enterprise can use other price strategies. In order to gain new customers, a compensatory strategy can be applied. This is based on fixing the price of basic services at a low level (for example travel in an inside cabin for four persons). Discount prices are set at the lowest cost level.

Calculation of prices is the result of analysis of competitive prices, the elasticity of demand and the potential for market segmentation. Prices of other services are

[12] Public administration – institutions involving in organization of process of satisfy aggregate needs, *in* Antoszewski, A. Herbut R. (ed.), *Lexicon of Politology*. Agency of Publishers and Advertisement, Wroclaw 1998, p. 9.]

[13] In ferry shipping, fixed costs amount to 80% of the total.

established at a higher level in order to compensate for losses at the basic price (for example, for external two-person cabins in business class).

The level of prices used by Polish ferry operators depend, amongst others, upon the range of added services. The price differs dependent upon the number in the cabin and the equipment offered. Prices applied by Polferries can be used an example where the cheapest tickets are for 4-person cabins and the most expensive for 2-person cabins with a WC and shower. A similar situation is found at Unity Line which offers a wide range of cabin classes; from the cheapest 4-person cabin without WC to one more then 5 times expensive: a 2-person external cabin of De Luxe class (with 2-person bed) (Table 13).

Ferry shipping might also set prices by comparison with the competition. However this may be unsafe because the quality of services may not be taken into consideration. However if administrative costs, quality and the range of services offered are taken into consideration, then prices can be set on a similar, lower or higher lever dependent on strategy. In this way there is no risk of losses and at the same time it facilitates positioning of products in relation to the competition. This is clearly the case for the two Polish ferry operators Unity Line and Polferries, which between Swinoujscie (Poland) and Ystad (Sweden) have identical base prices for individual and group passengers and their cars.[14]

Another price strategy is orientated to demand. The price is set on an estimation of consumption of potential customers for passenger or freight carriage although this limits prices to those adopted by competitors otherwise the enterprise may not withstand the competition.

Table 13: Prices unity line Swinoujscie-Ystad (June 2002 – January 2003).

Cabins	***01.06.02 - 31.08.02***	***01.09.02 - 12.01.03***
	Price for a person / Night (SEK)	
2 Person External De luxe Class	998	998
2 Person External Business Class	380	370
2 Person Internal Business Class	350	340
3 Person External Business Class	290	280
3 Person Internal Business Class	260	250
4 Person External Tourist Class	220	210
4 Person Internal Tourist Class	190	180
4 Person Internal Without WC*	100	90

*other cabins with WC and shower
Source: Unity Line.

Overall prices of ferry shipping services should be set at a level that will achieve the following effects:

- will ensure earning capacity, covering full costs of the operator;
- will ensure a realistic relationship with the financial possibilities of potential customers;
- will sustain competition with other ferry operators, alternative transport modes and different forms of tourism;
- will ensure a close relationship of price to quality; and
- will ensure consistent sales during the year, not only in the high season.

[14] Following comparison of the published price-lists of both ferry operators.

8. The tactical role of pricing in Polish ferry shipping

For ferry operators price plays a tactical as well as strategic role. For example, through lowering prices, commonly at the last minute, enterprises can influence ultimate demand. Such tactics are based initially on setting prices for services according to the main price strategy but failure to sell sufficiently creates losses (for example empty cabins). In a way used by low cost airlines, price tactics in ferry shipping need to be adapted to the actual demand and the Polish market is no exception. Price differentiation is another significant approach and takes place when two or more of the same products are sold at different prices, adapting them to the differential demands of different groups of passengers. This is reflected in seasonal prices whereby during the summer period, prices are higher than in the low season reflecting the change in demand by the tourist market. Consequently ferry companies divide the year into high season (June, July, August) and low season (other months) calculating an average profitable price for the year. High season prices are often 5 to 15% higher (or more dependent on route) than in other months.

Differential pricing can also be applied for different days of the week. Taking into consideration the greater demand over weekends, higher prices may be set. Prices may also be varied depending on the hour, including reductions for day returns. Stena Line is an excellent example which has proved very successful in the Polish market. Different tariffs exist depending on the day of week and hour of the day. Cheap tickets exist for day cruises from Gdynia (Poland) on Mondays, Wednesdays and Fridays, and the most expensive are for night travel on Wednesdays and Saturdays (Table 14).

Table 14: Differentiation in pricing by Stena Line (June-August 2002)

Tariff	*Price (SEK)*	*Departure from Gdynia*		*Departure from Karlskrona*	
		Hour	**Day of week**	**Hour**	**Day of week**
A	290	9.00	Monday, Thursday, Friday	9.00	Tuesday, Wednesday, Thursday, Sunday
B	345	9.00	Tuesday, Wednesday, Saturday, Sunday	9.00	Monday, Tuesday, Wednesday, Saturday
		21.00	Thursday, Friday	21.00	Tuesday, Friday, Saturday
C	365	21.00	Wednesday, Saturday	21.00	Thursday

*car one way
Source: Stena Line

One of the criteria for the differentiation of prices is based on the likely financial situation of customers. Ferry operators from Poland offer discounts for youths, students and pensioners. Polferries, gives lower prices for children and youths under 16 years and students under 26 and pensioners. Children under 7 travel free (Table 15).

Another price differentiation criterion relates to the number of tickets sold to a customer, for example family tickets, multi journeys tickets etc.). Examples of such tactics come from Polferries (Gdansk (Poland)-Nynäshamn (Sweden)):

- discounts for two-way journeys for 2 persons in 2-person cabin with breakfast or for 4 persons in 4-person cabin;
- discounts for departures on Thursday for passengers with car;
- discounts for multi-journeys tickets for regular customers traveling by car below 2 meters height and 6 meters length.

Table 15: Differentiation in Pricing by Polferries (January 2002-January 2003).

	Low Season		***High Season***	
	One way	**Two way**	**One way**	**Two way**
Adult	450	750	520	820
Children under 7 years	Free	free	free	free
Youths 8-16 years, students under 26 years, pensioners	370	640	430	700

Source: Polferries.

Thus price positioning in the Polish market could also be set according to the following elements and it is this sort of area that urgently needs to be addressed particularly by Polferries if it is to survive:

- quality of service and the scale of additional offers;
- time - season, day of week, hour;
- market segmentation - students, businessmen, retired, youth;
- time of travel - weekend, multi-trips, day-trips;
- frequency of travel.

Price decisions are important in the strategic sense but in a tactical sense their significance is perhaps even greater, exacerbated by the inability to store transport provision and the costs associated with unused capacity.

9. Conclusions

Clearly there is much happening in the Polish ferry sector and many opportunities exist for the coming years. However, the environment is highly competitive and issues such as price and strategy will remain paramount. Polferries in particular faces some very difficult decisions in the coming years as the need for new vessels becomes urgent. Unity Line has more opportunity to adapt and develop as its current position is that much stronger but in both cases the role of foreign competitors is likely to increase as the burgeoning freight and passenger market on the Baltic Sea becomes more significant in the light of EU membership for Poland.

The SWOT analysis identified a number of significant problems especially for Polferries and these are now becoming so intense that it seems unlikely that the company can survive in its present form. It is indicative that the Polish government remains the owner and has failed in repeated attempts to sell the company so far. Competitors (including Unity Line) await its demise before absorbing its market into their operations.

References

Antoszewski, A. and Herbut, R. (ed.) (1998) *Lexicon of politology*, Agency of Publishers and Advertisement, Wroclaw.

Daszkowska, M. (ed.) (1993) *Outline of marketing of services*, University of Gdansk Publishers, Gdansk.

Dębicka, O. (1996) *Ferry shipping on the Baltic Sea, Polish case. Transit chains in the Baltic Sea region*, University of Turku, Turku.

Economic Commission for Europe (2002) *Investiguide 2001-2002. Project opportunities and contacts for the CEI Region.* United Nations, New York.
Garbarski., L., Rutkowski I. and Wrzosek, W. (1996) *Marketing. reversible point of the modern firm.* Polish Economic Publishers, Warsaw.
Jeliński, B. (2003) “Norway. More and more important partner”, *Foreign markets*, 41-42, 4.
Kalisiewicz, D. (ed.) (1999) *Encyclopaedia of Polish publishers of science in three volumes. Volume 1*. Polish Publishers of Science, Warsaw.
Kapsa, E. (2003) *Perspectives of ferry shipping in Poland on the base of development of Baltic market. Perspektywy żeglugi promowej w Polsce na tle rozwoju rynku bałtyckiego.* Technical University of Gdansk, Gdansk.
Klimek, K. (1999) “Motorways in Poland - Opportunity for Success or Threat”, in *Competitiveness of marine transport of Poland,* Science Exercises of The University of Gdansk.
Kotler, P. (1994) *Marketing. Analysis, planning, training and control.* Gebethner Ltd., Warsaw..
Kramer, T. (undated) *SWOT Analysis as a base of strategic decisions of a firm*. Economic Academy, Katowice.
Marciniak, S. (1998) *Macro and micro economics. Basic problems.* Polish National Publishers, Warsaw.
Marcinkiewicz, C. (2001) *Marketing of tourist services,* Management Faculty of Technical University of Czestochowa, Czestochowa..
Ministry of Transport and Marine Economics (1999) *Assumption of development strategy of Polish ferry shipping,* Ministry of Transport and Marine Economics, Warsaw.
Ministry of Transport and Marine Economics (1999) *Tourism in 1998*, Main Statistical Office, Warsaw.
ShipPax Statistics (2001) *The Yearbook for passenger shipping traffic figures*. Halmstad, Sweden.

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Analysis of driver's response to real-time information in Switzerland

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Abstract

We present behavioral models designed to capture the response of drivers to real-time traffic information. In 2003, we have conducted a survey in Switzerland in order to collect both Revealed Preferences (RP) and Stated Preferences (SP) about choice decisions in terms of route and mode. The RP data contains socio-economic characteristics of the individuals in our samples, their actual usage of ITS as well as their actual route and mode choice behavior. The SP data provide us with stated route and mode choices when drivers are faced with different hypothetical choice situations involving real-time information about the state of the network. First we present a Mixed Binary Logit model with panel data to analyze the drivers' decisions when traffic information is provided during their trip by the mean of Radio Data System (RDS) or Variable Message Signs (VMS). This model is referred to en-route choice model. Second we present Nested Logit models capturing the behavior of drivers when they are aware of traffic conditions before their trip. These last models allow to predict pre-trip route choice decisions with regard to route and mode when traffic information is available. The calibrated models are subsequently included in a simulator which predicts travelers' behavior in specific scenarios (described by adjustable parameters) allowing the sensitivity analysis of the demand with regard to the variations of various parameters. In this paper, we discuss the results of the estimation process, including some comments about the Value of Travel Time Savings (VTTS) and present some scenarios developed with our simulator.

Keywords: Discrete choice; Response to traffic information; Route and mode choice.

1. Introduction

Intelligent Transportation Systems (ITS) are aiming at the improvement of transportation systems through advanced information and control technologies. Namely, Dynamic Traffic Management Systems (DTMS) combine those technologies with the appropriate decision-aid tools.

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Demand models play a central role in such systems. Indeed, the impact of ITS on travelers' behavior must be captured, understood and explicitly predicted. In this context, representing transportation demand through (possibly dynamic) origin-destination matrices is not sufficient. A disaggregate representation is necessary, where individuals are considered with their characteristics (trip purpose, available ITS equipment, etc.) and with their decisions in terms of route and mode choice.

Most recent methodologies for the evaluation and management of ITS are based on behavioral models, predicting the response of users to the ITS environment. Among them, we can cite the software systems developed at the Massachusetts Institute of Technology: MITSIM Laboratory (Ben-Akiva et al., 1997) for the evaluation of DTMS and DynaMIT (Ben-Akiva et al., 2001) for real-time traffic information and prediction. Other tools, like VISSIM or AIMSUM in Europe, and DYNASMART and TRANSIM in the US are also based on a disaggregate representation of the demand.

The use of such tools allows for an operational approach of telematics, which optimizes the impact of existing infrastructures, such as Variable Message Signs (VMS), RDS, etc. Disaggregate demand models also help to analyze the impact of longer term strategies such as road-pricing, congestion-pricing, diversion strategies, etc.

During the last decade, various behavioral models have been proposed in the literature to capture response to traffic information. Although various methodologies have been used, such as cluster analysis (Conquest et al., 1993) or Poisson regression (Khattak et al., 2003), most approaches are based on discrete choice models. Khattak et al. (1996) present multinomial logit models estimated on both revealed preferences and stated preferences data. Wardman et al. (1997) and Chatterjee et al., (2002) propose a multinomial logit model capturing the response to information provided by Variable Message Signs. Mahmassani and Liu (1999) propose a Multinomial Probit model. Karthik et al. (2003) estimate a mixture of logit models (logit kernel) using a sample of commuters in the same city. We also refer the reader to Zhao (1996) and Dia (2002) for similar approaches.

In this paper, we also adopt a discrete choice approach and present behavioral models capturing the response of Swiss travelers to traffic information, designed to be used in a DTMS. Compared to most approaches in the literature, we extend the analysis to both radio information and information coming from VMS, and consider SP data from different samples. As a consequence, we had to segment the population and include various socio-economic characteristics in the model. Also, in contrast to the existing literature (except for Conquest et al., 1993), we do not focus only on route-switching decisions. We consider also pre-trip mode-switching decisions. Finally, we adopt state-of-the-art models, such as a mixture of logit model with agent effects, and nested logit models jointly estimated on multiple data sets.

The models presented here are the result of a research project conducted between 2002 and 2004. The research team was composed of two engineering consulting firms (Robert-Grandpierre et Rapp, SA, Lausanne, and Büro Widmer, Frauenfeld), IVT (Institute for Transport Planning and Systems), ETH Zürich, and the Operations Research Group ROSO, EPFL.

The data collection process is described in Section 2. The model for en-route behavior is presented in Section 3 while the models for pre-trip behavior are presented in Section 4. Before concluding in Section 6, we illustrate examples of how these models can be used in a simulator in Section 5.

2. Data collection

Data was collected in two phases. In the first phase, the respondents were asked to report in a diary up to five trips performed during one given day, their associated use of advanced information systems, and their socio-economic characteristics. The usual set of diary question was expanded to include items about the use of information systems, trip planning, time constraints, the route taken and alternative routes. It was clearly more difficult for the respondents than the usual diary. The revealed preference (RP) questionnaire included a question about the respondent's willingness to participate in the second phase of the study, involving a stated preferences (SP) experiment based on the answers in the RP diary. Each phase was separately pre-tested for response behavior and question quality. The surveys were undertaken in the spring (pre-test RP), summer (main study RP) and autumn (pre-test and main study SP) of 2003.

Three groups were targeted:

- commuters and car drivers in the French speaking canton Vaud. The addresses were provided by SIEMENS and the automobile club, TCS, which sent our diaries and reminders;
- commuters and car drivers in the German speaking canton Zürich. The addresses were provided by the automobile club, TCS, which sent our diaries and reminders;
- owners of a second home in Ticino from the German speaking part of the country, as they are very likely to undertake long-distance leisure journeys. The diary was adjusted to ask about the last relevant journey. The sample was constructed from public records about the owners of second homes in this canton south of the Alps.

The last group was designed to obtain long trips (typically, Zürich-Lugano represents 215km), as the impact of travel information is believed to be more significant for long distance trips.

The response to the RP survey is summarized in Table 1. A questionnaire was not considered useful if the description of the trips was not detailed enough, or if the longest reported trip was shorter than 7 km, a distance deemed necessary for information systems to have an impact on drivers' behavior. The value 7 km has been chosen to keep most inter-city trips in the sample.

Table 1: Pre-test and main RP surveys: Response behaviour.

Response	*Vaud*	*Zürich*	*Ticino*	*Total*
Total sent	826	600	323	1749
Total received	232	195	147	574
Without reminder	180	110	62	352
After reminder	52	85	85	222
Usable	223	182	137	542
Share of usable responses [%]	27	30	42	31

The response rates are low, both because only one reminder was possible and because of the complexity of the diary. The contrast between the travelers to the Ticino, for whom a congested journey is a regular occurrence and who already benefit from radio-distributed information, and the rest of the sample is striking. The increased response indicates an increased interest. The TCS based sample includes persons not working, as well as those never faced with congestion in the more rural parts of the respective cantons. Given that the changes between pre-test and main study were minor we included the usable responses from the pre-tests for the further analysis.

The stated preferences experiments were generated based on the longest reported trip (referred to as the "reference trip" in the rest of the paper) of each respondent. The orthogonal experimental design generated by SPSS had been cleaned, so that no dominated choices remained. Each respondent received seven hypothetical pre-trip choice situations (route and mode choice) and seven hypothetical en-route choice situations (route choice only). In the pre-trip case, we assume that traffic information is available two hours before the trip starts. Three alternatives were presented in each case: the base alternative, an alternative recommended by the information system and a realistic public transportation alternative derived from the official timetable. The attribute values of the base alternative are based on those of the reported trip, in order to create a realistic choice context. The attributes of the two other alternatives were based on an orthogonal experimental design corrected for dominant alternatives.

The attributes for the road-based alternatives are

- Departure time
- Estimated non-congested travel time
- Estimated congested travel time
- Estimated total travel time (the sum of the previous two)
- Percentage of error for the predicted times,
- Arrival time,
- Cost (operating costs including fuel, oil and maintenance).

Note that the percentage of error for the predicted times is meant to capture the overall perceived reliability of the information system.

The attributes of the public transportation alternative are

- Departure time from the closest public transportation stop
- Travel time to the final stop (closest to the destination)
- Arrival time at the final stop (the sum of the two previous)
- Fare (accounting for yearly passes and specific discounts)

We excluded the public transport access and egress time to reduce the complexity of the presentation and because it is generally fixed and not under control of the service operator.

Having described alternatives in the pre-trip context, an hypothetical situation is obtained by giving realistic numerical values to the different characteristics of the above alternatives.

These values are calculated based on information about the reference trip which has been described by respondents in the RP phase of the survey.

Desired arrival time obtained by taking arrival time described for the reference trip and subtracting the possible minutes of delay or adding the possible minutes of early arrival.

Free-flow travel time for the reference trip calculated by using the software package "Route 66 2003 pour l'Autriche et la Suisse" allowing for door-to-door planning of itineraries. Note that we provided to the software the departure point, the destination as well as intermediate points described in the RP questionnaire.

Distance for the reference trip provided by the software mentioned above once the itinerary has been calculated.

Car cost per kilometer taking into account fuel consumption, oil consumption, and maintenance costs with regard to the car used in the reference trip.

Departure time, departure station and stop station by public transportation On the basis of the departure point and the destination for the reference trip, we have used the CFF website (Swiss railways company www.sbb.ch/en) which allows for door-to-door planning in order to determine the best alternative by public transports. The arrival time at the end station was chosen such that it would allow to reach the destination at the desired time, accounting for the walking time between the end station and the final destination. The departure time and travel time for the public transportation alternatives were directly derived from this information.

Cost by public transportation The price of the train ticket was obtained from CFF website, taking into account possible discounts available to each respondent. For the rest of the trip (bus, subway, …), we have used an experimental formula which is classical in such studies in Switzerland:

$$2.5 \log(\min(1, \text{length of the remaining of the trip}))$$

The numerical values used to describe alternatives of the pre-trip choice context have been obtained by using the factors contained in Table 2.

The columns of this table are labeled as follows:

NBR is the identifier of a set of factors.

CF1 represents the congested travel time on route 1 and it is expressed in minutes.

ERROR1 represents the error on information predicted for route 1 and it is expressed in percentage.

FF2 represents the additional free-flow (non-congested) travel time for route 2 and it is expressed in minutes.

CF2 represents the congested travel time for route 2 and it is expressed in minutes.

ERROR2 represents the error on information predicted for route 2 and it is expressed in percentage.

COST2 represents the multiplying factor for the cost of the trip on route 2 and it is expressed in percentage.

PTT represents the multiplying factor for the travel time by public transportation and it is expressed in percentage.

TRADEOFF tells us if the set of factors gives rise to a choice situation involving a trade-off or not: 1 if the choice requires a trade-off, 0 otherwise.

Table 2: Factors for pre-trip experimental design.

NBR	CF1	ERROR1	FF2	CF2	ERROR2	COST2	PTTT	TRADEOFF
1	10	5	18	10	8	110	85	0
7	10	5	18	5	12	90	85	1
29	15	2	18	10	3	110	85	0
27	10	2	8.5	10	8	110	100	0
8	15	2	18	5	3	90	85	1
13	10	2	8.5	5	12	90	90	1
19	15	5	8.5	10	3	110	90	1
21	15	5	8.5	5	3	90	100	1
3	10	2	4	0	3	90	85	1
10	10	5	4	0	3	90	90	0
17	10	2	4	0	3	110	85	1
18	10	5	4	0	3	110	100	1
31	25	2	18	0	3	90	100	1
15	25	2	18	0	3	110	90	1
28	15	2	4	0	8	90	100	1
32	15	5	4	0	8	90	85	1
6	25	2	4	10	12	90	85	1
2	25	5	4	10	12	90	100	1
16	15	2	4	0	12	110	90	1
20	15	5	4	0	12	110	85	1
4	25	2	4	5	8	110	85	1
24	25	5	4	5	8	110	90	1
26	25	5	8.5	0	3	90	85	0
23	25	5	8.5	0	3	110	85	1
25	45	5	18	0	8	90	90	0
22	45	5	18	0	12	110	100	1
9	45	2	4	10	3	90	90	0
5	45	5	4	10	3	90	85	0
14	45	2	4	5	3	110	100	1
11	45	5	4	5	3	110	85	1
12	45	2	8.5	0	8	90	85	0
30	45	2	8.5	0	12	110	85	1

Among the 32 possible sets of factors in Table 2, we have kept only 23 sets presenting a trade-off. For each respondent, we chose randomly 7 sets of factors.

We present the way these values were actually computed. In Tables 3, 4 and 5, the column on the left contains the attributes of the alternative and the column on the right describes how they were computed. Information in *italic* corresponds to information calculated on the basis of the reference trip and information in **bold** comes from Table 2.

Table 3: Computation of attributes for route 1.

Route 1	
Departure time	*Desired arrival time* - estimated total travel time
Estimated non-congested travel time	*Free-flow travel time for the reference trip*
Estimated congested travel time	**CF1**
Estimated total travel time	Sum of the previous two
Predicted arrival time	*Desired arrival time*
Error on predictions	**ERROR1**
Cost	*Distance for the reference trip* × *Car cost per kilometer*

Table 4: Computation of attributes for route 2.

Route 2	
Departure time	*Desired arrival time* - estimated total travel time
Estimated non-congested travel time	*Free-flow travel time for the reference trip* + **FF2**
Estimated congested travel time	**CF2**
Estimated total travel time	Sum of the previous two
Predicted arrival time	*Desired arrival time*
Error on predictions	**ERROR2**
Additional distance	**FF2** × 60 km/h
Cost	(*Distance for the reference trip* + additional distance) × *Car cost per kilometer* × (**COST2**/100)

Table 5: Computation of attributes for public transportation.

Public transportation	
Departure time	*Departure time by public transportation*
Estimated travel time	*Duration* × (**PTTT**/100)
Predicted arrival time	Departure time + estimated travel time
Cost	*Cost by public transportation*

In the en-route case, we assume that traffic information is available during the trip. We also suppose that the radio is turned on and that there are VMS along the route. Two alternatives are included: the base alternative and alternative recommended by the information system. Their attributes are

- Estimated travel time to the destination from the current location
- Percentage of error on the predicted time
- Type of road to the destination: motorway and similar (labeled *national*), other roads (labeled *non-national*), or both,
- Source of information: Radio or Variable Message Signs (VMS)

The numerical values associated with the attributes described above are chosen in the Table 6.

Table 6: Factors for on-trip experimental design.

NBR	*TT1*	*ERROR1*	*MIX1*	*SOURCE1*	*TT2*	*ERROR2*	*MIX2*	*SOURCE2*	*TRADEOFF*
1	25	10	2	2	25	10	1	2	1
2	30	2	2	1	15	15	0	1	1
3	45	2	1	2	15	10	0	2	0
4	25	2	1	1	35	5	1	2	1
5	45	10	1	2	15	15	2	1	1
6	25	10	1	1	35	10	0	1	1
7	30	2	0	2	35	15	1	1	1
8	25	10	0	1	15	10	2	1	1
9	30	10	1	1	25	5	1	1	0
10	45	5	2	1	35	5	2	1	0
11	25	5	2	2	25	15	0	1	1
12	30	10	0	2	35	5	0	1	1
13	45	10	2	1	35	15	0	2	1
14	30	5	0	2	35	10	2	2	1
15	30	2	1	1	25	15	2	2	1
16	45	2	0	1	25	10	2	1	1
17	30	5	2	1	15	10	1	1	0
18	30	5	1	1	25	10	0	1	0
19	25	5	0	1	15	15	1	2	1
20	45	5	0	1	25	5	0	2	0
21	25	2	2	2	25	5	2	1	1
22	45	2	2	1	35	10	1	1	1
23	45	5	1	2	15	5	1	1	0.5
24	30	10	2	1	15	5	2	2	0.5
25	25	5	1	1	35	15	2	1	0
26	25	2	0	1	15	5	0	1	1
27	45	10	0	1	25	15	1	1	1

The information contained in this table is:

NBR is the identifier of the set of factors.

TT1 represents the remaining travel time on route 1 and it is expressed in minutes.

ERROR1 represents the error on predictions for route 1 and it is expressed in percentage.

MIX1 gives the type of road to the destination on route 1 using the following coding: 0 for *national* roads, 1 for Mix of *national* and *non-national* roads, and 2 for *non-national* roads.

SOURCE1 gives the source of information on route 1 using the following coding: 1 for Radio and 2 for VMS.

TT2 represents the remaining travel time on route 2 and it is expressed in minutes.

ERROR2 represents the error on predictions for route 2 and it is expressed in percentage.

MIX2 gives the type of road to the destination on route 2 using same coding as MIX1.

SOURCE2 gives the source of information on route 2 using the same coding as SOURCE1.

TRADEOFF tells us if the set of factors gives rise to a choice situation involving a trade-off or not: 1 if the choice requires a trade-off, 0.5 if there is no trade-off and it is not straightforward to identify it, and 0 if there is obviously no trade-off.

Among the 27 possible sets of factors in Table 6, we have kept only 20 sets presenting a trade-off. For each respondent, we chose randomly 7 sets of factors.

The response to the SP survey is summarized in Table 7. A further 21 usable SP returns were obtained from the participants of the RP pre-test.

Table 7: Main SP survey: Response behaviour.

Response	*Vaud*	*Zürich*	*Ticino*	*Total*
Total sent	103	91	86	280
Total received	71	65	72	208
Without reminder	52	31	36	119
After 2 reminders	19	34	36	89
Usable (en-route model)	65	63	66	194
Usable (pre-trip model)				186
Share of usable responses [%]	63	69	77	69

The response is a satisfactory 69%, which is normal after respondents have committed themselves to further participation. Table 14 compares the samples' characteristics with the Mikrozensus 2000, the national travel survey (Bundesamt für Raumentwicklung and Bundesamt für Statistik, 2001) for the usable 542 responses from the RP, and for the 186 SP questionnaires actually used in the pre-trip model. The shift in the sample structure is noticeable. While this shift is not a problem for parameter estimation[1], it is worth keeping it in mind. It reminds us, just how difficult SP experiments are and that SP designers should find new ways to present and construct the experiments. It also needs to be kept in mind during application, as any result will then need to be reweighted to the population means.

3. En-route model

A mixed logit model (see Train, 2003) for panel data has been estimated using the software package Biogeme (Bierlaire, 2003, Bierlaire, 2005). The specification of the two linear-in-parameters utility functions is reported in Table 8, where "radio" is 1 if information is received by the radio, 0 otherwise; "VMS" is 1 if information is received by VMS, 0 otherwise; "non-national" is 1 if the trip to the destination is using non-national roads, 0 otherwise; "frequent_usage" is 1 if the traveler frequently uses the radio to get traffic information, 0 otherwise; "unfrequent_usage" is "1-frequent_usage", that is 1 if the traveler does not frequently use the radio to get traffic information, 0 otherwise. The probability for individual n of choosing alternative i is given by

$$P_n(i \mid \{i,j\}) = \int_{\xi_n} \prod_t \frac{e^{V_{int} + \sigma_{\text{panel}}\xi_n}}{e^{V_{int} + \sigma_{\text{panel}}\xi_n} + e^{V_{jnt}}} f(\xi_n) d\xi_n$$

where the product ranges over all experiments t of individual n, σ_{panel} is an unknown parameter to be estimated, and ξ_n is a standardized normal random parameter $\xi_n \sim N(0,1)$, so that

$$f(\xi_n) = \frac{1}{\sqrt{2\pi}} e^{-\xi_n^{\,2}/2},$$

[1]Exogenous Sampling Maximum Likelihood provides consistent estimates for all parameters, see Manski and Lerman (1977), Manski and McFadden (1981) and Ben-Akiva and Lerman (1985, chap. 8)

and V_{int} the utility associated by individual n to alternative i during experiment t. Note that the term $\sigma_{\text{panel}}\xi_n$ captures unobserved agent effects, constant over experiments.

Table 8: En-route model specification.

	Current route	*Alternative route*
β_{current}	1	0
β_{time}	remaining time	remaining time
$\beta_{\text{error\_radio\_freq}}$	error * radio * frequent _ usage	error * radio * frequent _ usage
$\beta_{\text{error\_radio\_unfreq}}$	error * radio * unfrequent _ usage	error * radio * unfrequent _ usage
$\beta_{\text{error\_vms}}$	error * VMS	error * VMS
$\beta_{\text{non-national}}$	non-national	non-national

A total of 1358 observations have been used (7 questions per respondent, 194 respondents). The estimated parameters are reported in Table 9.

Table 9: Estimated parameters of the en-route model.

Name	*Value*	*Std error*	*t -test*
β_{current}	0.552	0.110	5.015
β_{time}	-0.133	0.012	-10.869
$\beta_{\text{error\_radio\_freq}}$	-0.055	0.016	-3.405
$\beta_{\text{error\_radio\_unfreq}}$	-0.076	0.023	-3.352
$\beta_{\text{error\_vms}}$	-0.078	0.016	-4.938
$\beta_{\text{non-national}}$	-0.270	0.101	-2.679
σ_{panel}	-0.716	0.156	-4.576
$K = 7$			
$L(0) = -940.601$			
$L(\beta^*) = -701.949$			
$\rho^2 = 0.254$			
$\bar{\rho}^2 = 0.246$			

All parameters are significant. We briefly discuss each of them.

β_{current} is the Alternative Specific Constant associated with the first alternative. It is positive as expected. This captures a type of inertia to change.

β_{time} is negative, as expected.

$\beta_{\text{error\_radio\_freq}}$, $\beta_{\text{error\_radio\_unfreq}}$, $\beta_{\text{error\_vms}}$ are all negative, capturing the impact of uncertainty on travelers' choice, as people do not favor alternatives for which imprecise information is available. Comparing the three values, it appears that a same level of error is more penalized for a VMS than for the radio. Also, travelers who currently listen and use traffic information from the radio have a tendency to penalize the errors made by this media less. This could be explained by the fact that travelers have a better experience of radio than VMS.

$\beta_{\text{non-national}}$ is negative, capturing the fact that travelers are reluctant to leave the main road network. However, its absolute value is less than β_{current}, showing that, everything else being equal, travelers prefer their current route on non-national roads, rather than an alternative itinerary using national roads.

σ_{panel} is significant, showing that it was important to include intra-personal effects in the model. Its sign is irrelevant.

Note that we have tried to estimate separate models for each subsample, but they did not appear to be significantly different.

4. Pre-trip models

We have estimated a joint nested logit model, combining a model for the Ticino sample (second home owners) and the rest of the sample (we did not discover any significant difference between the French and German speaking parts). The nested logit model is given by

$$P(i) = P(i \mid m)P(m) = \frac{e^{\mu_m V_i}}{\sum_{j \in C_m} e^{\mu_m V_j}} \frac{e^{\mu \tilde{V}_m}}{\sum_{k \in C} e^{\mu \tilde{V}_k}}$$

with

$$\tilde{V}_m = \frac{1}{\mu_m} \ln \sum_{i \in C_m} e^{\mu_m V_{im}}$$

where i is one of the alternatives in the choice set $C = \{$Route 1, Route 2, Public transportation$\}$, m is the nest containing i, that is either Nest A or Nest B, and C_m is the set of alternatives within nest m. Tables 10 and 12 reports the linear-in-parameter specification of V_i.

The nested logit is a natural modeling approach to capture the correlation between the two car alternatives. Note that a mixed version of this model was also estimated to capture the unobserved agent effect. It appeared that it was not useful for the pre-trip models, as individual characteristics are already captured by fixed coefficients.

A total of 1302 observations have been used (7 questions per respondent, 186 respondents). A total of 34 parameters have been estimated: 2 nest parameters, one scale parameter, 11 parameters specific to the Ticino model, 16 specific parameters to the other model, and 4 parameters common to both models: β_{cost}, β_{error}, $\beta_{\text{radio\_usage}}$ and $\beta_{\text{profession}}$. The joint estimation appeared to be very useful to obtain efficient estimates of the common parameters.

- Initial log-likelihood: $L(0) =$ -1399.63
- Final log-likelihood: $L(\beta^*) =$ -767.245
- Rho-square: $\rho^2 =$ 0.451824

Although jointly estimated, we present the results separately.

Table 10: Specification of the pre-trip model for Ticino.

	Nest A Route 1	Route 2	*Nest B* Public transportation
$\beta_{\text{ASC1-Ticino}}$	1	0	0
$\beta_{\text{ASC2-Ticino}}$	0	1	0
β_{cost}	cost	cost	-
β_{error}	error	error	-
$\beta_{\text{time\_jam1-Ticino}}$	time in jam	-	-
$\beta_{\text{time\_jam2-Ticino}}$	-	time in jam	-
$\beta_{\text{radio\_usage}}$	frequent _ usage	-	-
$\beta_{\text{aware-Ticino}}$	-	aware	-
$\beta_{\text{impact-Ticino}}$	-	impact	-
$\beta_{\text{half\_fare-Ticino}}$	-	-	half-fare ticket
$\beta_{\text{people\_nbr-Ticino}}$	-	-	people
$\beta_{\text{car\_nbr-Ticino}}$	-	-	cars
$\beta_{\text{profession}}$	-	-	manager
$\beta_{\text{income-Ticino}}$	-	-	income(> 8000CHF)
$\beta_{\text{public\_transportation-Ticino}}$	-	-	usage _ percentage

The specification of the Ticino model is reported in table 10, where "frequent_usage" is 1 if the traveler frequently uses traffic information, 0 otherwise; "aware" is 1 if the traveler was informed by radio about the traffic state during the reference trip, 0 otherwise; "impact" is 1 if the traveler has actually used traffic information during the reference trip, 0 otherwise; "half-fare ticket" is 1 if the traveler owns a ticket which entitles to a 50% rebate on all main line services, 0 otherwise; "people" is the number of persons within the traveler's household; "cars" is the number of cars in the household; "manager" is 1 if the traveler is working as a manager or working at home, 0 otherwise; "income(> 8'000 CHF)" is 1 if the monthly household income is above 8'000 CHF[2], 0 otherwise; "usage_percentage" is the percentage of public transportation trips among all trips to the second home.

Note that there is not enough variability in travel time and cost for the public transportation alternative in the Ticino sample, explaining why these attributes are not included in the model.

[2]In 2006, 1 CHF ≈ 0.645€

Table 11: Estimated parameters for the Ticino pre-trip model.

Name	*Value*	*Std error*	*t-test*
β_{cost}	-0.145	0.034	-4.214
β_{error}	-0.021	0.009	-2.209
$\beta_{\text{radio\_usage}}$	0.401	0.125	3.218
$\beta_{\text{profession}}$	-2.297	0.409	-5.613
$\beta_{\text{ASC1-Ticino}}$	12.11	3.225	3.754
$\beta_{\text{ASC2-Ticino}}$	12.67	3.293	3.847
$\beta_{\text{half\_fare-Ticino}}$	2.386	0.862	2.768
$\beta_{\text{income-Ticino}}$	3.186	1.314	2.425
$\beta_{\text{aware-Ticino}}$	-0.354	0.182	*-1.942*
$\beta_{\text{impact-Ticino}}$	0.505	0.196	2.579
$\beta_{\text{people\_nbr-Ticino}}$	-1.210	0.391	-3.094
$\beta_{\text{car\_nbr-Ticino}}$	-1.173	0.446	-2.634
$\beta_{\text{public\_transportation-Ticino}}$	0.190	0.053	3.579
$\beta_{\text{time\_jam1\_Ticino}}$	-0.048	0.014	-3.322
$\beta_{\text{time\_jam2\_Ticino}}$	-0.073	0.025	-2.967
$\mu_{\text{Nest A-Ticino}}$	4.057	0.971	3.147^{*}
λ_{scale}	0.580	0.151	-2.787^{*}

Superscript * means that the t-test is against 1.

The results of the estimation are reported in Table 11. All parameters are significant at the 95% level of confidence, except $\beta_{\text{aware-Ticino}}$. However, the t-test is close to the 1.96 threshold. Therefore, we have decided to keep the parameter in the model.

$\beta_{\textbf{cost}}$ is negative, as expected for a travel cost coefficient.

$\beta_{\textbf{error}}$ is negative, as expected. Same conclusion as in the en-route model.

$\beta_{\textbf{radio\_usage}}$ is positive. It seems to show that the inertia is larger for frequent users of the traffic information at the radio. It is not clear if it is a feature of the model, or if the frequent usage of the radio indeed encourages inertia, because of bad experiences. This requires more investigation.

$\beta_{\textbf{profession}}$ is negative, illustrating the aversion of managers and home-working persons to use public transportation.

$\beta_{\text{ASC1-Ticino}}$ and $\beta_{\text{ASC2-Ticino}}$ are the Alternative Specific Constants. There are positive, illustrating the attractiveness of the car versus public transportation.

$\beta_{\text{half\_fare-Ticino}}$ is positive, showing a propensity to use public transportation by the owners of a half-fare ticket.

$\beta_{\text{income-Ticino}}$ is positive, indicating the higher willingness of higher income travelers to shift, as they are better able to afford the costs of rail travel and of taxi as well as of related services after their journey. It is an indirect indicator of their higher value of time.

$\beta_{\text{aware-Ticino}}$ is negative, capturing an inertia, a preference toward the current alternative for more informed people. This is consistent with the comments about $\beta_{\textbf{radio\_usage}}$ (note that $\beta_{\text{aware-Ticino}}$ is in the utility function of the alternative route).

$\beta_{\text{impact-Ticino}}$ is positive, showing that people who have used traffic information to modify their decision during the reference trip have a propensity to change. It seems to support the assumption about the bad experience proposed in the analysis of the sign of $\beta_{\textbf{radio\_usage}}$.

$\beta_{\text{people\_nbr-Ticino}}$ is negative. Indeed, the marginal cost of one more person in the family is much more important for public transportation than for private transportation.

$\beta_{\text{car\_nbr-Ticino}}$ is negative. Indeed, the more cars in the household, the less likely the use of public transportation.

$\beta_{\text{public\_transportation-Ticino}}$ is positive, showing an attractivity for the public transportation by the most frequent users of public transportation.

$\beta_{\text{time\_jam1\_Ticino}}$ and $\beta_{\text{time\_jam2\_Ticino}}$ are both negative. The sensitivity to the predicted time in jam for the alternative route is more important. Note also that the free flow travel time did not appear significant in the model. It is due to the very low variability of this attribute for the Ticino sample.

The specification of the commuters model is reported in Table 12, where "d(0-50)" is 1 if the trip length is between 0 and 50km, 0 otherwise; "d(50-100)" is 1 if the trip length is between 50 and 100km, 0 otherwise; "frequent_usage" is 1 if the traveler frequently uses traffic information, 0 otherwise; "aware" is 1 if the traveler was informed by radio about the traffic state during the reference trip, 0 otherwise; "manager" is 1 if the traveler is working as a manager or working at home, 0 otherwise; "early_arrival" is the number of minutes between the arrival by public transportation and the scheduled arrival time; "fare" is the public transportation fare; "timetable" is the scheduled travel time from the timetable; "age(0-40)" is 1 if the traveler is younger than 40, 0 otherwise; "car_as_mode" is 1 if the car was the chosen mode for the reference trip, 0 otherwise; "car_availability" is 1 if a car is available to the traveler, 0 otherwise[3]; "car_type" is 1 if a company car has been used during the reference trip, 0 otherwise; "kilometers" is the number of kilometers traveled by car per year.

[3]Car availability is understood by respondents as a question about car ownership. Other cars can still be available to license holders, such as those from the popular car-sharing firm "Mobility" or those of family and friends.

Table 12: Specification of the pre-trip model for commuters.

	Nest A		*Nest B*
	Route 1	Route 2	Public transp.
β_{ASC1}	1	0	0
β_{ASC2}	0	1	0
β_{cost}	cost	cost	-
β_{error}	error	error	-
$\beta_{time\_jam\_short}$	time in jam * d(0-50)	time in jam * d(0-50)	-
$\beta_{time\_jam\_medium}$	time in jam * d(50-100)	time in jam * d(50-100)	-
$\beta_{time\_free\text{-}short}$	fr. flow time * d(0-50)	fr. flow time * d(0-50)	-
$\beta_{time\_free\text{-}medium}$	fr. flow time * d(50-100)	fr. flow time * d(50-100)	-
β_{radio_usage}	frequent _ usage	-	-
$\beta_{internet\_usage}$	frequent _ usage	-	-
β_{aware}	-	aware	-
β_{early}	-	-	early arrival
β_{fare}	-	-	fare
$\beta_{timetable}$	-	-	timetable
$\beta_{profession}$	-	-	manager
β_{age}	-	-	age(0-40)
β_{mode}	-	-	car _ as _ mode
$\beta_{availability}$	-	-	car _ availability
β_{type}	-	-	car _ type
β_{kms}	-	-	kilometers

The results of the estimation are reported in Table 13. All parameters are significant to the 95% level of confidence, except $\beta_{\text{internet\_usage}}$ and β_{fare}. However, the t-tests are close to the 1.96 threshold value, and we have decided to keep them in the model.
Parameters $\beta_{\textbf{cost}}$, $\beta_{\textbf{error}}$, $\beta_{\textbf{radio\_usage}}$ and $\beta_{\textbf{profession}}$ have been discussed above.

β_{ASC1} and β_{ASC2} are the Alternative Specific Constants for the two first alternatives. They are negative, which is difficult to interpret. Indeed, the cost and time parameters are alternative specific. For instance, if we compare alternatives with a cost of 10 CHF, a travel time of 50 minutes (both for car and public transportation), the probability of choosing the public transportation is significantly smaller than the probability to choose the car, as expected.

β_{mode} is negative, meaning that people reporting to use their car have a preference toward the car, so it affects negatively the public transportation alternative.

$\beta_{\text{availability}}$ is negative, meaning that people who have a car available have a tendency to use it, so it affects negatively the public transportation alternative.

β_{type} is negative, for the same reason as described above.

$\beta_{\text{internet\_usage}}$ is negative, showing that people who use Internet to access the information have a propensity to switch route. It is interesting to note that the parameter $\beta_{\text{radio\_usage}}$ is positive in comparison.

β_{aware} is positive, showing that people who are aware of alternative routes, have a propensity to switch. Note that, in comparison to the Ticino model, the commuter model deals with situations where the number of feasible routes is usually higher.

β_{age} is negative, showing that people younger than 40 have a preference for the car.

β_{kms} is negative, showing that the more the car is used per year, the less appealing public transportations are.

β_{early} is negative, capturing the inconvenience of mismatch between the actual arrival time and desired arrival time when using public transportation.

β_{fare} is negative, as expected for a cost coefficient. Note that it is less negative than the cost coefficient for the car alternatives.

$\beta_{\text{timetable}}$ is negative, as expected for a travel time coefficient.

$\beta_{\text{time\_jam\_medium}}$, $\beta_{\text{time\_jam\_short}}$, $\beta_{\text{time\_free\_medium}}$, $\beta_{\text{time\_free\_short}}$ are all negative, as expected. As discussed below, although they have the correct sign, we are somehow suspicious about the parameters estimates for the short trips. Indeed, there are plenty of context-specific constraints associated with short trips that are not accounted for in this model. The fact that travel time in free flow conditions is more penalized than travel time in jam is counter-intuitive. In the "medium" case (trips between 50 and 100km), travel time in traffic jam is more penalized than travel time in free flow conditions.

Table 13. Estimated parameters for the pre-trip commuters model.

Name	*Value*	*Std error*	*t-test*
β_{cost}	-0.145	0.034	-4.214
β_{error}	-0.021	0.009	-2.209
β_{radio_usage}	0.401	0.125	3.218
$\beta_{profession}$	-2.297	0.409	-5.613
β_{ASC1}	-3.054	1.144	-2.670
β_{ASC2}	-2.780	1.141	-2.436
β_{mode}	-1.390	0.297	-4.683
$\beta_{availability}$	-3.659	1.081	-3.386
β_{type}	-3.016	1.093	-2.760
$\beta_{internet\_usage}$	-0.239	0.125	*-1.910*
β_{aware}	0.708	0.156	4.523
β_{age}	-1.197	0.341	-3.513
β_{kms}	-0.041	0.012	-3.420
β_{early}	-0.033	0.011	-3.166
β_{fare}	-0.037	0.022	*-1.674*
$\beta_{timetable}$	-0.066	0.009	-7.019
$\beta_{time\_jam\_medium}$	-0.088	0.019	-4.543
$\beta_{time\_jam\_short}$	-0.084	0.015	-5.582
$\beta_{time\_free\text{-}medium}$	-0.066	0.011	-5.752
$\beta_{time\_free\text{-}short}$	-0.122	0.015	-8.081
$\mu_{\text{Nest A}}$	1.951	0.311	3.051^{*}
λ_{scale}	0.580	0.151	-2.787^{*}

Superscript * means that the t-test is against 1.

It is interesting to analyze the Value Travel Time Savings (VTTS), as provided by the commuter model. As we use a linear specification, this quantity is simply given by the ratio between the travel time coefficient and the travel cost coefficient.

VTTS (CHF/min)	*Free flow*	*in Jam*
Short distance ($\leq$ 50km)	*50.7*	34.8
Medium distance ($>$ 50km)	27.3	36.5

The values for the medium distances are comparable with the results provided by Koenig et al. (2004): 35.9 CHF, assuming an income of 10’000 CHF/month and a business trip of 75km. However, for the short distance, our values are significantly higher. Koenig et al. (2004) obtain 24.22 CHF, assuming an income of 10’000 CHF/month and a business trip of 25km. Clearly, in our model, we have a low granularity of distances and travel times for short distance trips. The approach by Koenig et al. (2004) is more appropriate to estimate VTTS for short trips. Anyway, the value 50.7 CHF, reported in italic above, does not seem valid to us. We believe the time and cost parameters capture other effects associated with short trips, that should be explicitly analyzed.

Note that it appeared that adding an error component to capture the agent effect was not useful for the pre-trip models, as individual characteristics are already captured by fixed coefficients.

5. Simulation

The models presented above are based on stated preference data. Like any such models, they cannot directly be used for the prediction of market shares, but are very useful for policy analysis using “what-if” scenarios. We have therefore implemented a simulator based on the estimated models. The simulator is an Excel sheet available from the authors upon request. We have selected here a couple of illustrative examples based on the en-route model, to give a flavor of the results.

Figure 1 is a screen-shot of the simulator for the En-route model, where the probability of the two alternatives is presented as a function of the predicted travel time on the alternative route, ranging from 15 to 35 minutes. In this scenario, the predicted travel time on the usual route is assumed to be 30 minutes, the error on the information is 5 minutes for both alternatives, the source of information is radio for the usual route and VMS for the alternative route, and the individual is assumed to have a daily usage of the radio. The type of road is “national” for both alternatives. Among other things, it is interesting to note that the 50% probability is reached when the alternative route is 25 minutes, compared to the 30 minutes on the usual route. Also, if both routes are said to be 30 minutes, the probability to switch route is only about 34%, illustrating the inertia to change.

Figure 2 is also a screen-shot of the simulator for the En-route model, where the probability of the two alternatives is presented as a function of the estimated error on the alternative route, ranging from 5 to 15 minutes. In this scenario, the error on the information about the usual route is assumed to be 10 minutes, the predicted travel time is 35 minutes on the usual route and 30 minutes on the alternative route, the source of information is radio for the usual route and VMS for the alternative route, and the individual is assumed to have a daily usage of the radio. The type of road is “national” for both alternatives.

Note that 50% probability is reached for a value of about 8.5. If both errors are 10 minutes, the probability to switch is about 47%.

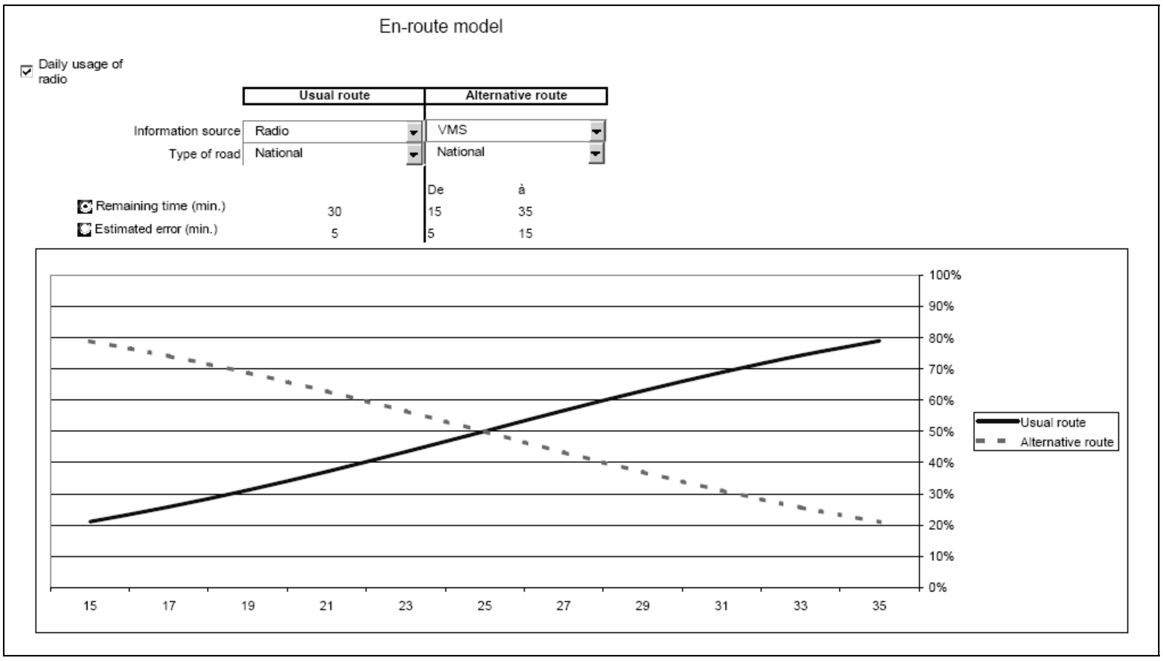

Figure 1: First scenario.

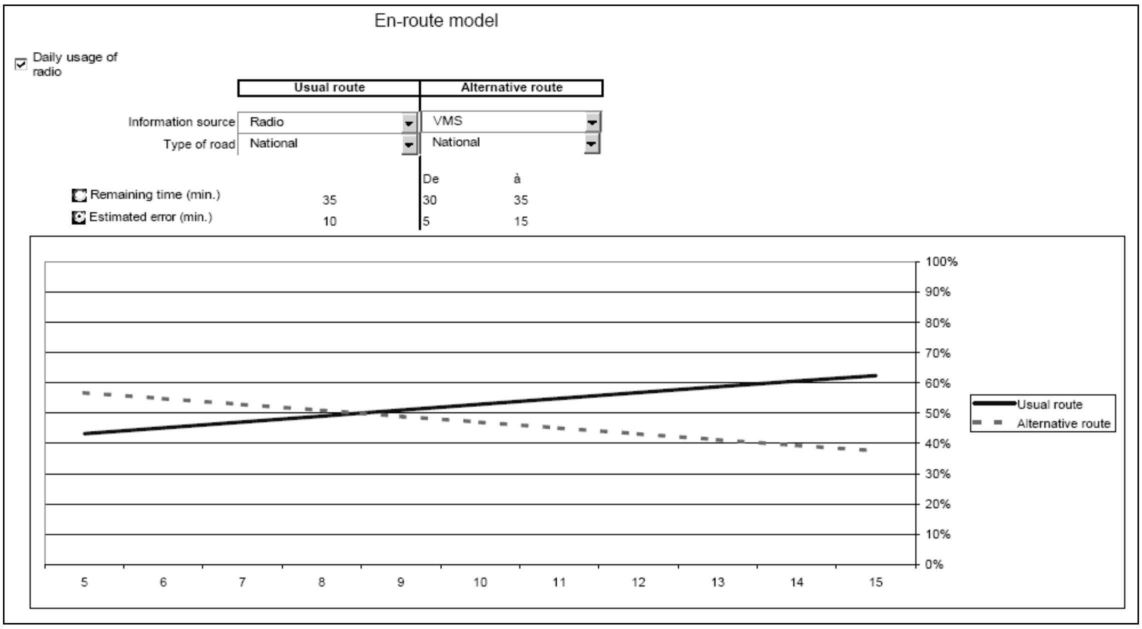

Figure 2: Second scenario.

Finally, Figure 3 illustrates the same scenario as Figure 2, except that the information about the usual route is obtained from a VMS instead of the radio. We note that the 50% value shifts from about 8.5 to about 11.5, illustrating that travellers have less confidence in VMS, everything else being equal.

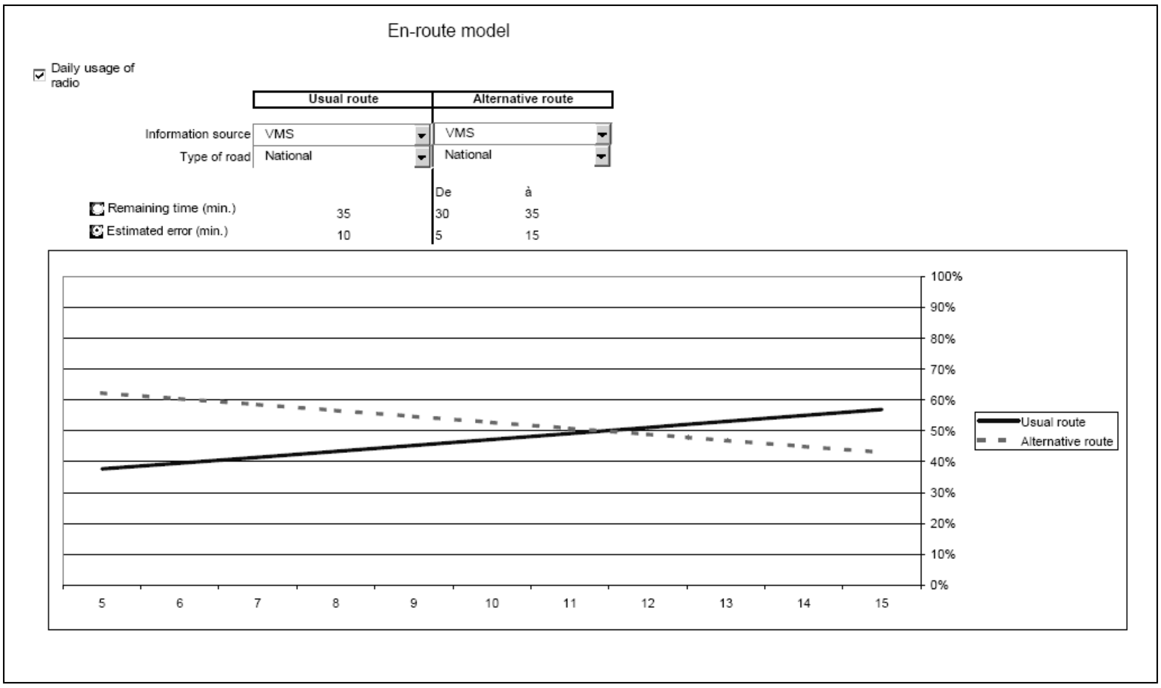

Figure 3: Third scenario.

6. Conclusions

We have estimated a model capturing the response to en-route information, and two models capturing the response to pre-trip information, based on data collected in Switzerland during 2003.

The en-route model enables to measure the level of inertia to en-route switching and the preference toward national roads, among other things. It has been illustrated using some examples of the simulator.

In the pre-trip models, the heterogeneity of the sample has been emphasized. Indeed, the socio-economic characteristics play a significant role in these models. First, a model for the owners of a second home in Ticino has been estimated. It allows to capture and predict the important role of traffic information, and of public transportation in this specific context, and may help to design appropriate focused policies for long distance, non-work related, trips. Second, a model for commuters has been estimated. While the model seems valid for medium distance trips, we have significant suspicions of its validity for short distance trips. More investigation is necessary to better understand the constraints and the choice context of such trips. The attributes included in our SP experiments are probably not sufficient to explain them.

The models that have been estimated are advanced random utility models. The en-route model is a mixed binary logit model with panel data. The pre-trip models are heterogeneous nested logit models. They have all been estimated using the Biogeme software package.

We conclude by mentioning some potentially interesting streams of investigations:

- The diversity of behaviors emphasized in this study suggests the development of regular surveys to better understand this phenomenon. The cost of collecting such data being important, organizing regular surveys would also bring very valuable information at a low marginal cost. Moreover, it would allow to analyze the behavioral dynamics, in order to understand how travelers change their behavior as they experience the use of ITS.

- The abnormally high VTTS for short distance trips should be investigated. For instance, mixed GEV models could be considered, along the lines discussed by Hess et al. (2005).
- It appears from the models that the level of error in an information system significantly influences its perception. However, this concept has been kept at an abstract level in our surveys, and would deserve a deeper analysis.
- Our sample is biased toward private car users. A more systematic analysis of mode choice would require more public transportation users in the sample.

Table 14: Socio-economic characteristics.

	Nat. Travel survey 2000	Usable RP		SP used	
Sex					
Male	46.4%	354	65.3%	122	65.6%
Female	53.7%	188	34.7%	64	34.4%
Education					
Primary+lower secondary	34.0%	30	5.5%	4	2.2%
Vocational training	40.7%	252	46.5%	76	40.9%
A-level, tertiary	25.3%	260	48.0%	106	57.0%
Working status					
None	47.4%	113	20.8%	36	19.4%
Employed	46.8%	358	66.1%	126	67.7%
Self-employed	5.8%	71	13.1%	24	12.9%
Driving license					
Yes	78.4%	493	91.0%	176	94.6%
No	21.6%	49	9.0%	10	5.4%
Railpass "General abonment"					
Yes	6.0%	61	11.3%	20	10.8%
No	94.0%	481	88.7%	166	89.2%
Half-fare card					
Yes	34.8%	379	69.9%	138	74.2%
No	63.2%	163	30.1%	48	25.8%
Income [CHF]					
< 2K	3.1%	5	0.9%	0	0.0%
2K-4K	14.8%	34	6.3%	8	4.3%
4K-6K	22.5%	90	16.6%	23	12.4%
6K-8K	16.2%	125	23.1%	46	24.7%
8K-10K	9.7%	109	20.1%	51	27.4%
10K-12K	5.2%	51	9.4%	21	11.3%
12K-14K	2.6%	42	7.7%	17	9.1%
> 14K	4.0%	45	8.3%	17	9.1%
No response	21.9%	41	7.6%	3	1.6%

The use of demand models is more and more critical in the ITS context. The models estimated in this paper allows to better understand and predict the response of travelers to traffic information. From a system design point of view, the most notable conclusions of our study are linked to

- the willingness of the respondents to act when informed
- the impact of errors in the information

The willingness to act invites further investment into information provision, both en-route and pre-trip. It invites specifically investment in information with little error (see the relatively high trade-offs, which the respondents' parameters imply). This is a real challenge, as error-free information is based on both fast and reliable data collection, as well as on a system which can anticipate the response of the drivers to any information.

References

Ben-Akiva, M., Bierlaire, M., Burton, D., Koutsopoulos, H. and Mishalani, R. (2001) "Network state estimation and prediction for real-time transportation management applications", *Networks and Spatial Economics* 1(3/4), pp. 293– 318, 19

Ben-Akiva, M. E. and Lerman, S. R. (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*, MIT Press, Cambridge, Ma.

Ben-Akiva, M., Koutsopoulos, H. N., Mishalani, R. and Yang, Q. (1997) "Simulation laboratory for evaluating dynamic traffic management systems", *Journal of Transportation Engineering* 123(4), pp. 283–289.

Bierlaire, M. (2003) *BIOGEME: a free package for the estimation of discrete choice models*, Proceedings of the 3rd Swiss Transportation Research Conference, Ascona, Switzerland. www.strc.ch.

Bierlaire, M. (2005) *An introduction to BIOGEME* version 1.4. biogeme.epfl.ch.

Bundesamt für Raumentwicklung and Bundesamt für Statistik (2001) *Mobilität in der schweiz, ergebnisse des mikrozensus 2000 zum verkehrsverhalten*, Bern and Neuenburg.

Chatterjee, K., Hounsell, N. B., Firmin, P. E. and Bonsall, P. W. (2002) "Driver response to variable message sign information in London", *Transportation Research* Part C 10(2), pp. 149–169.

Conquest, L., Spyridakis, J., Haselkorn, M. and Barfield, W. (1993) "The effect of motorist information on commuter behavior: Classification of drivers into commuter groups", *Transportation Research* Part C.

Dia, H. (2002) "An agent-based approach to modelling driver route choice behaviour under the influence of real-time information", *Transportation Research* Part C 10(5–6), pp.331–349.

Hess, S., Bierlaire, M. and Polak, J. (2005) "Estimation of value of travel-time savings using mixed logit models", *Transportation Research* Part A 39(3), pp. 221– 236.

Karthik, S. and Mahmassani, H. S. (2003) "Analyzing heterogeneity and unobserved structural effects in route-switching behavior under ATIS: a dynamic kernel logit formulation", *Transportation Research* Part B 37(9), pp. 793– 814.

Khattak, A. J., Yim, Y. and Prokopy, L. S. (2003) "Willingness to pay for travel information", *Transportation Research* Part C 11(2), pp. 137–159.

Khattak, A., Polydoropoulou, A. and Ben-Akiva, M. (1996) "Modeling revealed and stated pretrip travel response to advanced traveler information systems", *Transportation Research Record* 1537: pp. 46–54.

Koenig, A., Abay, G. and Axhausen, K. (2004) Zeitkostenansaetze im personenverkehr, Schriftenreihe 1065, Bundesamt fr Strassen, UVEK, Bern. Final report for SVI 2001/534.

Mahmassani, H. S. and Liu, Y.-H. (1999) "Dynamics of commuting decision behaviour under advanced traveller information systems", *Transportation Research* Part C 7(2–3), pp. 91–107.

Manski, C. and Lerman, S. (1977) "The estimation of choice probabilities from choice-based samples", *Econometrica* 45, pp. 1977–1988.

Manski, C. and McFadden, D. (1981) "Alternative estimators and sample designs for discrete choice analysis", in Manski, C. and McFadden, D. (eds), *Structural analysis of discrete data with econometric application*, MIT Press, Cambridge, Mass.

Train, K. (2003) *Discrete Choice Methods with Simulation*, Cambridge University Press. http://emlab.berkeley.edu/books/choice.html.

Wardman, M., Bonsall, P. W. and Shires, J. D. (1997) "Driver response to variable message signs: a stated preference investigation", *Transportation Research* Part C 5(6), pp. 389–405.

Zhao, S. (1996) "A study on route choice behavior in response to traffic information using drivers' perception", *PhD thesis*, University of Tokyo, Japan.

A Service Quality experimental measure for public transport

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Abstract

In this paper the importance of service quality attributes for public transport is estabilished by Importance Value calculation. Attribute weights (IV) are calculated by a specific empirical procedure in which a rate is assigned to each attribute according to the preferences of passengers.

Finally, a Service Quality Index (SQI) for measuring the effectiveness of supplied services is calculated according to the main service quality attributes and their weights. This index can be useful to planners to choose more appropriate public transport agencies. Futhermore, it can be used by transport agencies to improve supplied service regarding more convenient service quality attributes.

Keywords: public transport; service quality attributes importance value; service quality index.

Introduction

Over the last few years, the public transport industry in many countries has been involved in a process of deep transformation. At the moment, individual is used more than public transport. This fact causes many problems like traffic congestion, air and noise pollution, energy consumption and therefore serious consequences on the environment.

In Italy, public transport transformation is linked to a normative reform; one of the most important aspects of reform is service management reorganization by changing from a concessionary to a competitive system. Therefore, transit agencies are becoming more competitive and are concerning themselves with service quality and customer satisfaction.

Service quality measurement is one of the most important practical themes for service providers and regulatory agencies, but it also continues to be a challenging research theme.

For these reasons, it is important to identify service quality attributes and to establish their importance and influence on customer behaviour.

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This paper deals with the experimental results of a sample survey conducted on University of Calabria students. Then, a statistical data analysis was carried out.

In addition, a way of identifying the importance of service quality attributes on global customer satisfaction is proposed. Further, a Service Quality Index (SQI) has been calculated, which provides an operationally appealing measure of current or potential service effectiveness.

1. Service quality measure for public transport

Generally, transit agencies have given too much importance to saving money at the expense of service quality levels; therefore they have essentially focused on cost efficiency and cost effectiveness. A measure of cost efficiency is typically defined as produced services (e.g. vehicle kilometres), while a measure of service effectiveness is defined as consumed service (e.g. passenger kilometres) (see figure 1).

However, transit agencies actually have an interest in obtaining a high service quality level, taking into account passengers priorities and requirements (Bertini and El-Geneidy, 2003).

For this reason, the necessity of using techniques to identify the importance of service quality attributes on global satisfaction and to assess service quality, increases.

In the literature there are many techniques for measuring service quality and customer satisfaction, for public transport as in other service industries. These techniques are based on customer evaluation. The evaluation of service quality and customer satisfaction can be obtained according to different methods: by asking customers the perception/satisfaction on service quality, by asking the expectation/importance, or by asking both perception and expectation; in addition, perception can be compared with the zone of tolerance of expectations (the range defined by the maximum desired level and minimum acceptable level of expectations). (Figini, 2003). A rating or ranking of individual service attributes can be asked to customers. Furthermore, a rating on overall satisfaction can be asked.

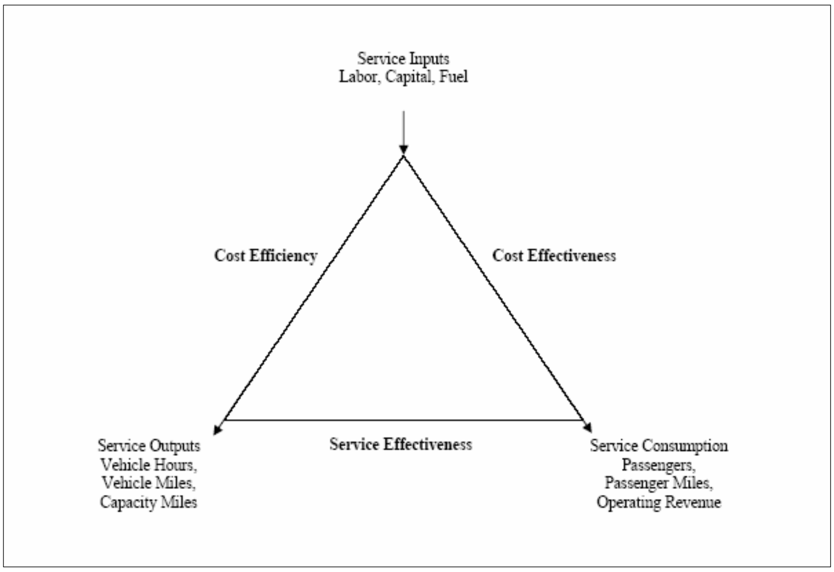


Figure 1: Relationship between efficiency and effectiveness indicators.
Source: Bertini R.L., El-Geneidy A., TRB, 2003.

The techniques for measuring service quality and customer satisfaction can be identified in two different categories.

The first one includes methods of statistical analysis, such as quadrant and gap analysis, factor analysis, scattergrams, bivariate correlation, cluster analysis, and conjoint analysis. Some of these provide an evaluation of the individual service attributes, others provide the relationship of attributes with overall satisfaction.

Many authors have introduced some indexes for measuring overall satisfaction or service quality. On the basis of the method introduced by Kano (Kano, 1984), some indexes (Better, Worse and Quality Improvement) were proposed by Berger (Berger, 1993). One of the best-known indexes is the SERVQUAL, a service quality evaluation method developed by marketing academics. It produces a subjective measure of the gap between expectations and perceptions in five service quality dimensions common to all services. (Zeithaml et alii, 1986). This technique was applied in several research fields, see for example Hartikainen et alii (2003) and Akan (1995). A Customer Satisfaction Index (CSI was adopted by Bhave; this index is calculated by using an importance weighting based on an average of 1. The customers assign a rate of importance (weighting) and a rate of satisfaction (score) to each service attribute. Each weighting is divided by the average of the weightings expressed by customers. In this way, average weightings based on an average of 1 are obtained. Then, a weighted score is calculated for each attribute as a product of score and average weighting. Finally, the CSI is the sum of all weighted scores. (Bhave, 2002). Many others techniques are reported in the literature, see for example Hill (2000), Cuomo (2000), Hill (2003).

The second category of techniques consists in estimation of the coefficients by modelling. The models relate global service quality (dependent variable) to some attributes (independent variables). There are linear models, like multiple regression models, and non-linear models, like the structural equation model (SEM) (Bollen, 1989) and Logit models in which all random components are independently and identically distributed according to a Gumbel random variable (Cascetta, 2001).

Examples of SEM are reported in Vilares, Coelho (2003) and in Grønholdt and Martensen (2005). An ordinal regression technique has been proposed by Siskos et alii (1997).

As far as the authors' know, not many techniques for measuring customer satisfaction and service quality in public transport are reported in the literature.

In the "Handbook for Measuring Customer Satisfaction and Service Quality", published by the Transportation Research Board, the "impact score" technique is described (TRB, 1999). "Impact score" is the impact of each service quality attribute on global customer satisfaction. For each attribute, the sample is divided into two categories, those respondents who have not recently experienced a problem with the attribute and those respondents who have had a recent problem with it. The mean satisfaction rating of each attribute of the two groups of respondents are compared. The difference between the two mean satisfaction rates, called "gap score", is multiplied by the percentage of passengers who have had a problem with an attribute.

An example of modelling for public transport is proposed by Hensher (Prioni and Hensher, 2000; Hensher, 2001; Hensher and Prioni, 2002; Hensher *et alii*, 2003). By the estimation of coefficients of discrete choice models, like Multinomial Logit or Mixed Logit, the importance of service quality attributes on global customer satisfaction is evaluated. A Service Quality Index (SQI) is calculated by using estimated coefficients. This index, as the utility related to each alternative of choice, is calculated like a linear combination of attributes, each one weighted on its importance; each alternative represents a service package. For models calibration the combination of RP (Revealed Preferences) and SP (Stated Preferences) data is used; the major advantage of SP data compared with RP data is that they exploit a more extensive attributes space. Furthermore, today some attributes do not exist on many urban buses so we are unable to estabilish their influence. Thirteen service quality attributes were selected: each attribute varying on three levels. This variation produces different alternatives (bus packages). Attribute weights were estimated according to users choices, and then current and potential service quality levels were calculated. A similar method was proposed by Jones (Swanson et al., 1997), in which a linear regression model for each interviewed user was calibrated; for each coefficient, a mean of estimated coefficients from individual models was calculated. In addition, the monetary value of each attribute was calculated. This value enables the measurement of the user's availability to pay an additional fare for a better service.

The use of these techniques presumes the selection of some service quality attributes. By consulting the literature it is possible to identify a large set of attributes (see, for example, TRB, 1999; Prioni and Hensher, 2000). Generally, all the attributes are grouped in macro-factors defined by one or more attributes. Examples of these are transport network design (e.g. number and regularity of bus stops, having stops near destination), service supply and reliability (e.g. frequency, regularity and punctuality of rides), comfort (e.g. availability of seats on bus, bus overcrowding), fare (e.g. fairness/consistency of fare structure, ease of paying fare), information (e.g. availability of information on schedules/maps, explanation and announcement of delays), safety (e.g. safe and competent drivers, security against crimes), relationship with personnel (e.g. friendly, courteous personnel), customer preservation (e.g. repayment, complaint number), environmental protection (e.g. use of vehicles with low environmental impact), quality of system (quality of stops furniture, cleanliness of bus exterior).

All the attributes contribute to global service quality, each one in a different measure. Therefore there is the necessity to quantify the importance of each one.

2. The sample survey: statistical analysis of results

2.1 Experimental context

A sample survey of the University of Calabria students was conducted. The campus is sited in the urban area of Cosenza, in the South of Italy. It is attended by 32,000 students and 2,000 members of staff approximately (December 2004). Currently the University is served by a bus service, which does not resolve the students' mobility demand in a suitable way; where possible, they prefer to use individual transport, producing congestion both on the access and on the internal campus road networks. In a working day, about 10,000 students travel by bus, 8,800 by urban and 1,200 by extra-urban bus (AA. VV., 2006).

Respondents were asked to provide information about their trip and transport mode to get to the university and, in addition, about some service quality attributes.

Specifically, the part of the interview on service quality is divided into three sections; the first one is addressed to public trasport non-users asked to rank, in descending order, non-use reasons; the second section is addressed to public transport users which were asked to rank use reasons; finally, in the third section, both users and non-users were asked to rank service quality attributes according to their importance. Among the interviewed students there were some of them that are both regular users and non-users, and therefore they have answered all the sections of the interview. The users had the possibility of ranking not all the attributes, but only some of them.

The reasons for public transport non-use to ranking are:

- Long wait at bus stops;
- Overcrowded buses;
- Low frequency;
- Slowness of vehicles;
- Service unreliability;
- Need for transfers;
- Difficulty of carrying loads;
- High fare;
- Poor accessibility to bus stops;
- Other reasons.

The reasons for public transport use to ranking are:

- Inexpensive service;
- Quick service;
- Car nonavailability;
- Lower risk of road accidents;
- Difficulty of car parking;
- Practicality (less tiring trip);
- No driving licence;
- Other reasons.

Service quality attribute to ranking are:

- Frequency;
- Number of bus stops;
- Cleanliness of interior, seats, etc.;
- Comfort on bus;
- Security against crimes on bus;
- Availability of shelter and benches at stops;
- Information on services;
- Availability of seats on bus;
- Other reasons.

The interviews were proposed to a sample of 382 students of all different faculties, who live out of the urban area of Cosenza and who have expressed their choices on the extra-urban public transport services that allow the university campus to be reached. In some cases, access to the campus also involves the use of both urban and extra-urban buses.

The sample is composed of 257 females and 125 males. The age range is between 18 and 37, but 72.5% of the sample is between 19 and 23. About 40% of interviewed students have a low income and about 40% a medium income. The majority of the sampled students lives inside the Cosenza traffic basin (65% of the total). 53% of the students have the possibility of using the car to reach the campus.

The results regarding service quality are reported in the following paragraphs.

2.2 Statistical analysis for public transport non-use reasons

A statistical-descriptive analysis of public transport non-use reasons is performed. Interviewed students who answered this section are 176, out of the 382 students undertaking the interview (sampling rate equal to 14.6%). We consider that the most significant data relate to the first chosen factors. In figure 2 the number of consumers who preferred one of the factors as their first chosen factor is shown.

from an analysis of the stated preferences the main public transport non-use reason proves to be low service frequency (70 preferences on 176, equal to 39.8%), followed by vehicle overcrowding, chosen as the first reason by 15.9% of respondents (28 preferences out of 176). The third chosen factor is slowness of the vehicles (12.5%, 22 preferences out of 176), while approximately 9% of students (16 preferences out of 176) indicated long waits at bus stops and the necessity of transferring to reach their final destination. The other factors were chosen with very small percentages.

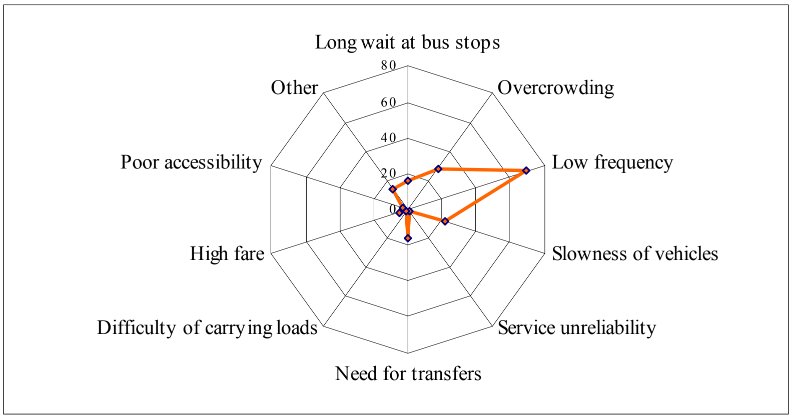


Figure 2: Statistical analysis for public transport non-use reasons.

An additional analysis was made considering all data independently of ranking. In this case, only the times that each factor was chosen are examined and the information about preference level is lost. The results are similar to the previous ones.

2.3 Statistical analysis for public transport use reasons

Similarly, a statistical-descriptive analysis of public transport use reasons is performed. 220 out of 382 sampled students living out of the urban area (sampling rate equal to 18.3%) answered this section.

Also in this case the number of consumers who preferred one of the factors as their first chosen factor is drawn. The headings "car nonavailability" (36.8%, equal to 81 preferences out of 220), "no driving licence" (15.5%, equal to 34 preferences) and "difficulty of car parking" (3.6%, equal to 8 preferences) are excluded from the graph (figure 3); these headings represent the 55.9% of the chosen reasons. In total, 97 preferences are only drawn.

The percentages of stated preferences on the headings excluded from the analysis indicates that public transport is primarily used for reasons not related to service quality, but only to a difficulty in the use of the private car.

Service quality factors that have been significantly chosen are service inexpensiveness, indicated by 45.4% of total (44 preferences out of 97), and practicality in terms of a less tiring trip, chosen by 36.1% of all the consumers (35 preferences out of 97). Additionally, a considerable percentage is represented by lower risk of road accidents, chosen in 10.3% of the cases.

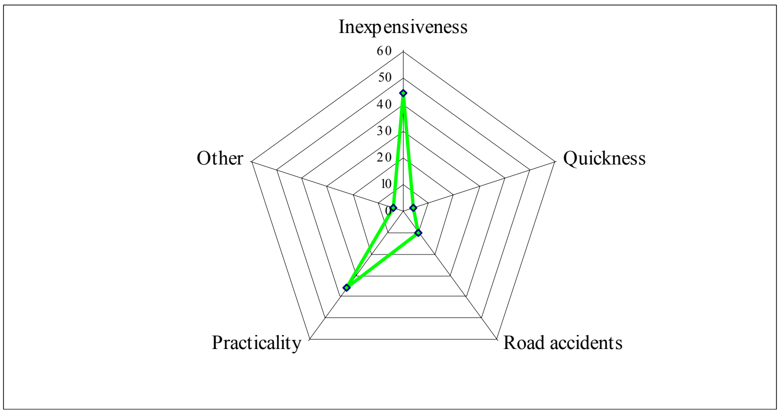


Figure 3: Statistical analysis for public transport use reasons.

2.4 Statistical analysis for service quality attributes

A number of 341 students, out of 382, answered the last section (sampling rate equal to 28.4%). In figure 4 the number of consumers who have indicated one of the listed service quality attributes as their first chosen factor is reported.

The most chosen attributes are frequency (51.3%, 175 preferences out of 341), availability of seats on bus (17.9%, 61 preferences) and number of bus stops (6.2%, 21 preferences). The attribute "cleanliness of the vehicles" is chosen by 4,7% of respondents, while the attribute "information on services" is indicated in small measure (3.5%), because extra-urban public transport passengers are generally habitual and informed.

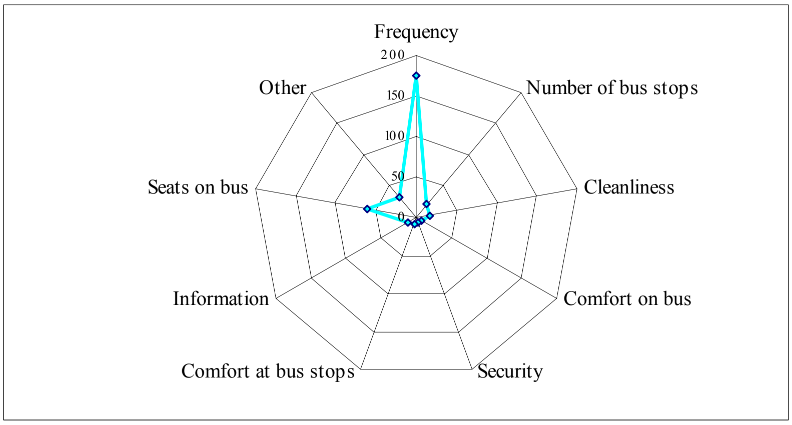


Figure 4: Statistical analysis for service quality attributes.

3. The calculation of Importance Value and of Service Quality Index

Generally, the techniques for measuring service quality and customer satisfaction are based on rating data and calculate the average values of expressed rates to define a classification of service quality attributes (see Impact Score technique) or aggregate index, like CSI and SERVQUAL (TRB, 1999; Hill, 2000; Zeithalm, 1986).

With the aim of determining the relative weights of all the attributes on global customer satisfaction, a technique to calculate an Importance Value (IV) of each service quality attribute is proposed, according only to public transport users stated preferences on some service quality attributes.

In this case, it was decided to use a ranking, because generally rank data is arguably simpler and more reliable than rating data. Individuals are expected to be able to say that they prefer A to C and C to B with greater confidence and consistency than they can have in assigning scores to each alternative. (Ortùzar and Willumsen, 1994). In order to apply the IV technique, rank data were transformed into rate data. The rates were weighted on the percentage of users indicating that attribute. The preferences expressed by users in terms of descending ranking was changed into a rating by a specific empirical procedure. The adopted methodology can be debatable because transforming ranking into rating involves a degree of discretionality. However, the statistical methods of analysing ranking data do not provide a quantitative measure of the degree of preference expressed by the users. In addition, the users had the possibility of ranking not all the attributes, but only some of them. Therefore, the users implicitly chose the most important attributes; in this way the risk of making errors in the assignment of the rates is reduced.

In order to assign a rate, the stated choices were divided into sets according to the number of expressed preferences (i.e. factors indicated in order of importance), which can vary from 1 up to 5. In each choice set a rate was assigned in descending order to each factor, so that inside each set the sum of the rates is equal to 100. As an example, in the case in which only one preference is expressed, the corresponding rate is assumed equal to 100; in the case of two preferences, a rate equal to 60 is assigned to the first chosen factor and a rate equal to 40 to the second factor, and so on, as reported in table 1.

Table 1: Factor rates of each preference sets.

Sets	Rate					
	1st factor	*2nd factor*	*3rd factor*	*4th factor*	*5th factor*	*Total*
Set with 1 preference	100					*100*
Set with 2 preferences	60	40				*100*
Set with 3 preferences	50	32	18			*100*
Set with 4 preferences	46	30	15	9		*100*
Set with 5 preferences	43	29	14	8	6	*100*

Inside every set of preferences, each rate differs from the following one by a quantity that decreases from the first to the last chosen factor. Besides, a higher rate has been assigned to a factor within a set with a smaller number of preferences, while the same factor assumes a lower rate within a set with a greater number of preferences.

The Importance Value is calculated through the following formula:

$$IV(X_i) = \sum_j [IV(X_i)]_j = \sum_j (\sum_k W_k \cdot \%US_k)_j \qquad (1)$$

with:

X_i i-th factor, in which i varies from 1 to n (number of factors, in the specific case equal to 9);
j, that varies from 1 to m (number of set of preferences, in the specific case equal to 5);
W factor weigth, in which k varies from 1 to j;
%US percentage of users who expressed a preference for factor X_i within a set with j preferences.

The Importance Value calculated for each service quality attribute is reported in table 2. These factors can be grouped in service quality macro-factors, usually adopted in customer satisfaction surveys by transit agencies. In many cases, macro-factors correspond to service quality attributes analyzed within the surveys; only "comfort on board" macro-factor is defined by more service quality attributes.

As a result it emerges that service quality attributes with a major weight are service frequency (IV equal to 38.3), seats on bus (IV equal to 21.9). Considering all the factors that can be grouped in "comfort on board" the IV is equal to 31.9; in any case this value is lower than the frequency Importance Value. Among the other attributes that have a minor weight, information has a respectable value. It should be noted that the factors not considered in this analysis have a considerable weight, equal to 7.5; this means that among the omitted factors there could be factors with a weight comparable to others, like security against crimes that has an IV equal to 2.2.

Table 2: Importance Value of quality factors and macro-factors.

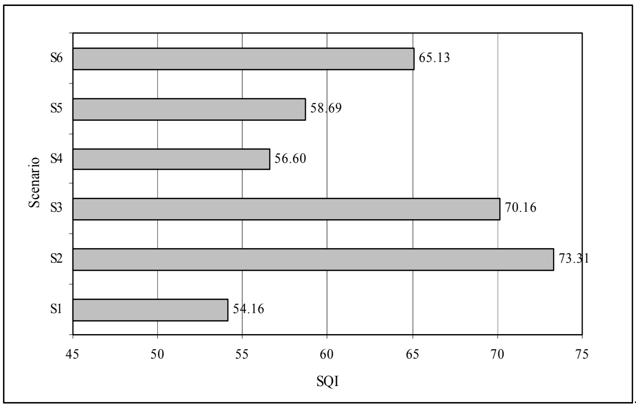
Macro-factor	Factor	Importance	
Transport network design	Number of bus stops	6.2	6.2
Service supply and reliability	Frequency	38.3	38.3
Comfort on board	Cleanliness	6.9	
	Comfort on bus	3.1	
	Seats on bus	21.9	31.9
Comfort at bus stops	Comfort at bus stops	4.9	4.9
Safety	Security against crimes	2.2	2.2
Information	Information	9.1	9.1
Other	Other	7.5	7.5
Total		*100.0*	*100.0*

Finally, SQI has been calculated. A linear relation between SQI and the attributes is supposed. This index allows an operational measure of the services effectiveness according to the weight assigned to each factor (Importance Value). SQI is calculated by the following formula:

$$SQI = \sum_i [IV(X_i) \cdot X_i] \qquad (2)$$

in which:
$IV(X_i)$ is the i-th factor Importance Value;
X_i is the value assumed by the i-th factor.

As an example, SQI was calculated for different scenarios of extra-urban public transport service to get to university campus. The attributes levels have been estabilished *a priori.* The weights of each factors are the same as shown in table 2; the values assumed by factors are assigned on a scale of three levels (low level 0, intermediate level 0.5 and high level 1). This assumption implies a linear effect going from a level to another.



Factor	*Scenario*					
	1	*2*	*3*	*4*	*5*	*6*
Frequency	0.5	1	0.5	0.5	0.5	0.5
Number of bus stops	1	1	1	1	1	1
Cleanliness	0.5	0.5	1	0.5	0.5	0.5
Comfort on bus	0.5	0.5	1	0.5	0.5	0.5
Security against crimes	1	1	1	1	1	1
Comfort at bus stops	0.5	0.5	0.5	1	0.5	0.5
Information	0.5	0.5	0.5	0.5	1	0.5
Seats on bus	0.5	0.5	1	0.5	0.5	1
Other	0.5	0.5	0.5	0.5	0.5	0.5

Figure 5: SQI for different service quality scenarios.

SQI assumes values between 54.16 and 73.31. In figure 5 service quality scenarios are shown.

As expected, the highest index values were obtained by improving the frequency (scenario 2) or, alternatively, the comfort factors (scenario 3). Obviously, by assigning the highest level to a major number of attributes SQI has a higher value. In addition, SQI with reference to the real situation in this experimental context has been calculated. For this aim, a perceived level of each attribute was asked a reduced sample of users. In reference to the attributes reported in figure 5, the average perceived levels are equal to 0.75, 0.65, 0.69, 0.69, 0.85, 0.36, 0.37, 0.73, 0.66 respectively. The value of SQI is equal to 67.59. Finally, the improvement of the SQI produced by an increase of the level of an attribute has been calculated. As an example, the SQI improvement by considering an increase of the frequency (the attribute with the highest value of the IV) and the security against crimes (the attribute with the highest level perceived by the users) has been calculated. Specifically, a 10% improvement of the level of the frequency determines an SQI increase of 4%, but a 10% improvement of the level of the security against crimes determines an SQI increase of 0.27%.

4. Conclusions

In this paper transport service quality attributes which influence global customer satisfaction have been analysed.

The importance of each attribute perceived by the University of Calabria students has been evaluated, particularly the students who do not live in the urban area of Cosenza.

With the aim of determining the relative weights of all the attributes on global customer satisfaction, the Importance Value (IV) technique has been proposed.

As a result it emerges that service quality attributes with a major weight on global customer satisfaction are service frequency and seats on the bus.

The introduced tecnique can be debatable, because it uses rank data transformed into rate data. Neverthless, the results are realistic and frequency, as expected, has the major weight.

The degree of discretionality introduced by the transformation of ranking in rating could be compensated by asking the users both ranking and rating preferences. In this way, some checks can be carry out. Firstly, the correspondence between ranking and rating data can be verified. Secondly, the degree of discretionality of assigned rates from the IV procedure can be measured by comparing assigned rates with rates expressed by users. Finally, the IV procedure can be also verified by using expressed rather than assigned rates.

Moreover, unlike the statistical analysis techniques for measuring service quality and customer satisfaction, IV technique allows the relative weights of all the attribute on global customer satisfaction to be determined. Furthermore, by using these weights an aggregate index can be calculated (Service Quality Index). This index permits supplied services effectiveness to be measured and service quality attributes to be identified to improve it.

As an example, SQI with reference to the real situation has been calculated. For this aim, a perceived level of each attribute was asked the users. From the results, it is deduced that the actual public transport service used by students to reach the campus is satisfactory because SQI has a value higher than 60, on a scale from 1 to 100. SQI can be useful to planners to choose more appropriate public transport agencies and to the said agencies to improve supplied service regarding suitable service quality attributes.

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References

AA. VV. (2006) *Sistemi di trasporto collettivo avanzati a media potenzialità: analisi funzionali ed economico-finanziarie*, Laruffa editore, Reggio Calabria.

AA. VV (2000) *Valutazione della qualità e customer satisfaction: il ruolo della statistica. Aspetti oggettivi e soggettivi della qualità*, Vita e Pensiero, Milano.

Akan, P. (1995) “Dimensions of service quality: a study in Instanbul”, *Managing Service Quality,* 5(6), pp. 39–43.

Berger, C., Blauth, R., Boger, D., Bolster, C., Burchill, G., DuMouchel, W., Pouliot, F., Richter, R., Rubinoff, A., Shen, D., Timko, M. and Walden, D. (1993) “Kano’s methods for understanding customer-defined quality”, *The Center for Quality Management Journal*, 2(4).

Bertini, R. L. and El-Geneidy, A. (2003) “Using archived data to generate Transit performance measures”, *82th TRB Annual Meeting*, 12-16 January, Washington D.C.

Bhave, A. (2002) “Customer Satisfaction Measurement”, *Quality & Productivity Journal*, February.

Bollen, K. A. (1989) *Structural Equations with Latent Variables*, John Wiley & Sons Inc., New York, USA.

Cascetta, E. (2001) *Transportation Systems Engineering: Theory and Methods*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Cuomo, M. T. (2000) *La customer satisfaction. Vantaggio competitivo e creazione di valore*, CEDAM, Padova.

Figini, M. (2003) *Dare valore alle esigenze dei clienti e dei dipendenti dell’azienda*, Franco Angeli, Milano.

Grønholdt, L. and Martensen, A., (2005) “Analysing Customer Satisfaction Data: A Comparison Of Regression And Artificial Neural Networks”, *International Journal of Market Research*, 47(2).

Hensher, D. A., (2001) “Service quality as a package: what does it mean to heterogeneous consumers?”, *9th World Conference on Transport Research*, 22-27 July, Seoul, Korea.

Hensher, D. A. and Prioni, P. (2002) “A service quality index for area-wide contract performance assessment regime”, *Journal of Transport Economics and Policy*, 36(1), pp. 93-113.

Hensher, D. A., Stopper, P. and Bullock, P. (2003) “Service quality-developing a service quality index in the provision of commercial bus contracts”, *Transportation Research*, 37(A), pp. 499-517.

Hill N. (2000) *Handbook of Customer Satisfaction and Loyalty Measurement*, Gower Publishing, Ltd, Aldershot, Hampshire.

Hill, N. (2003) *How to Measure Customer Satisfaction*, Gower Publishing, Ltd, Aldershot, Hampshire.

Kano, N., Seraku, N., Takahashi, F. and Tsjui, S. (1984) “Attractive quality and must-be quality”, *Hinshitsu*, 14(2), pp. 147-56.

Hartikainen, M., Salonen, E. P. and Turunen, M. (2004) “Subjective Evaluation of Spoken Dialogue Systems Using SERVQUAL Method”, ICSLP, pp. 2273-2276.

Ortùzar, J. de D. and Willumsen, L. G., (1994) *Modelling Transport*, John Wiley and Sons Ltd., England.

Prioni, P. and Hensher, D. A. (2000) “Measuring service quality in scheduled bus services”, *Journal of Public Transport* 3(2), pp. 51-74.

Siskos, Y., Grigoroudis, E., Zopounidis, C., and Saurais, O. (1998) “Measuring Customer Satisfaction Using a Collective Preference Disaggregation Model”, *Journal of Global Optimization*, 12, pp. 175-195.

Swanson, J., Ampt, L. and Jones, P. (1997) “Measuring bus passenger preferences”, *Traffic Engineering and Control*, 38(6), pp. 330-336.

Transportation Research Board (1999) *A handbook for measuring customer satisfaction and service quality*, Washington, D.C.: National Academy Press, Transit Cooperative Research Program, Report 47.

Vilares, M. J. and Coelho, P. S. (2003) “The employee-customersatisfaction chain in the ECSI model”, *European Journal of Marketing*, 37(11/12), pp. 1703-1722.

Zeithaml, V. A., Parasuraman, A. and Berry, L. L. (1986) *Servqual: a multiple item scale for measuring perceptions of service quality*, Marketing Science Institute, Cambridge.

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Measuring airline hub timetable co-ordination and connectivity: definition of a new index and application to a sample of European hubs

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Abstract

In this paper a new index for measuring the timetable co-ordination of an airline hub is proposed, with application to a sample of European hubs. This index is both quite accurate and easy to use, so that it may prove a useful schedule analysis tool for airline managers. In section 1 of this paper, the definition of "wave-system structure" and "ideal wave" are given. In section 2 the problem of measuring hub connectivity and hub timetable co-ordination is discussed. Then, both the so-called "weighted indirect connection number", which is an index for measuring hub connectivity, and the "connectivity ratio", which is an index for measuring hub timetable co-ordination, are described, in section 3 and 4 respectively. In section 5, a new index for measuring hub timetable co-ordination is illustrated: the "weighted connectivity ratio". Some examples of hub timetable co-ordination measures performed with the new index are reported in section 6.

Keywords: Airline hub; Wave-system; Connectivity; Schedule co-ordination; Weighted connectivity ratio.

Introduction

Following deregulation of the airline industry, "hubbing" was soon developed by most of the major companies as a crucial schedule-based product feature (Doganis, 2002).

Federal Express first developed effective hubbing in the aviation industry in the 1970s, using its airport base at Memphis for the carriage of overnight express parcels throughout the United States. Effective hubbing requires that flights from different airports, which are at the "spokes" of a network, arrive at the "hub" airport at approximately the same time. The aircraft then wait on the ground simultaneously, in

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order to facilitate the rapid interchange of passengers and baggage or, in the case of Federal Express, of express parcels. Afterwards, flights depart in quick succession back out along the spokes. The process that involves a wave or bank of arrivals followed shortly afterwards by a wave of departures is described as a "complex" or "wave".

An airline which operates a "hub-and-spoke" network offers flights between its one or few hub airports and its spoke airports. The airline co-ordinates arrivals and departures at its hub in order to minimize delays for passengers continuing through the hub to final destinations on spokes other than the one on which they originated. This strategy targets passengers travelling between origins and destinations for which traffic volume is not sufficient for conveniently frequent non-stop flights. Passengers departing from any non-hub origin to other destinations in the network generally proceed first to the hub. Similarly, passengers travelling to non-hub destinations generally arrive at these destinations from the hub.

A hub-and-spoke network to be developed requires (Danesi and Lupi, 2005):

1) spatial concentration of the network structure,
2) temporal co-ordination of the flight schedules at hub airports in waves,
3) integration of via-hub sub-services, i.e. the airline has to sell passengers one via-hub fare, from passengers' point of origin to passengers' final destinations, and has also to provide automatic baggage transfer at the hub.

European airlines often pride themselves on having operated hub-and-spoke networks long before US airlines. Actually, they only operated spatially concentrated networks not co-ordinated in time, before deregulation. This pattern was a result of pre-deregulation bilateral air service agreement constraints, which polarised flag carrier networks around their main national airports. Therefore, pre-deregulation star-shaped networks of European airlines are not equivalent to hub-and-spoke networks, as long as timetable co-ordination is lacking and a substantial number of services provide transfer only by chance (Burghouwt and De Wit, 2005).

Indeed, the main characteristics of hub-and-spoke services make the definition of "hub" a somewhat contentious one (Dennis, 1994b; Button, 2002; Holloway, 2003). In the US the word "hub" has been traditionally used to define any large airport. In particular, the Federal Aviation Administration defines as a "hub" airport any US airport generating 0.05 per cent or more national passenger boardings, without loading the term with any scheduling or other operational implications[1].

Colloquial and journalistic usage of the term "hub" often refers either to airports that handle large volumes of traffic or to large airline operational bases. Therefore, also in this case the term "hub" has not got any connotation of transfer traffic and does not consider any inbound and outbound flight schedule co-ordination. However, the concept of "hub" simply as a large airport no longer remains very valid (Dennis, 1994b). In recent years, the term "hub" has become more closely associated with an integrated interchange point where one or more specific airlines concentrate traffic and operate waves of flights[2].

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[1] According to FAA, 0.05 - 0.249 per cent of passenger boardings qualifies an airport as a "small hub", 0.25 – 0.999 per cent as a "medium hub" and one per cent or over as a "large hub".

[2] US experience and more recent experience in Europe suggest that for an airport to be effectively a hub it must possess some critical attributes (Doganis, 2002; Bootsma, 1997; Dennis, 1994b): (1) a central geographical location in relation to the markets which the airport is to serve, in order to minimize airline and passenger travel time and costs; (2) ample operational and environmental air-side capacity, which allows the airline to schedule a large number of flights simultaneously, in order to operate its complexes of flights efficiently; (3) ample land-side capacity and suitable configuration of the terminal, which allows

1. Wave-system structures and ideal waves

Temporal co-ordination of an airline hub-and-spoke network refers to the hub timetable organisation, which is based on a certain wave-system structure. According to the definition proposed by Bootsma (1997) and by Burghouwt and De Wit (2005), a wave-system structure of an airline hub is specified, given:

1) the number of flight waves,
2) the time interval between the same points of two consecutive waves, i.e. the so-called "hub-repeat cycle" (Dennis, 1994b),
3) the short-haul and medium-haul aircraft stabling locations.

The short-haul and medium-haul aircraft stabling locations refer to the locations where the airline continental fleet stays overnight. Generally speaking, an airline which operates a hub-and-spoke network can stable aircraft at the hub, at the spokes or, in the so-called "dual stabling" case, both at the hub and at the spokes[3].

Let N be the number of waves of a wave-system structure, H the hub-repeat cycle and S a dummy variable, such that: $S = 0$, if airline continental fleet is stabled at the hub; $S = 1$, if airline continental fleet is stabled at the spokes; $S = 2$, in case of dual stabling. Hence, the triple *(N, H, S)* identifies an airline wave-system structure univocally. The three factors that define a wave-system structure are interrelated. For instance, H will tend to decrease, if N increases, and S affects N too.

An example of airline wave-system structure is represented by the triple *(2,6,0)*: this is a 2-wave structure based on a 6-hour hub-repeat cycle, with continental fleet stabling at the hub and one wave which results broken overnight. On the other hand, considering the structure *(2,6,1)*, i.e. switching the continental fleet from stabling at the hub to stabling at the spokes, the broken wave becomes a complete one. In order to increase the number of waves, the hub-repeat cycle has to decrease and wave-system structures such as *(3,5,0)* and *(4,4,1)* can be obtained. A hub-repeat cycle of about 4 hours is the maximum that can be reached by 4-wave structures. For adding other waves, more advanced wave-system structures are usually developed, by using a combination of stabling at the hub as well as at the spokes ($S = 2$). In particular, wave-system structures such as *(5,3,2)* and *(7,2,2)* are characterised by a value of the hub-repeat cycle which is shorter than the continental fleet round-trip times (intra-European round trip times are typically clustered around five hours) and this forces the aircraft to operate only a limited number of waves within the wave-system structure[4].

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the airline to process a large number of transfer passengers and baggage very rapidly; (4) satisfactory average weather conditions, in order to prevent the reliability of airline hubbing operation to be frequently jeopardized by fog, snow or thunderstorms; (5) ideally, strong local demand from/to the hub, which helps to support a wide range of airline services from the airport; (6) obviously, an airline willing and prepared to operate hubbing at the airport, scheduling flights in complexes.

[3] About the stabling location of short and medium-haul aircraft, it should be noted that airlines have traditionally located as many aircraft as possible at their home base, during the nighttime period. This minimises lodging expenses for crew and facilitates servicing and maintenance. However, this arrangement is not ideal in hub operations, because it leads to one complex of connections being broken overnight (the last bank of arrivals in the late evening is followed only the day after, typically in the early morning, by one bank of departures).

[4] For instance, some destinations may be linked to the hub with flights that depart from one wave, skip the next wave and return to the hub in the second next wave (Bootsma, 1997).

Focusing on the structure of a single wave of flights within an airline hub wave-system, an "ideal wave" or "basic wave" of flights (Bootsma, 1997; Burghouwt and De Wit, 2005) can be defined as a complex of incoming and outgoing flights, structured such that each incoming flight creates a bookable connection with every outgoing flight.

In an ideal wave of flights, the arrival wave, the transfer period and the departure wave can be identified. The arrival wave corresponds to the time-window in which the arriving flights are scheduled to arrive at the hub. The transfer period, which allows passengers and baggage to transfer from the arriving flights to the departing flights, corresponds to the time-window in which no flight is scheduled to arrive or depart to/from the hub. Finally, the departure wave corresponds to the time-window in which departing flights are scheduled to depart from the hub.

Minimum connect times for continental and intercontinental flights, maximum acceptable connect times and the maximum number of flights, which can be scheduled per time period, are the elements that define an ideal wave of flights.

First, connections have to meet the minimum connect time, i.e. the minimum time interval that must elapse between a scheduled arrival and a scheduled departure for the two services to be bookable as a connection (Dennis, 1994b). Minimum connect time is constrained by the minimum transfer time required to passengers and baggage to be transferred at the hub and by the minimum time to turnaround the aircraft. A range of different minimum connect times may be in operation at hub airports, depending on the airport, airline, type of passenger and route. However, minimum connect times for European hubs are typically clustered around 45 minutes.

Secondly, a trade-off exists between the maximum acceptable connect time for passengers and the maximum number of flights that can be scheduled in a time period. Since no airport has unlimited capacity, extra-connections can only be scheduled at the edges of an existing bank and this involves long connection times, which may not be acceptable for transfer passengers. Bootsma (1997) has defined standard maximum connect times for different types of flights and different connection quality thresholds. On the other hand, Dennis (2001) argues that the optimal size of a European hub complex is likely to be around 50 aircraft.

It should be noted that an ideal wave of flights is not very likely to be scheduled by airline managers: for instance, slot shortage, very strong local traffic, need to match competitors' frequencies or profitable opportunities to raise aircraft utilisation may induce hub-and-spoke carriers to operate flights unconnected to any hub complex. Generally speaking, actual waves are quite far from being ideal: they do not show sharp outlines and sometimes they are difficult to identify. A useful analysis tool for detecting hub waves within an airline hub schedule has been proposed by Bootsma (1997).

2. Measuring hub timetable co-ordination and connectivity

The most relevant purpose of any hub wave-system is to maximise connectivity. Hub connectivity refers to the number and the quality of indirect flights available to passengers via an airline hub (Bootsma, 1997). Hub connectivity depends on:

1) the number of markets linked to the hub with direct services,

2) service frequencies,
3) times of arrival and departure of the flights scheduled at the hub.

Large hub airports have a major advantage, because connectivity tends to increase in proportion to the square of the number of flight movements. Nevertheless, smaller airline hubs can try to compensate for this, by offering a higher level of timetable co-ordination, which does not depend on the size of hub operations (Rietveld and Brons, 2001).

Hub timetable co-ordination can be defined as the action and the effect of organising a hub schedule according to an ordered pattern, so that connectivity can be enhanced without increasing the number of flights. Indeed, concentrating flights in complexes is the common approach adopted by airline managers for implementing hub timetable co-ordination.

A quantitative estimate of hub timetable co-ordination can be obtained by calculating the ratio between the actual value of connectivity registered at the hub and the value of connectivity that would be observed, if flights to/from the hub were scheduled following a fixed reference pattern (such as, for instance, a random uniform distribution of flights). In other words, hub timetable co-ordination can be measured by measuring the degree to which it contributes to improve connectivity.

Hub connectivity can be evaluated through different methodologies, according to the ultimate goal of the measure. Generally, an accurate analysis of both the total number and the quality of hub connections is needed. An example of this kind of approach for measuring hub connectivity is the methodology proposed by Burghouwt and De Wit (2005). On the other hand, Doganis and Dennis (Doganis and Dennis, 1989; Dennis, 1994b and 2001; Doganis, 2002) adopt a less detailed and more straightforward approach for measuring hub connectivity, because they need a connectivity measure only for calculating the so-called "connectivity ratio", which actually is a hub timetable co-ordination measure.

Both the connectivity measure suggested by Burghouwt and De Wit, i.e. the so-called "weighted indirect connection number", and the "connectivity ratio" suggested by Doganis and Dennis are illustrated in this paper. Furthermore, a new hub temporal co-ordination measure is proposed in section 5.

3. "Weighted indirect connection number"

Burghouwt and De Wit (2005) suggest to measure airline hub connectivity using an approach that combines the methodologies proposed by Veldhuis (1997) and Bootsma (1997). In order to measure hub connectivity, Burghouwt and De Wit investigate both the quantity and the quality, in terms of passenger attractivity, of indirect flight connections.

Generally speaking, the attractivity of any hub connection depends on several factors (Burghouwt and De Wit, 2005; Veldhuis, 1997; Bootsma, 1997). First, the attractivity of connections declines, with increasing hub transfer time. Secondly, the attractivity of connections declines, with increasing backtracking and in-flight time compared to the direct flight alternative. Flight departure and arrival times, service frequency and aircraft type also affect connection passenger attractivity. Moreover, in order to evaluate the attractivity of any connection, the attractivity of the other competitive direct and indirect links available to passengers should be evaluated as well. Thus, evaluating passenger attractivity of hub connections is quite a difficult issue, which has to be simplified, in order to get a practical index for measuring hub connectivity.

For the evaluation of hub connectivity, Burghouwt and De Wit (2005) suggest to determine the quality levels of connections, focusing on the role which is played by the perceived transfer time and in-flight time compared to the direct flight option. The authors do not simply distinguish between viable and non viable connections: they propose to calculate the so-called "weighted indirect connection number", WNX , as a global measure of airline hub connectivity. Considering on-line same-day airline hub connections only,

$$WNX = \sum_k WI_k \ . \tag{3.1}$$

WI_k indicates a "weighted indirect connection", being $k = (i, j)$, $i = 1,...,n_a$ and $j = 1,...,n_d$:

$$\begin{cases} WI_k = \dfrac{1\left(1 - \dfrac{IFT_k - DFT_k}{DFT_k}\right) + 2.4\left(1 - \dfrac{TT_k}{MACT_k}\right)}{3.4} = \\ \quad = \dfrac{2 - \dfrac{IFT_k}{DFT_k} + 2.4\left(1 - \dfrac{TT_k}{MACT_k}\right)}{3.4}, \quad if \begin{cases} MCT_k \le TT_k \le MACT_k \\ 1 < \dfrac{IFT_k}{DFT_k} \le 1.40 \end{cases} ; \\ WI_k = 0, \quad otherwise. \end{cases} \tag{3.2}$$

$i = 1,...,n_a$ is any flight arriving at the hub during the time period T . $j = 1,...,n_d$ is any flight departing from the hub during the time period T . $t_{a,i}$ is the arrival time of flight i , $t_{d,j}$ is the departure time of flight j , $TT_k = t_{d,j} - t_{a,i}$ is the transfer time scheduled between the arrival of flight i and the departure of flight j , $MACT_k$ is the maximum acceptable connect time between flight i and flight j and MCT_k is the minimum connect time between flight i and flight j , which depends on the connection type as well as on the airport facilities themselves. IFT_k is the indirect in-flight time corresponding to connection $k = (i, j)$, i.e. the sum of the in-flight times of i and j , and DFT_k is the estimated in-flight time for covering the great circle distance between the origin of flight i and the destination of flight j .

The number of direct flights to/from the hub, the minimum connect times and the quality of connections with respect to the maximum acceptable connect times determine the weighted indirect connection number WNX for an airline hub. The quality of a generic connection depends on the hub transfer time and on the indirect in-flight time compared to the direct in-flight time. In particular, WI_k is a linear function of both indirect in-flight time and transfer time. It is assumed by the authors that passengers value transfer time 2.4 times as long as in-flight time.

It can be noted that $WI_k < 1$, because: (1) $TT_k \geq MCT_k > 0$; (2) $IFT_k > DFT_k$, due to the extra landing and take-off operations required by the via-hub travel option compared to the direct flight option, even without any circuity involved. With regard to maximum available connect times, the authors suggest to respect the thresholds proposed by Bootsma (1997) for connections with a poor quality level: $MACT_k = 180'$, in case of connections between two continental flights, $MACT_k = 300'$, in case of connections between one continental flight and one intercontinental flight and $MACT_k = 720'$, in case of connections between two intercontinental flights.

According to Burghouwt and De Wit (2005): if $WNX \geq 2500$, hub connectivity can be considered "high"; if $500 \leq WNX < 2500$, hub connectivity can be considered "medium"; if $WNX < 500$, hub connectivity can be considered "low".

4. "Connectivity ratio"

In order to measure airline hub temporal co-ordination, Doganis and Dennis propose the so-called "connectivity ratio", an index that shows the degree to which airline hub connections are more than just purely random (Doganis and Dennis, 1989; Dennis, 1994b and 2001; Doganis, 2002). According to the definition given by Doganis and Dennis, a viable connection is any flight departure, which respects both the minimum connect time MCT and the maximum acceptable connect time $MACT$ after each arriving flight at the hub. Doganis and Dennis suggest $MCT = 45'$ and $MACT = 90'$ as the thresholds to be respected by a couple of one arriving flight and one departing flight for creating a viable connection: these values represent more severe quality standards compared to those proposed by Bootsma (1997).

Let $i = 1,...,n_a$ be any flight arriving at the airline hub during the time period T, $j = 1,...,n_d$ any flight departing from the hub during the time period T, $t_{a,i}$ the arrival time of flight i, $t_{d,j}$ the departure time of flight j and $TT_k = t_{d,j} - t_{a,i}$, $k = (i, j)$, the transfer time scheduled between flight i and flight j. Furthermore, let m_{ij} be a dummy variable such that: $m_{ij} = 1$, if $MCT = 45' \leq t_{d,j} - t_{a,i} \leq MACT = 90'$; $m_{ij} = 0$, otherwise. Thus, the connectivity ratio proposed by Doganis and Dennis can be written as:

$$CR = \frac{N_c}{N_r} \qquad (4.1)$$

being

$$N_c = \sum_i \sum_j m_{ij} \tag{4.2}$$

the total number of viable connections offered at the airline hub during the time period T and

$$N_r = n_a \frac{n_d}{T}(MACT - MCT) = n_a n_d \frac{MACT - MCT}{T} \tag{4.3}$$

the approximate number of viable connections that would be expected to occur in case of a purely random (uniform) arrival and departure timetable across T. Typically, it is assumed that T is equal to one airline operational day, i.e. $T = 15 \div 18$ h.

Indicating with

$$n_c = \frac{N_c}{n_a} \tag{4.4}$$

the average number of viable connections per flight arrival[5] and with

$$n_r = \frac{N_r}{n_a} \tag{4.5}$$

the average number of viable connections per flight arrival in case of a purely random flight timetable across T, the connectivity ratio can also be written as:

$$CR = \frac{n_c}{n_r} = \frac{n_c}{n_d \dfrac{MACT - MCT}{T}} . \tag{4.6}$$

The main advantage of the connectivity ratio is that it is very easy to be calculated. On the other hand, a major disadvantage is that all viable connections are considered

[5] It should be noted that the average number of viable connections per flight arrival, n_c, is not a suitable index for measuring hub temporal co-ordination, due to the quadratic nature of market coverage, which can be obtained through hub-and-spoke operations. Every direct link to/from the hub results in a multiplicity of via-hub connections. Thus, airlines offering more direct flights from an airport will generally show a larger value of n_c.

equal. Doganis and Dennis distinguish only between viable and non viable connections and the problem of evaluating the quality of hub connections is not investigated. A connection is simply considered as an indirect link within the airline network that may exist or may not, as it meets or does not meet the hub minimum connect time and maximum acceptable connect time constraints. Connection de-routing and competing paths are not taken into account.

Dennis (1994b) argues that CR should ideally be in the range of 2 to 3 for optimal hub temporal co-ordination; connectivity ratios of 1 or less indicate random or even counterproductive hub schedule co-ordination.

5. A new index for measuring hub timetable co-ordination

The connectivity ratio is very useful for evaluating airline hub timetable co-ordination. A major advantage is that the connectivity ratio is very straightforward. On the other hand, this index is easy to be used mainly because it evaluates hub connectivity by means of a very simple procedure, which appears to be a bit rough for some applications (Burghouwt and De Wit, 2005). In particular:

1) connections are classified only between viable and non viable connections, without any investigation about the relative quality of viable connections, which are considered equivalent;
2) viable connections are defined only looking at temporal constraints, i.e. hub minimum connect time and maximum acceptable connect time, and no spatial or other factor is considered;
3) both minimum connect time and maximum acceptable connect time are considered to be hub constants, and it is not taken into account that they depend on the particular connection type, i.e. continental, intercontinental or between one continental and one intercontinental flight.

The weighted indirect connection number (Burghouwt and De Wit, 2005), which specifically aims to evaluate hub connectivity, does suggest some modifications that could be applied to improve the connectivity ratio. A new index for measuring hub temporal co-ordination is proposed and illustrated in this paragraph. This new index is named "weighted connectivity ratio" and it tries to maintain the straightforward structure of the connectivity ratio, while introducing a more accurate procedure to evaluate hub connectivity.

Let $i = 1,...,n_a$ be any flight arriving at the airline hub during the time period T, $j = 1,...,n_d$ any flight departing from the hub during the time period T, $t_{a,i}$ the arrival time of flight i, $t_{d,j}$ the departure time of flight j and $TT_k = t_{d,j} - t_{a,i}$, $k = (i, j)$, the transfer time scheduled between flight i and flight j. Furthermore, let $n_{a,cont}$ be the number of continental flights arriving at the hub and $n_{d,cont}$ the number of continental flights departing from the hub during the time period T. Similarly, let $n_{a,inc}$ and $n_{d,inc}$ be the number of arriving and departing intercontinental flights.

Now, considering on-line same-day airline hub connections only, let MCT_k be the minimum connect time between i and j, $MACT_k$ be the maximum acceptable connect time for passengers having a viable connection between flight i and j and let define "intermediate connect time" (ICT_k) an intermediate threshold for taking into account the different quality levels, in terms of passenger attractivity, of "rapid connections" ($MCT_k \le TT_k \le ICT_k$) compared to the other viable but less desirable connections ("slow connections", $ICT_k < TT_k \le MACT_k$). In Tab. 1, typical values of MCT_k are listed and possible values of ICT_k and $MACT_k$ are suggested for both continental and intercontinental connections.

Table 1: Values of minimum, intermediate and maximum acceptable connect times proposed for the calculation of the weighted connectivity ratio[6].

CONNECT TIMES (minutes)		*MCTk*	*ICTk*	*MACTk*
CONNECTION TYPE	Continental - Continental	45	90	120
	Continental - Intercontinental	60	120	180
	Intercontinental - Intercontinental	60	120	180

Recalling and adjusting the definition of "connectivity matrix" given by Ivy (1993), the "temporal connectivity matrix" can be defined as the matrix $\underline{\underline{TCM}}$, with n_a rows and n_d columns, such that, for the generic element τ_{ij}, $i = 1,...,n_a$, $j = 1,...,n_d$, the following holds:

$$\begin{cases} \tau_{ij} = 1 & if \quad MCT_k \le t_{d,j} - t_{a,i} \le ICT_k \\ \tau_{ij} = 0.5 & if \quad ICT_k < t_{d,j} - t_{a,i} \le MACT_k \\ \tau_{ij} = 0 & \quad otherwise \end{cases} \tag{5.1}$$

Similarly, the "spatial connectivity matrix" can be defined as the matrix $\underline{\underline{SCM}}$, with n_a rows and n_d columns, such that, for the generic element δ_{ij}, $i = 1,...,n_a$, $j = 1,...,n_d$, the following holds:

[6] In Tab. 1, minimum connect times correspond to typical values for European hubs, but they actually depend both on the connection type and on the particular airport facilities. Note also that the values of maximum acceptable and intermediate connect times represent more severe level-of-service standards compared to the thresholds proposed by Bootsma (1997); in particular, note that the same thresholds have been chosen for connections between two intercontinental flights and for connections between one continental flight and one intercontinental flight.

$$\begin{cases} \delta_{ij} = 1 & if \quad DR_k \le 1.20 \\ \delta_{ij} = 0.5 & if \quad 1.20 < DR_k \le 1.50 \\ \delta_{ij} = 0 & \quad otherwise \end{cases} \tag{5.2}$$

where

$$DR_k = \frac{ID_k}{DD_k} \tag{5.3}$$

is the so-called “de-routing index” ($DR_k \ge 1$), with DD_k the great circle distance between the point of origin of flight i and the destination of flight j and ID_k the sum of the great circle distances corresponding to flights i and j.

Furthermore, the “weighted connectivity matrix” can be defined as the matrix $\underline{\underline{WCM}}$, with n_a rows and n_d columns, such that the generic element w_{ij}, $i = 1,...,n_a$, $j = 1,...,n_d$, corresponds to the so-called “weighted connection”

$$w_{ij} = \tau_{ij}\delta_{ij} \tag{5.4}$$

Now, the “weighted connectivity ratio” can be defined as:

$$WCR = \frac{WN_c}{WN_r} \tag{5.5}$$

where

$$WN_c = \sum_i \sum_j w_{ij} = \sum_i \sum_j \tau_{ij}\delta_{ij} \tag{5.6}$$

is the number of weighted connections offered at the airline hub during the time period T and

$$WN_r = [\ n_{a,cont} \frac{n_{d,cont}}{T}\left(ICT_1 - MCT_1 + \frac{MACT_1 - ICT_1}{2} \right) +$$

$$
\begin{aligned}
&+n_{a,cont}\frac{n_{d,inc}}{T}\left(ICT_2-MCT_2+\frac{MACT_2-ICT_2}{2}\right)+\\
&+n_{a,inc}\frac{n_{d,cont}}{T}\left(ICT_2-MCT_2+\frac{MACT_2-ICT_2}{2}\right)+\\
&+n_{a,inc}\frac{n_{d,inc}}{T}\left(ICT_3-MCT_3+\frac{MACT_3-ICT_3}{2}\right)\ ]\frac{\sum_i\sum_j\delta_{ij}}{n_a n_d}=\\
&=\frac{\sum_i\sum_j\delta_{ij}}{n_a n_d}\Big[n_{a,cont}n_{d,cont}\frac{MACT_1+ICT_1-2MCT_1}{2T}+\\
&+\left(n_{a,cont}n_{d.inc}+n_{a,inc}n_{d,cont}\right)\frac{MACT_2+ICT_2-2MCT_2}{2T}+\\
&+n_{a,inc}n_{d,inc}\frac{MACT_3+ICT_3-2MCT_3}{2T}\ \Big]=WN_r
\end{aligned}
\qquad (5.7)
$$

the approximate number of weighted connections that would be expected to occur in case of a purely random (uniform) arrival and departure timetable across T (for both continental and intercontinental flights)[7]. For practical applications, it is typically assumed that T is one airline operational day, i.e. $T = 15 \div 18\ h$.

The weighted connectivity ratio shows if the viable weighted connections are more than purely random. Thus, the thresholds suggested by Dennis (1994b) indeed remain valid: ideally, WCR should be in the range of 2 to 3 for optimal hub temporal co-ordination, whereas connectivity ratios of 1 or less indicate random or even counterproductive hub schedule co-ordination.

In contrast to the connectivity ratio proposed by Doganis and Dennis, the weighted connectivity ratio classifies viable connections in different quality levels, according to their spatial as well as temporal characteristics. Indeed, the definition of two quality levels for both spatial and temporal attributes allows any weighted connection to vary between a set of three values other than zero:

$$
\begin{cases}
w_{ij}=1 & if \quad \delta_{ij}=\tau_{ij}=1\\
w_{ij}=0.5 & if \quad \delta_{ij}+\tau_{ij}=1.5\\
w_{ij}=0.25 & if \quad \delta_{ij}=\tau_{ij}=0.5\\
w_{ij}=0 & \quad\ \ otherwise
\end{cases}
\qquad (5.8)
$$

[7] In formula (5.7), continental, intercontinental and continental-intercontinental connections have to be distinguished, as they refer to different minimum, intermediate and maximum connect times. Furthermore, rapid and slow connections have to be considered separately, because they lead to different values of τ_{ij}. Finally, the arithmetic mean of the elements of $\underline{\underline{SCM}}$ has to be taken into account, in order to compute WN_r.

with $i = 1,...,n_a$, $j = 1,...,n_d$. Moreover, different connect time thresholds can be considered, with respect to the different connection types that may occur (continental, continental - intercontinental, intercontinental) and to the particular hub facilities. Indeed, the hub connectivity evaluation procedure, which leads to the computation of WCR, is quite precise and WN_c could be considered itself an acceptable hub connectivity measure.

6. Examples of application of the new index

Fig. 1 and Fig. 2 illustrate the Alitalia hub timetable structures, which correspond to the Alitalia Winter 2004/2005 schedule (schedule "AZW05").

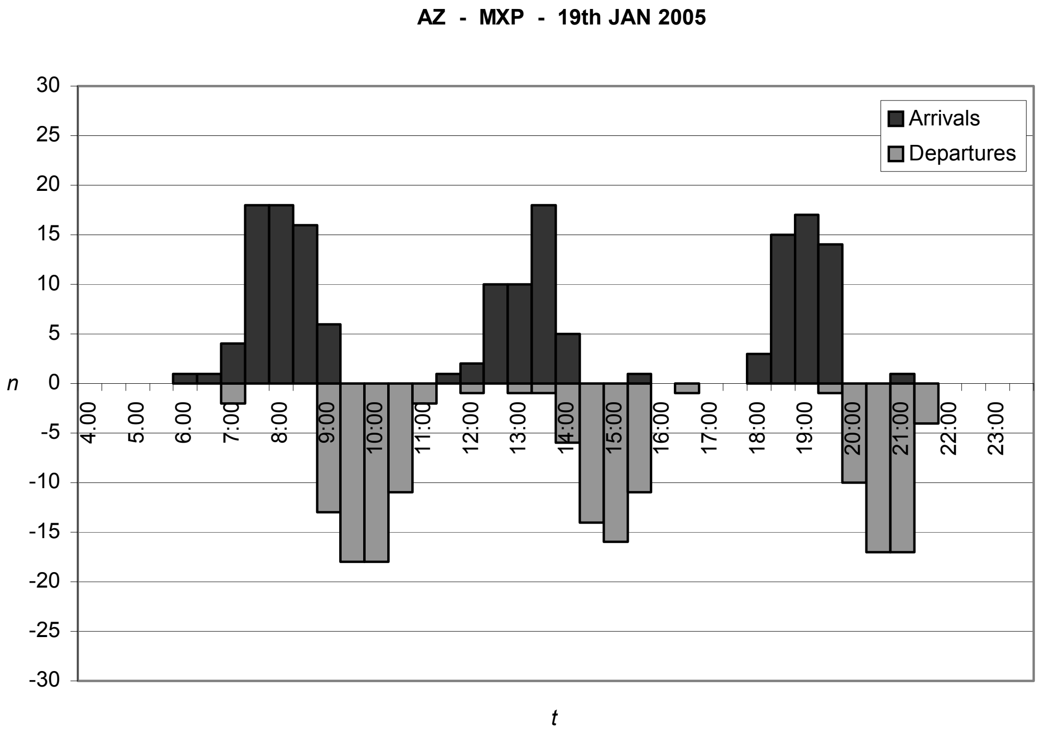

Figure 1: Schedule structure of Alitalia hub in Milan Malpensa (MXP), on Wednesday 19th January 2005.

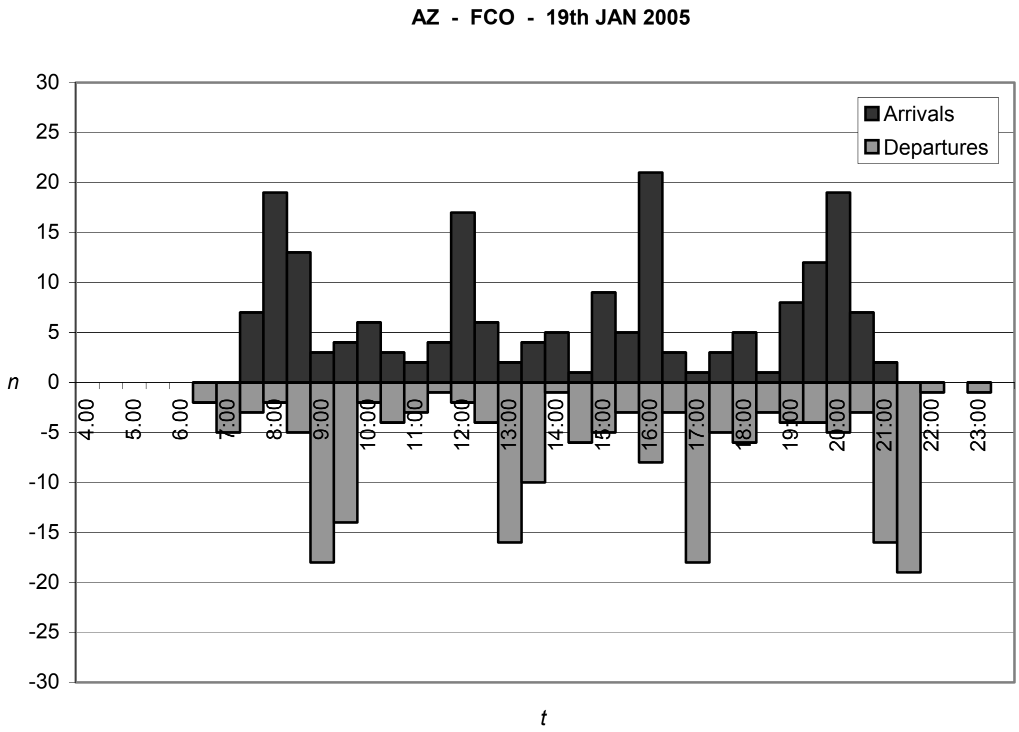

Figure 2: Schedule structure of Alitalia hub in Rome Fiumicino (FCO), on Wednesday 19th January 2005.

Schedule AZW05 requires 127 narrow-body aircraft and 19 wide-body aircraft to serve a wide range of continental as well as intercontinental destinations. As a result of schedule AZW05, the wave-system structure of Alitalia hub in Milan Malpensa (MXP) is characterised by three waves with centres at 8:55 a.m., 1:50 p.m. and 8:00 p.m. Since the continental fleet is stabled at the spokes and the average hub-repeat cycle is equal to 5h30', the wave-system structure of Alitalia hub in Milan Malpensa can be described by the triple *(3, 5 ½, 1)*. On the other hand, with schedule AZW05, the wave-system structure of Alitalia hub in Rome Fiumicino (FCO) is characterised by four waves with centres at about 9:00 a.m., 1:00 p.m., 5:00 p.m., 9:00 p.m. As the continental fleet is stabled at the spokes and the average hub-repeat cycle is equal to four hours, the wave-system structure of Alitalia hub in Rome Fiumicino can be described by the triple *(4, 4, 1)*.

Fig. 3, Fig. 4, Fig. 5 and Fig. 6 illustrate the Winter 2004/2005 schedule structures of some major European airline hubs, namely: KLM hub in Amsterdam (Fig. 3), British Airways hub in London Heathrow (Fig. 4), Iberia hub in Madrid Barajas (Fig. 5), Air France hub in Paris Charles de Gaulle (Fig. 6). It can be observed that the schedule structures of KLM hub in Amsterdam and of Air France hub in Paris Charles de Gaulle, as well as the schedule structures of Alitalia hubs, exhibit quite clear wave-system patterns. In particular, it can be noted that KLM hub in AMS is based on a 4-wave-system structure, whereas Air France hub in CDG is based on a 6-wave-system structure. On the other hand, no flight wave can be easily identified within the schedule structures of British Airways in LHR and of Iberia in MAD. In any case, a computerised analysis tool, like that proposed by Bootsma (1997), is needed for an accurate detection of the number and the characteristics of hub waves within an airline hub schedule.

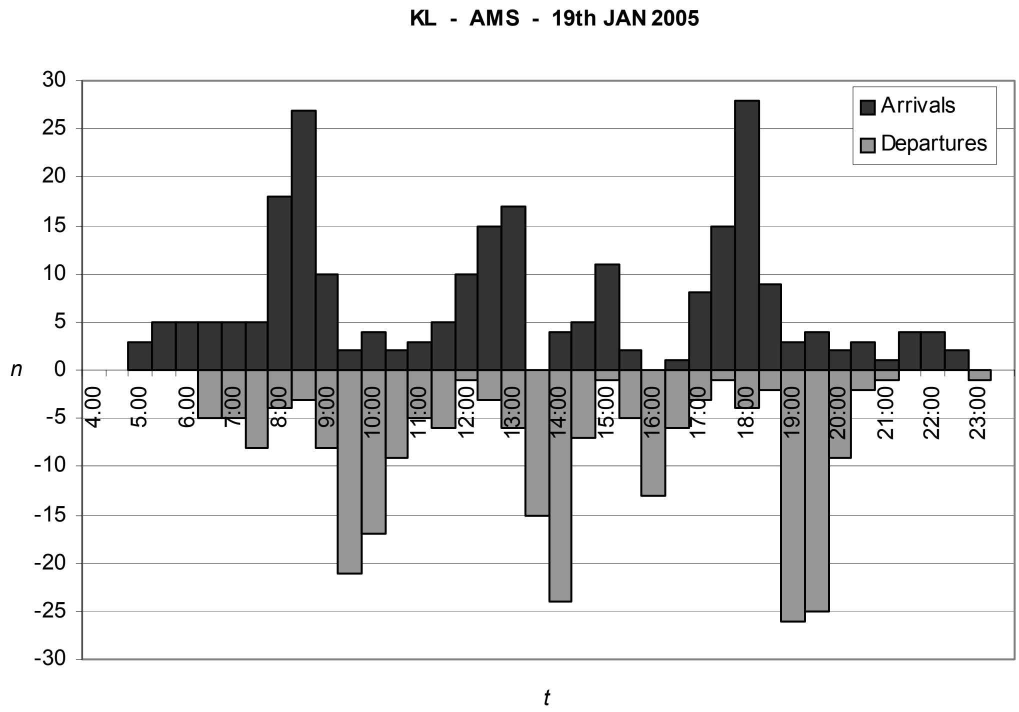

Figure 3: Schedule structure of KLM hub in Amsterdam (AMS), on Wednesday 19th January 2005 (source OAG data).

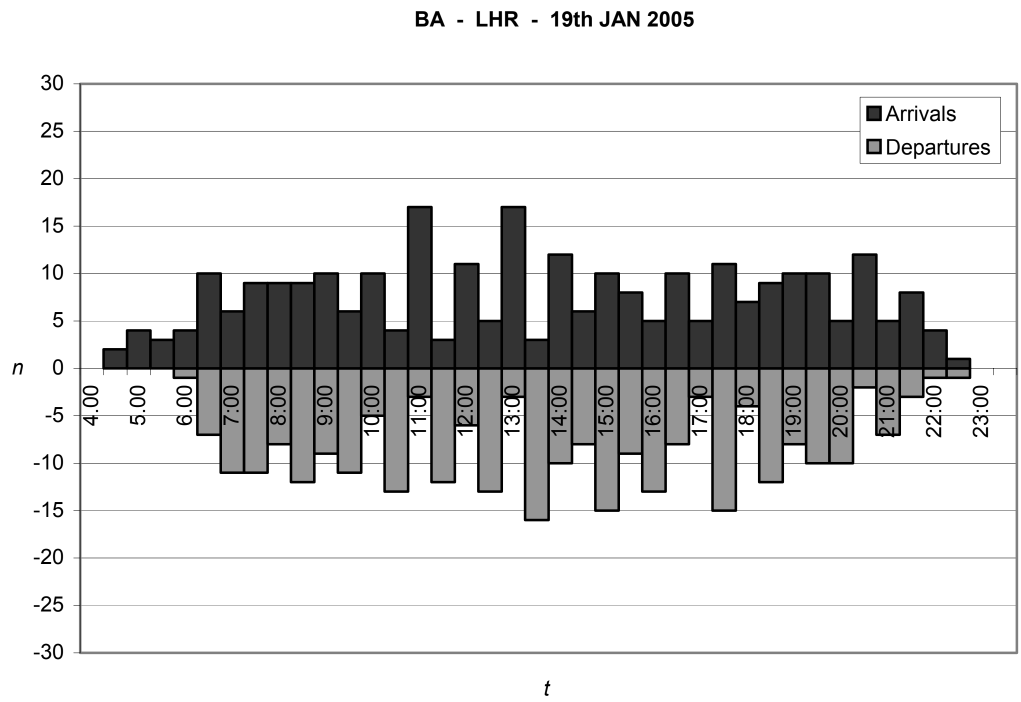

Figure 4: Schedule structure of British Airways hub in London Heathrow (LHR), on Wednesday 19th January 2005 (source OAG data).

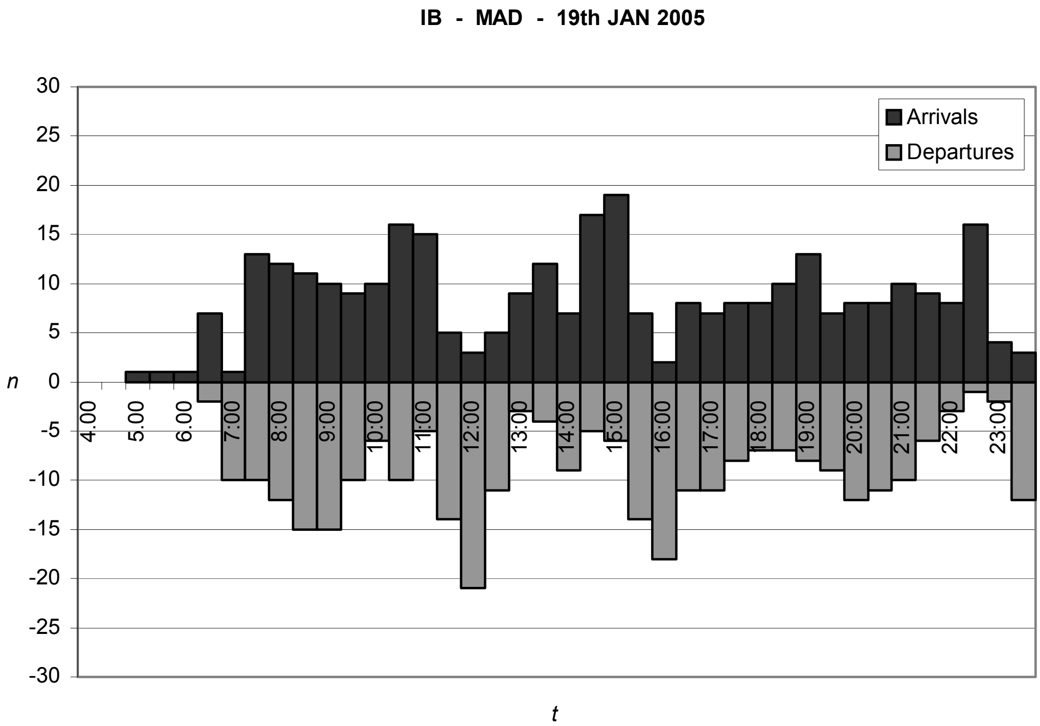

Figure 5: Schedule structure of Iberia hub in Madrid Barajas (MAD), on Wednesday 19th January 2005 (source OAG data).

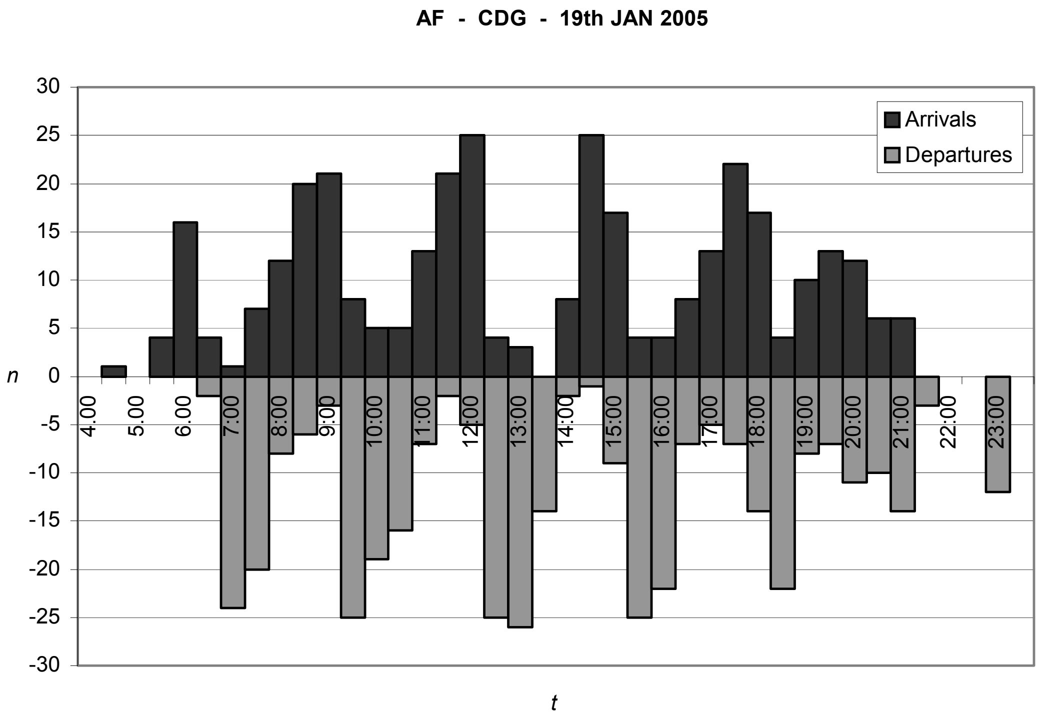

Figure 6: Schedule structure of Air France hub in Paris Charles de Gaulle (CDG), on Wednesday 19th January 2005 (source OAG data).

Tab. 2 reports the results of the analysis, which has been performed for comparing the temporal co-ordination and connectivity levels of the selected European hubs, on Wednesday 19th January 2005. According to the definition given in section 5, the weighted number of connections (WN_c) and the weighted connectivity ratio (WCR) have been calculated, in order to estimate hub connectivity and hub temporal co-ordination respectively. The results of the analysis demonstrate how even relatively small airline hubs can offer a huge number of weighted connections, through a satisfactory timetable co-ordination level, that is by achieving a high value of the weighted connectivity ratio. For example, KLM hub in Amsterdam offers 4526 weighted connections with 247 daily arriving flights, whereas Iberia hub in Madrid Barajas offers 3957 weighted connections with a far higher number of daily arriving flights (320). This can be easily explained, by observing that the weighted connectivity ratio is equal to 1.32 for Iberia at Madrid Barajas and to 1.75 for KLM at Amsterdam.

Alitalia hub in Milan Malpensa shows a very high degree of temporal co-ordination (2.48), which can be considered "ideal", according to the classification proposed by Dennis (section 4 and 5). This confirms the impression that could be derived comparing the representation of the waves of Milan Malpensa (Fig. 1) with the timetable structures of the other hubs. Indeed, Alitalia is able to offer as many as 2942 weighted connections, by scheduling only 163 daily arriving flights at Milan Malpensa hub. Alitalia hub in Rome Fiumicino exhibits a quite high degree of temporal co-ordination and connectivity as well: with 200 daily arriving flights and a weighted connectivity ratio equal to 1.53, almost 2000 daily weighted connections are available to passengers.

Table 2: Daily number of arriving flights (n_a), number of weighted connections (WN_c) and weighted connectivity ratio (WCR) for selected European hubs on Wednesday 19th January 2005[8] (source OAG data).

AIRLINE (CODE)	*AIRPORT (CODE)*	**na**	**WNc**	**WCR**
Air France (AF)	Paris (CDG)	380	7285	1.42
Iberia (IB)	Madrid (MAD)	320	3967	1.32
British Airways (BA)	London H. (LHR)	280	3788	1.23
KLM (KL)	Amsterdam (AMS)	247	4526	1.75
Alitalia (AZ)	Rome (FCO)	203	1983	1.53
Alitalia (AZ)	Milan (MXP)	163	2942	2.48

In Tab. 3, the estimates of hub temporal co-ordination obtained using the weighted connectivity ratio are compared to the values obtained using the connectivity ratio by Doganis and Dennis. Some significant though not radical differences can be observed, analysing the results produced by the two indices. This seems to confirm that the connectivity ratio is a valid tool for measuring hub timetable co-ordination but it also indicates that the weighted connectivity ratio can lead to considerably more accurate estimates, based on a more detailed connectivity analysis.

[8] Note that: $T = 18\ h$ for CDG, LHR and MAD; $T = 16\ h$ for AMS; $T = 15\ h$ for FCO and MXP.

Table 3: Weighted connectivity ratio (WCR) and connectivity ratio (CR) for selected European hubs on Wednesday 19th January 2005[9] (source OAG data).

AIRLINE (CODE)	*AIRPORT (CODE)*	WCR	CR
Alitalia (AZ)	Milan (MXP)	2.48	2.23
KLM (KL)	Amsterdam (AMS)	1.75	1.87
Alitalia (AZ)	Rome (FCO)	1.53	1.60
Air France (AF)	Paris (CDG)	1.42	1.70
Iberia (IB)	Madrid (MAD)	1.32	1.23
British Airways (BA)	London H. (LHR)	1.23	1.16

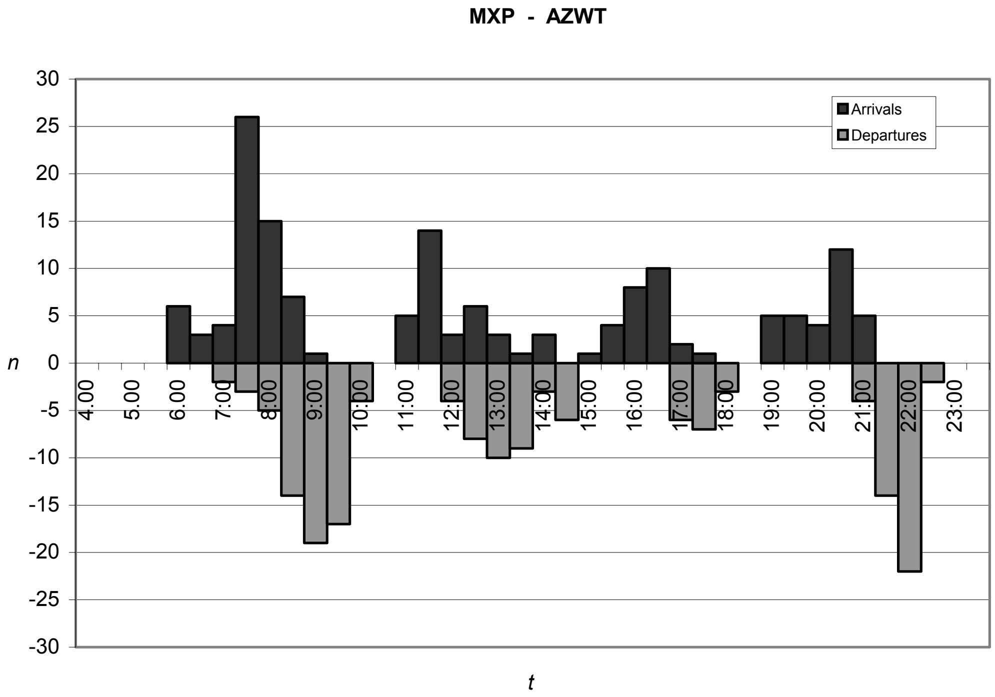

Figure 7: Schedule structure of Alitalia hub in Milan Malpensa, with test-schedule AZWT being operated.

In particular, the weighted connectivity ratio may prove very useful in order to evaluate hub temporal co-ordination of different schedule configurations of the same airline hub (Danesi, 2006). For example, a case study can be discussed, which regards the comparison of the temporal co-ordination levels of two different schedules of Alitalia hub in Milan Malpensa: the first one (Fig. 1) corresponds to the Alitalia Winter 2004/2005 schedule (schedule "AZW05"); the second one (Fig. 7) corresponds to the implementation of the test-schedule named "AZWT".

Schedule AZWT serves the same range of destinations and requires the same number and type of aircraft of AZW05, but it is based on a 4-wave-system structure (with

[9] Note that: $T = 18\ h$ for CDG, LHR and MAD; $T = 16\ h$ for AMS; $T = 15\ h$ for FCO and MXP.

centres at about 9:00 a.m., 1:00 p.m., 5:00 p.m., and 9:00 p.m.) at Milan Malpensa hub. Since the continental fleet is stabled at the spokes and the hub-repeat cycle is equal to four hours, the wave-system structure of Alitalia hub in Milan Malpensa, which corresponds to schedule AZWT, can be described by the triple *(4, 4, 1)*.

Tab. 4 presents the results of the analysis of Milan Malpensa hub timetable co-ordination, with reference to schedules AZW05 and AZWT. Schedule AZW05 achieves a *WCR* score equal to 2.48 and a *CR* score equal to 2.23, while schedule AZWT achieves a *WCR* score equal to 1.96 and a *CR* score equal to 2.05. Thus, both *CR* and *WCR* measures indicate that a reduction in the temporal co-ordination level of Alitalia hub in Milan Malpensa would occur, if schedule AZW05 were replaced by schedule AZWT. On the other hand, the difference between *CR* and *WCR* scores are quite significant and this justifies the more detailed connectivity analysis performed by *WCR* compared to *CR* index.

Table 4: Comparative analysis of the temporal co-ordination levels of schedule AZW05 and AZWT for Alitalia hub in Milan Malpensa: score of the connectivity ratio (CR) and score of the weighted connectivity ratio (WCR), with T = 15h.

Schedule	**CR (MXP)**	**WCR (MXP)**
AZW05	2.23	2.48
AZWT	2.05	1.96
Difference	-8.07%	-20,97%

Finally, some general considerations can be added. First, the choice of the wave-system structure is a major determinant of the temporal co-ordination level of an airline hub schedule. In particular, if a certain amount of flight frequencies is re-distributed within a higher number of hub waves, the connectivity and temporal co-ordination level of the hub schedule will tend to diminish. However, the hub temporal co-ordination measures, such as *CR* and *WCR*, do evaluate (actual) schedules and not wave-system structures (that are ideal models). Indeed, both *CR* and *WCR* could be applied to evaluate any type of timetable, even if no wave-system is operated at the airport and connections are purely random.

Second, the weighted connectivity ratio aims to estimate only one of a huge number of parameters to be optimised by airline managers for improving the quality of hub operations. In particular, *WCR* refers to the performance of a hub schedule and not to the performance of an airline network as a whole. Nevertheless, future researches may investigate the problem of evaluating the mutual co-ordination of different hub schedules implemented within a certain multi-hub system.

Conclusions

Temporal co-ordination of an airline hub-and-spoke network refers to the hub timetable organisation, which is based on a certain wave-system structure. The most relevant purpose of a hub wave-system is to maximise connectivity.

Hub connectivity refers to the number and the quality of indirect flights available to passengers via an airline hub. Large hub airports have a major advantage, because connectivity tends to increase in proportion to the square of the number of flight movements. Nevertheless, smaller airline hubs can try to compensate for this, by offering a higher level of timetable co-ordination, which does not depend on the size of hub operations.

Hub timetable co-ordination can be defined as the action and the effect of organising a hub schedule according to an ordered pattern, so that connectivity can be enhanced without increasing the number of flights. Indeed, concentrating flights in complexes is the common approach adopted by airline managers for implementing hub timetable co-ordination.

In order to measure hub connectivity, Burghouwt and De Wit propose to calculate the so-called "weighted indirect connection number". The authors investigate both the quantity and the quality, in terms of passenger attractivity, of indirect flight connections. Generally speaking, the attractivity of any hub connection depends on several factors and Burghouwt and De Wit suggest to focus on the role that is played by the perceived transfer time and in-flight time compared to the direct flight option.

The "connectivity ratio" by Doganis and Dennis is very useful for evaluating airline hub timetable co-ordination, which can be measured by measuring the degree to which it contributes to improve connectivity. A major advantage of the connectivity ratio is that it is very straightforward; on the other hand, this index is easy to be used mainly because it evaluates hub connectivity by means of a very simple procedure, which appears to be a bit rough for some applications.

A new index for measuring hub temporal co-ordination is proposed in this paper. Its name is "weighted connectivity ratio" and it tries to maintain the straightforward structure of the connectivity ratio, while introducing a more accurate procedure to evaluate hub connectivity. In contrast to the connectivity ratio proposed by Doganis and Dennis, the weighted connectivity ratio classifies viable connections in different quality levels, according to their spatial as well as temporal characteristics. Moreover, different maximum and minimum connect time thresholds can be considered, with respect to the different connection types that can occur (continental, continental - intercontinental, intercontinental-continental, intercontinental) and to the particular hub facilities.

The weighted connectivity ratio has been applied for evaluating the temporal co-ordination and connectivity levels of a sample of European hubs and for comparing the temporal co-ordination of two alternative schedule configurations of Alitalia hub in Milan Malpensa. The results of the analysis demonstrate how even relatively small airline hubs can offer a huge number of weighted connections, by achieving a high value of the weighted connectivity ratio. Furthermore, the case study indicates that the weighted connectivity ratio can generate more accurate estimates compared to the connectivity ratio by Doganis and Dennis, especially for evaluating the temporal co-ordination of different schedule configurations of the same airline hub. Thus, the weighted connectivity ratio is a hub schedule analysis tool that may prove particularly helpful to airline managers.

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References

Bootsma, P. D. (1997) *Airline Flight Schedule Development*, Elinkwijk B.V, Utrecht.

Burghouwt, G. and De Wit, J. (2005) "Temporal configurations of European airline networks", *Journal of Air Transport Management* 11, pp. 185-198.

Button, K. (2002) "Debunking some common myths about airport hubs", *Journal of Air Transport Management* 8, pp. 177-188.

Button, K. and Stough, R. (2000) *Air Transport Networks: Theory and Policy Implications*, Edward Elgar Publishing, Cheltenham.

Danesi, A. and Lupi, M. (2005) "Il sistema di trasporto aereo nazionale italiano: sviluppo della domanda passeggeri ed evoluzione strutturale della rete", *Trasporti & Territorio* n.1/2005, pp. 5-17.

Danesi, A. (2006) Spatial concentration, temporal co-ordination and profitability of airline hub-and-spoke networks*, Ph.D. thesis*, Università di Bologna.

Dennis, N. (1994a) "Scheduling strategies for airline hub operations", *Journal of Air Transport Management* 1, pp. 131-144.

Dennis, N. (1994b) "Airline hub operations in Europe", *Journal of Transport Geography* 2, pp. 219-233.

Dennis, N. (2001) "Developments of Hubbing at European Airports", *Air & Space Europe* 3, n.1/2, pp. 51-55.

Doganis, R. (2002) *Flying off course*, Routledge, New York

Doganis, R. and Dennis, N. (1989) "Lessons in Hubbing", *Airline Business*, March 1989, pp. 42-47.

Holloway, S. (2003) *Straight and Level: Practical Airline Economics*, Ashgate, Aldershot.

Ivy, R. L. (1993) "Variations in hub service in the U.S. domestic air transportation network", *Journal of Transport Geography* 1: 211-218.

Rietveld, P. and Brons, M. (2001) "Quality of hub-and-spoke networks: the effects of timetable co-ordination on waiting time and rescheduling time", *Journal of Air Transport Management* 7. pp. 241-249.

Shaw, S. L. and Ivy, R. L. (1994) "Airline mergers and their effect on network structure", *Journal of Transport Geography* 2, pp. 234-246.

Veldhuis, J. (1997) "The competitive position of airline networks", *Journal of Air Transport Management* 3, pp. 181-188.

Modelling passenger car equivalency at an urban mid-block using stream speed as measure of equivalence

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Abstract

The effect of traffic volume and its composition on Passenger Car Equivalency (PCE) of different vehicle types in a mixed traffic stream is investigated taking an urban mid-block section as the case study. The reduction in stream speed caused by marginal increment in traffic volume by a vehicle type is compared with that of caused by an old technology car, for the estimation of PCE of that vehicle type. A Neural Network (NN) approach is explored for capturing the underlying non-linear effects of traffic volume and its composition level on the stream speed. It is found that PCE of a vehicle type varies in a non-linear manner with total traffic volume and compositional share of that vehicle type in the traffic stream. The speed model using NN technique alone could establish the variation of PCE with vehicle type, traffic volume and its composition.

Keywords: Stream Speed; Heterogeneous/Mixed traffic; Neural Network; Passenger Car Equivalency; Measure of Equivalence.

Introduction

The growing congestion level on urban roads and its resulting delay, fuel loss, environmental degradation etc. is a major concern to transportation engineers. Urban traffic in most of the developing countries is heterogeneous in nature. Therefore, conversion of heterogeneous traffic into a stream of homogeneous one by using appropriate Passenger Car Equivalency (PCE) values is an elementary step for analyzing mixed traffic, and formulating traffic management measures for mitigation of congestion on urban roads. Besides this, appropriate PCE values are also used for capacity analysis as well as traffic engineering research and applications.

Highway Capacity Manual (HCM) (TRB 1994, 2000) defines PCE as "The number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions". PCE is also defined as the number of passenger cars having the same impedance effect as a vehicle of a given type under a

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prevailing roadway, traffic and control condition. PCE of a vehicle type is described with reference to prevailing roadway, traffic and control condition (Chandra et al. 1995; HCM 1994; HCM 2000; IRC 1990). The change of PCE with respect to roadway and control condition has been recognized by suggesting different sets of static PCE values for multilane highways, urban arterials, signalized intersections etc. (TRB 2000; IRC 1990). However, for a prevailing roadway and control condition, the effect of traffic volume and its composition on PCE has not been studied adequately. The change in traffic composition is predominant in highly heterogeneous traffic environment prevailing in developing countries. Using fixed PCE values for all traffic volume and composition levels may be misleading while estimating service volumes or formulating traffic management measures. This paper demonstrates a methodology for estimating PCE and studying the effect of traffic volume and its composition on the same for a prevailing roadway and control condition. An urban mid-block in a developing country is considered as a case study for demonstrating the methodology.

Background work

Enormous works have been done on estimation of PCE and capacity of roads in U.K and U.S.A. Other developed countries like Australia and Sweden have also developed their own capacity norms. The HCM 1950 (Highway Capacity Manual) considered a single factor of 2 to account for the impact of heavy vehicles on multilane highways in level terrain, i.e. trucks have same qualitative effects as two passenger cars do (HRB, 1950). Passenger Car Equivalency concept was first inducted in the HCM 1965 to account for the effect of trucks and buses in a traffic stream. After the advent of the concept of PCE in 1965, many researchers have quantified the damage caused by heavy vehicles in comparison with passenger cars by developing PCE values using different methodologies and equivalency criteria.

The HCM (TRB 2000) suggests different sets of PCE values for highway facilities like two-lane, multi-lane, freeways etc. In the process of developing PCE, some of the studies used field data whereas other studies resorted to traffic simulation techniques (Werner 1976; Huber, 1982; Van Aerde and Yagar 1984; Krammes and Crowley 1986; Webster and Elefteriadou 1999). Joseph et al. (1980) suggested a model for determination of PCE by considering actual traffic delays caused and volume of opposing traffic. They reported PCE values, which were significantly lower as compared to the HCM values, but followed same fluctuations. Carroll and Wiley (1982) studied PCE on rural highways by analyzing field data on two and four lane highways. An analytical model was developed to estimate PCE based on speed distribution, traffic volume and vehicle types. Roess and Messer (1984) identified three approaches for estimating PCE namely, constant volume-to-capacity approach, equal-density approach and spatial heady-way approach. Several investigations on performance of signalized/un-signalized intersections by different types of vehicles were also a special case of quantifying PCE (Branston and Van Zuylen 1978; Branston and Gipps 1981; Benekohal R. F and Zhao.W 1996; HCM, 1985, 1994).

In India, many researchers/organizations have worked out PCE at urban as well as for rural roads and intersections. Bhattacharya and Mandal (1980) developed a generalized model for PCE estimation based on headway at intersection. PCE estimation using headway in mixed traffic flow is not rational as it is difficult to measure headway in mixed traffic condition under poor lane discipline. Central Road Research Institute (CRRI 1988) adopted linear regression analysis technique to determine PCE for different classes of vehicle. Ramanayya (1988) developed simulation models to depict mixed traffic flow on single-lane one-way, two-lane one-way and two-lane two-way roads. Road User cost Study proposed PCE factors based on the length and speed of a vehicle type relative to those of a car (Kadiyali and Associates 1992). IRC: 106 (1990) recommended two sets of PCE considering compositional effect. It is recognized that the PCE of a vehicle type varied with proportion of that vehicle type in the traffic stream. Madhu et al. (2002) used linear regression technique to estimate PCE at urban signalized intersections.

Attempts have been made by researchers to estimate dynamic PCE values of different vehicle categories in a traffic stream. Chandra et al. (1995) worked on the estimation of dynamic PCE values and capacity of urban roads. Using least square analysis, several alternative forms of variables were tried out to incorporate the effect of influencing parameters on speed of individual vehicle type. Marwah and Singh (2000) analyzed traffic flow on urban roads using a two-lane one-way traffic simulation model. The Level of Service (LOS) experienced by different categories of vehicles were decided when the traffic stream contained 65 percent non-motorized vehicles.

Most of the research works have provided significant insight about mixed traffic operation, but recommended only static PCE values for different roadway and control conditions. For a roadway facility, the PCE of a vehicle type is assumed unaffected by traffic volume and its composition. Sometimes, such assumption may be misleading while estimating service volume of a facility or formulating traffic management measures.

DataBase

In order to demonstrate a methodology for studying the effect of traffic volume and its composition on PCE, an urban mid-block section, M. Karve Road in Mumbai Metro City (India) is considered. M. Karve Road is a four lane divided road with 7.0 m carriageway width in one direction. Classified traffic volumes and speeds of different vehicle types on one side of M. Karve road are recorded using Video-graphic technique. Although, speed and traffic volume data are extracted for every minute interval, the data for an interval of 5 min. is used in the present work after carefully observing the scatter of speed-flow data and the variation of estimated capacity values with different durations of counting (i.e. 1 min, 2 min, … , 15 min). Four different vehicle types namely, Heavy vehicles (HV), (i.e. combination of Buses and Commercial vehicles), Old Technology Car (OC), New Technology Car (NC) and Two-Wheeler (TW) are considered.

During the last decade, several new models of passenger cars have been launched in the Indian market. These cars are called as “New Technology Cars”. In general, most of these cars are smaller in size with a superior speed capabilities and acceleration/deceleration characteristics as compared to cars which were dominating the Indian market in the past (Kadiyali and Viswanathan 1993). The traditional cars, which are still in use, are referred to as “Old Technology Cars”.

A refined dataset of 330 data points, each representing 5-minute traffic state, is used for analysis. Classified traffic counts, speed of each vehicle type and traffic composition data are used for the development of database. The steam speed of traffic is calculated based on weighted speeds of different vehicle types.

Proposed approach for PCE estimation

Researchers have considered different Measures of Equivalence (MOE) for the estimation of PCE (Craus et al. 1980; Hubber 1982; Krammes and Crowley 1986). It has been indicated that for a given roadway and control condition, traffic stream alone should account for variation in PCE. Average stream speed is an equivalency criteria commonly used for different roadway facilities (HRB 1965; St. John 1976; Linzer et al. 1979; Van Erde and Yagar 1984; Elefteriadou et al. 1997; HCM 1994; IRC 1990). For urban roads, the stream speed is also used as a Measure of Effectiveness for defining the levels of service (HCM 1994; IRC 1990). Therefore, in the present study, stream speed is considered as a measure of equivalence (MOE) for modeling PCE at urban mid-blocks.

An attempt is made to model stream speed as a function of dynamic control variables like traffic volume and its composition. At any traffic state (defined by traffic volume and its composition), increase in traffic volume separately by each vehicle type is expected to cause different reductions in stream speed. The reduction in stream speed caused by increase in traffic volume by a vehicle type is compared with that of caused by old technology car, for the estimation of PCE of that vehicle type. Old technology car is taken as the reference vehicle for the estimation of PCE. The PCE of a vehicle type 'i' at volume level 'v' and composition 'm', is estimated as shown in (1). The volume level 'v' and composition 'm' are called base volume and base composition respectively. The speed model is used to study the variation of PCE with base volume and composition.

$$PCE_{i,v,m} = \frac{MD_{i,v,m}}{MD_{OC,v,m}} \tag{1}$$

where,

$MD_{i,v,m}$ = Marginal damage on MOE (i.e. reduction in stream speed) caused by a vehicle type 'i' at a base volume 'v' and base composition 'm'.

$MD_{OC,v,m}$ = Marginal damage on MOE (i.e. reduction in stream speed) caused by old technology car at a base volume 'v' and base composition 'm'.

The proposed approach for estimation of PCE requires suitable modeling of stream speed as a function of control variables like traffic volume and its composition. In the present work, modeling of stream speed is attempted using Neural Network (NN) to simulate the non-linear behavior between traffic volume along with its composition and resulting stream speed. There are ample applications of standard back propagation technique for modeling NN in traffic engineering field (Dochy et al. 1996; Dougherty and Cobbett, 1997). Although several supervised NN modeling rules are available, the feed-forward neural network with standard back propagation technique using gradient descent rule is attempted in the present work .

NN as modeling tool

A NN is a massively parallel-distributed information processing system that has certain performance characteristics resembling biological neural networks of the human brain (Heykin 1994). NN has a big role to play in the field of traffic engineering where a high degree of complex non-linear cause-effect relationship exists. In other words, when the possibility of representing the complex relationships is remote in terms of physical or conceptual modeling, NN may play an important role to model this in a more direct way without specifying any mathematical form. NN method is a data driven approaches, which opposes traditional model driven approaches. It is known that modeling process in NN is more direct than any conventional technique. Sometimes NN techniques outperform classical calibration and estimation procedure. The power of NN is that, it imposes fewer constraints on the form of functional relationship between input and output variables than any conventional fitting technique.

The problem of capturing complex non-linear relationships between the causal input vectors of traffic stream and the corresponding output i.e. stream speed falls under the category of pattern mapping and prediction. Although there are numerous types of NN models, by far the most widely used and well suited to the present system is feed-forward NN or multi-layer perceptron, which is organized as layers of computing elements called neurons, connected by weighted connections between layers (see figure 1). Typically, there is an input later, an output layer, and one or more intermediate layers, called hidden layers (Heykin 1994; Kosko 2000). To simulate unknown non-linear behavior of traffic system, sigmoidal function is used as an activation function for NN model development process.

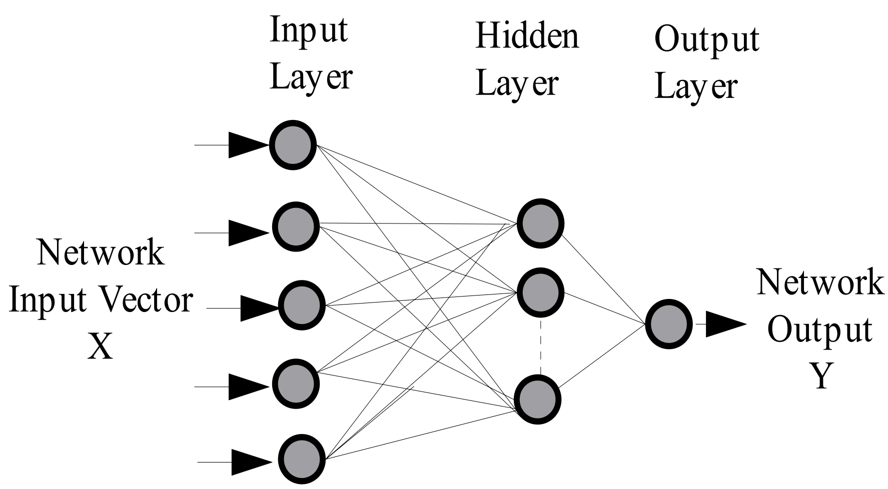

Figure 1: A feed-forward three-layer neural network.

Modeling stream speed using NN

Standard back propagation algorithm is used for training a neural network, which is of feed-forward type. The neural network is trained using 258 patterns (i.e. 78% of the total data). For the testing of the NN model, 72 unseen patterns (i.e. 22% of the total data) are used. Different NN models are attempted based on nature of input vectors, number of hidden layers, number of nodes per hidden layer, initialization of weight matrix, learning rate, momentum factor, number of training cycles etc. Finally, a 5-4-1 (i.e. 5 input nodes and 1 output node with a single hidden layer of 4 nodes) NN architecture is accepted after carefully observing RMSE, correlation coefficient, nature of variation of stream speed with traffic volume, and sensitivity of NN in estimating stream speed with respect to each vehicle type. In input vector layer, the first one represents the total vehicle volume in equivalent number of old technology car (V_{EQ}), whereas other four nodes represent the composition of four different vehicle types namely heavy vehicle (HV), old technology car (OC), new technology car (NC) and two wheeler (TW) in total volume representation.

V_{EQ} is calculated considering physical plan areas of different vehicle types as compared to that of old technology car as shown in (2). The Physical plan area considered for heavy vehicle (HV), old technology car (OC), new technology car (NC) and two wheeler (TW) are taken as 23 m^2, 7.82 m^2, 5.47 m^2, 1.44 m^2 respectively.

$$V_{Eq} = N_{HV} * \frac{23}{7.82} + N_{OC} + N_{NC} * \frac{5.47}{7.82} + N_{TW} * \frac{1.44}{7.82} \tag{2}$$

Where,
N_{HV} = Number of heavy vehicles per hour
N_{OC} = Number of old technology cars per hour
N_{NC} = Number of new technology cars per hour
N_{TW} = Number of two wheelers per hour

The training as well as testing performance of the accepted NN model is given in table 1. Variation of stream speed with an increase in traffic volume, as obtained from the selected NN model, is shown in figure 2. It is observed from figure 2. that the variation of stream speed with traffic volume as obtained from the accepted NN model is consistent with the established speed-flow relationship in stable flow zone (Gerlough and Huber, 1975). The base composition of traffic stream used for studying the speed-volume relationship includes 9.57% HV, 51.57% OC, 13.40% NC and 25.46% TW.

Table 1: Training and testing performance of the accepted ANN model.

	On Training Patterns	*On Testing Patterns*
RMSE	2.059474	2.16912
Correlation Co-efficient	0.964612	0.951291

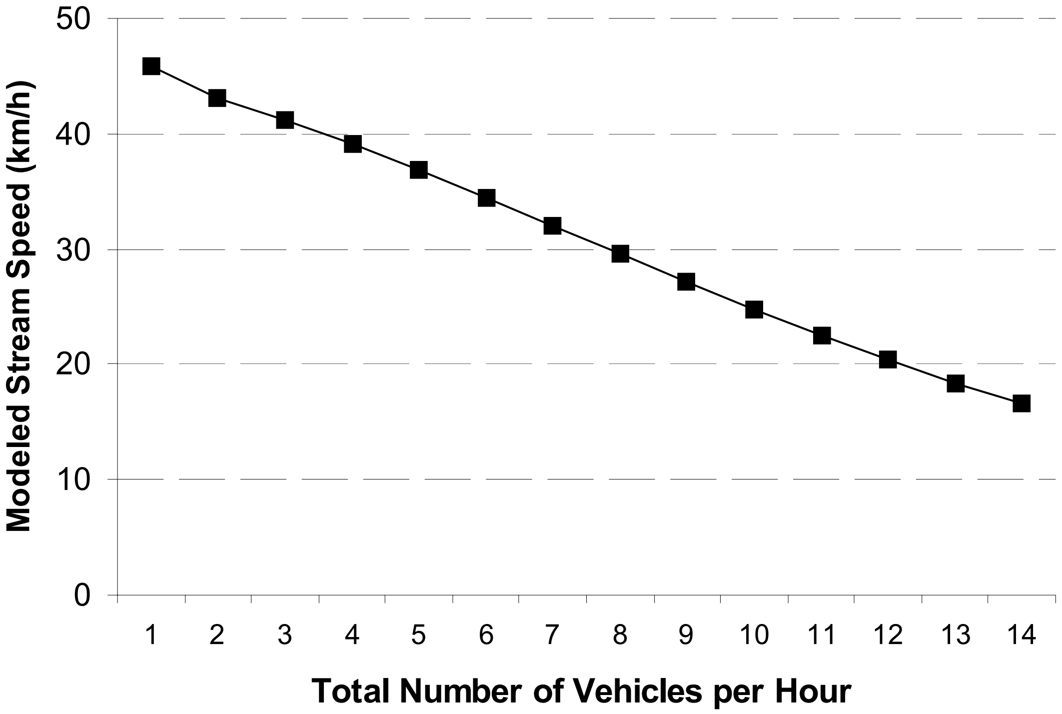

Figure 2: Variation of stream speed with traffic volume.

Estimation of PCE

The NN model is used for estimation of PCE at incremental traffic volumes. The base composition of traffic stream is kept the same as used for the development of speed–volume curve. Different base volumes are generated ranging from 500 to 3250 vehicles per hour with an increment of hourly traffic volume by 250 vehicles per hour. For different base volumes, marginal increment in total traffic volume is done separately by each vehicle type present in the traffic stream. As modeling of stream speed is based on 5-min traffic data, marginal increment in base volume implied addition of 12 vehicles of a type in hourly traffic volume.

PCE of each vehicle type at different base volumes is estimated and plotted as shown in figure 3. Heavy vehicles considered in the present work largely consist of city buses, which are in good operating condition and drivers are also familiar with route condition. Therefore, at or near free flow, there is hardly any speed damage to traffic stream due to the presence of buses and accordingly PCE of heavy vehicles is estimated even lower than unity. However, as volume increases, the physical dimensions and low maneuverability of heavy vehicles become dominating and therefore, heavy vehicles become more detrimental to the traffic stream as compared to all other vehicle types. New technology cars are smaller and have better speed capabilities than old technology cars, which justifies lower PCE value for new technology cars. Two-wheelers being the smallest vehicle have the least detrimental effect on the traffic stream at all flow levels.

Also, the effect of traffic volume is predominant on PCE of heavy vehicles, and negligible on PCE of two wheelers. New technology cars remain in between.

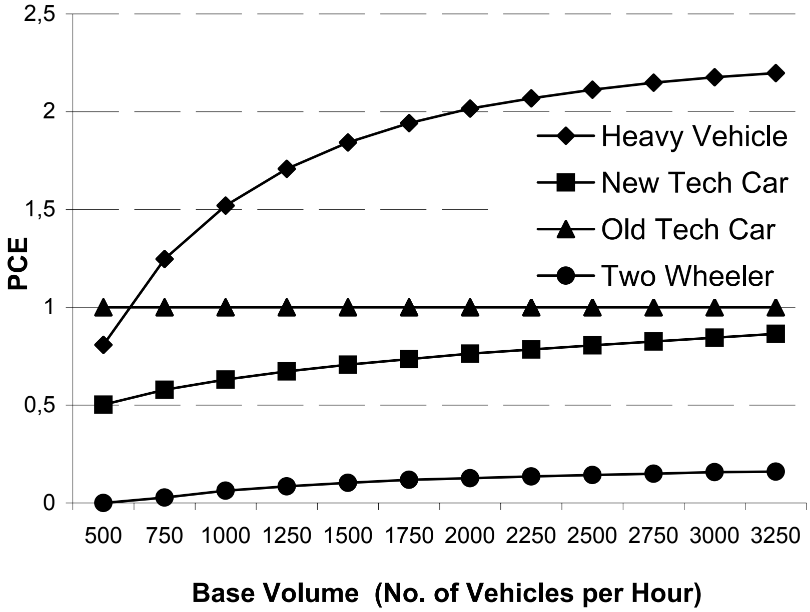

Figure 3: Modeled PCE values for different vehicle types.

Effect of composition and traffic volume on PCE

The variation of PCE with traffic volume as shown in figure 3 corresponds to a base composition of traffic stream. The effect of change in compositional share of a vehicle type on PCE of that vehicle type is also studied at different base volume levels. For this purpose different base compositions of traffic stream are assumed by varying composition of each vehicle type within the observed range. The change in share of a vehicle type is adjusted by appropriate increment or decrement in share of old technology cars to keep the total proportion as unity. Base compositions used for different vehicle types are summarized in Table 2. It may be observed from Table 2 that the effect of compositional share of heavy vehicles on the PCE of the same vehicle type is studied for 5%, 10% and 15% share of heavy vehicles in the traffic stream. Similarly, new technology cars' PCE is estimated for 45%, 50% and 55% share of new technology cars in the traffic stream, whereas two wheelers' PCE is estimated for 20%, 25% and 30% share of two wheelers in the traffic stream. The effect of compositional share of heavy vehicles, new technology cars and two wheelers on PCE is shown in figure 4, 5 and 6 respectively.

Table 2: Different compositions of traffic stream.

Target Vehicle Type	*Assumed Proportion of Different Vehicle Types*			
	Heavy Vehicle (HV)	Old Technology Car (OC)	New Technology Car (NC)	Two Wheeler (TW)
Heavy Vehicles (HV)	0.05	0.57	0.13	0.25
	0.1	0.52	0.13	0.25
	0.15	0.47	0.13	0.25
New Technology cars (NC)	0.1	0.55	0.1	0.25
	0.1	0.5	0.15	0.25
	0.1	0.45	0.2	0.25
Two Wheelers (TW)	0.1	0.57	0.13	0.2
	0.1	0.47	0.13	0.3
	0.1	0.52	0.13	0.25

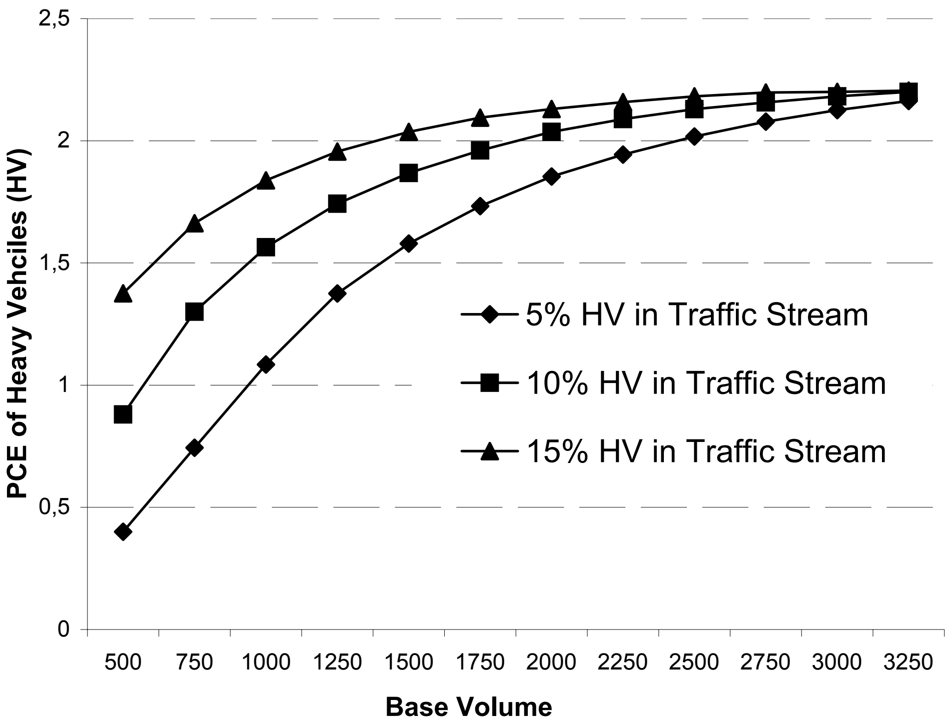

Figure 4: Effect of compositional share on PCE of heavy vehicles.

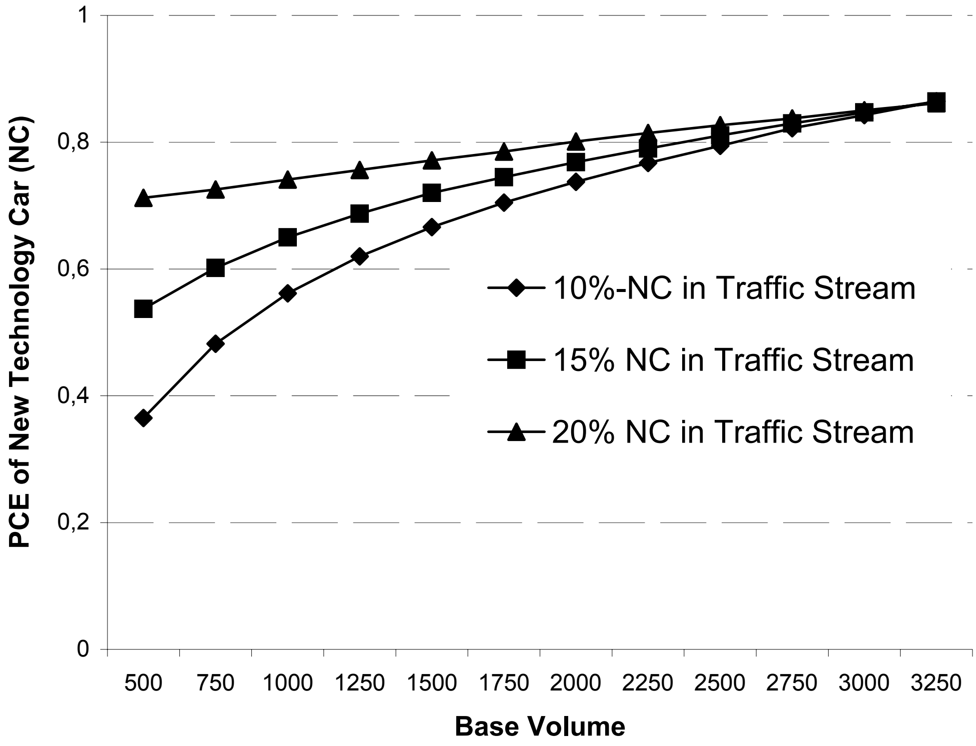

Figure 5: Effect of compositional share on PCE of new technology cars.

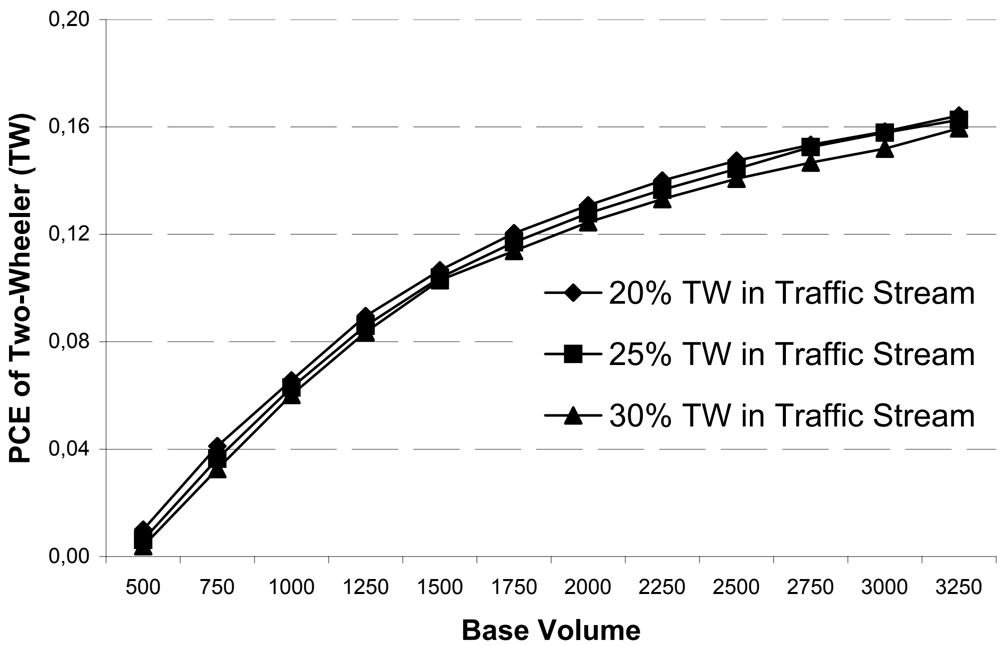

Figure 6: Effect of compositional share on PCE of two-wheelers.

It is observed that PCE of heavy vehicles or new technology cars increases with an increase in its share in total traffic volume. For these vehicle types, the effect of compositional variation on PCE is generally significant at lower traffic volumes. As the volume increases, the effect of share of heavy vehicles or new technology cars on the PCE of respective vehicle types becomes insignificant. Although PCE of both heavy vehicles and new technology cars are affected by the share of corresponding vehicle type in traffic stream, the effect is significant for heavy vehicles. On the other hand, PCE of two-wheelers is least affected by the change in compositional share of two wheelers in the traffic stream. Although PCE of two wheelers is found to decrease marginally with an increase in share of two wheelers in traffic stream, the change in PCE is practically insignificant.

The effect of share of a vehicle type on PCE of the same vehicle type is found to be compatible with the size of vehicle and its maneuverability as well as speed capability. Also, a single NN model could capture the non-linearity in PCE of each vehicle type with respect to traffic volume and its composition. The observed variation of PCE establishes the fact that PCE of a vehicle type varies with traffic volume and its composition.

Closure

In the present paper, the effect of traffic volume and its composition on Passenger Car Equivalency (PCE) is studied. Taking the stream speed as Measure of Equivalence (MOE), a methodology is demonstrated for the estimation of PCE. For the estimation of PCE, the reduction in stream speed caused by marginal increment in traffic volume by a vehicle type is compared with that of caused by an old technology car. Old technology car is taken as the reference vehicle for the estimation of PCE. For modeling stream speed, a NN approach is explored. Speed model using NN technique alone could establish the variation of PCE with traffic volume and its composition.

The case study presented in the paper reveals that PCE is affected by traffic volume and its composition. For all vehicle types, PCE values are found to increase with an increase in traffic volume. However, the effect of traffic volume on PCE is predominant for heavy vehicles. For heavy vehicles and new technology cars, PCE values are also found to increase with an increase in compositional share of respective vehicle types in the traffic stream. The PCE of two wheelers practically remains unaffected by its compositional share in the traffic stream.

The results presented in the paper are case specific but encouraging for further application of the proposed methodology on an enhanced database. Although, a feed-forward neural network with standard back propagation technique using gradient descent rule performed satisfactorily, it may be necessary to explore other supervised NN modeling rules for developing a more rational NN model on an enhanced database.

References

Benekohal, R. F. and Zhao, W. (1996) *Effects of heavy vehicles on intersection delay and passenger car equivalents. Moving Forward in a Scaled-Back World,* ITE International Conference, Dana Point, California, March.

Bhattacharya, P. G. and Mandal, A. G. (1980) "Investigation of passenger car equivalents at controlled intersection in Calcutta", *Highway Research Bulletin,* No. 14, Indian Roads Congress, New Delhi, pp. 41-64.

Branston, D. and Gipps, P. (1981) "Some experience with a multiple linear regression method of estimating parameters of the traffic signal departure process", *Transportation Research,* 15, pp. 445-458.

Branston, D. and van Zuylen, H. (1978) "The Estimation of saturation flow, effective green time and passenger car equivalents at traffic signals by multiple linear regression", *Transportation Research,* 12, pp. 47-53.

Carroll, J. M. and Wiley, D. C. (1982) "Passenger car equivalents for rural highways", *Transportation Research,* Record 905.

Central Road Research Institute (1988) *Capacity of Roads in Urban Areas,* Final Report of the Project Sponsored by Ministry of Surface Transport, New Delhi.

Chandra, S. (1997) "Capacity of urban roads- Towards revision of IRC: 106-1990", *Highway Research Bulletin,* No. 56, Indian Road Congress, New Delhi, pp. 43-70.

Chandra, S., Sikdar, P. K. and Kumar, V. (1995) "Dynamic PCU and estimation of capacity on urban roads", *Indian Highways*, pp. 17-28.

Craus, J., Polus, A. and Grinberg, I. (1980) "A revised method for determination of passenger car equivalents", *Transportation Research A*, Vol. 14, pp. 241-246.

Dochy, T., Danech-Pajouh, M. and Lechevallier, Y. (1996) *Short-term road traffic forecasting using neural network*, RTS English Issue 11.

Dougherty, M. and Cobbett, M. (1997) "Short-term inter-urban traffic forecasts using neural networks", *International Journal of Forecasting,* 13, pp. 21-31.

Elefteriadou, L., Torbic, D. and Webster, N. (1997) "Development of passenger car equivalents (PCE) for freeways, two-lane highways and arterials", *Transportation Research,* Record 1572, pp. 51-58.

Gerlough, D. L. and Huber, M. J. (1975) *Traffic Flow Theory, A Monograph*, Special Report 165, Transportation Research Board, National Research Council, Washington, DC.

Haykin, S. (1994) *Neural Networks: A Comprehensive Foundation*, Mac-Millan, New York.

"Highway Research Board" (1950) Highway Capacity Manual: Practical Applications for Reserarch, Department of Traffic and Operations, Committee on Highway Capacity, United States Government Printing Office, Washington, D.C.,

"Highway Research Board" (1965) Special Report 87, Highway Capacity Manual, National Research Council, Department of Traffic and Operations, Committee on Highway Capacity, Washington, DC.

"Highway Capacity Manual" (1985) Spec. Rep. 209, 3rd edition, Transportation Research Board, National Research Council,Washington, D.C.

"Highway Capacity Manual" (1994) Spec. Rep. 209, 3rd edition, Transportation Research Board, National Research Council,Washington, D.C.

"Highway Capacity Manual" (1998) Third Edition. Transportation Research Board, National Research Council, Washington, D.C.

"Highway Capacity Manual" (2000) Transportation Research Board, National Research Council, Washington, D.C.

Hubber, M. J. (1982) "Estimation of PCE of trucks in traffic stream", *Transportation Research,* Record 869, Transportation Research Board, National Research Council, Washington, D. C., pp. 60-70.

Huber, M. (1982) "Estimation of passenger car equivalents of trucks in traffic stream", In: *Transportation Research,* Record 869. TRB, National Research Council, Washington, DC.

IRC: 106 (1990), *Guidelines for Capacity of urban Roads in Plain Areas*, Indian Road Congress, New Delhi.

Joseph, C., Polus, A. and Grinberg, I. (1980) "A revised method of the determination of PCE", *Transportation Research,* Part A. vol. 14, pp. 241-246.

Kosko, B. (2000) *Neural networks and fuzzy systems: A dynamical systems approach to machine intelligence,* Prentice Hall of India Pvt. Ltd., New Delhi.

Kadiyali and Associates (1992) *Study for Updating Road User Cost Data*, Ministry of Surface Transport, New Delhi.

Krammes, R. A. and Crowley, K. W. (1986) “Passenger car equivalents for trucks on level freeway segments”, *Transportation Research,* Record 1091, Transportation Research Board, National Research Council, Washington, D. C., pp. 10-16.

Linzer, E., Roess, R. and McShane, W. (1979) “Effect of trucks, buses, and recreational vehicles on freeway capacity and service volume”, In: *Transportation Research,* Record 699. TRB, National Research Council, Washington, DC.

Madhu, E., Reddy, T. S. and Murth, A. V. H. N. (2002) Estimation of PCU Values and Saturation Flow at Signalized Intersection, Proc. of National Seminar on Road Transportation in India- Emerging Trends and Techniques (ROTRAN 2002), IIT Kharagpur, pp. 5.19-5.28.

Marwah, B. R., and Singh, B. (2000) Discharge characteristics of heterogeneous traffic at signalized intersections, Transportation Research Circular E-C018: 4th International Symposium on Highway capacity, Maui, Hawaii, pp. 258-270.

Ramanayya, T. V. (1988) “Highway capacity under mixed traffic condition”, *Traffic Engineering and Control*, Vol. 29, pp. 284-287.

Roess, R. P., and Messer, C. J. (1984) “Passenger car equivalents for interrupted flow: Revision of circular 212 values”, *Transportation Research,* Record 971, pp. 7-13.

St. John, A. D. (1976) “Nonlinear truck factor for two-lane highways”, In: *Transportation Research,* Record 615. TRB, National Research Council, Washington, DC.

Van Aerde, M. and Yagar, S. (1984) “Capacity, speed, and platooning vehicle equivalents for two-lane rural highways”, In: *Transportation Research,* Record 971. TRB, National Research Council, Washington, DC.

Webster, N. and Elefteriadou, L. (1999) “A simulation study of truck passenger car equivalents (PCE) on basic freeway sections”, *Journal of Transportation Research*, Part B 33 (5), pp. 323–336.

Werner, W. (1976) “Passenger car equivalencies of trucks, buses, and recreational vehicles for two-lane rural highways”, In: *Transportation Research,* Record 615. TRB, National Research Council, Washington, DC.

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Formal development and evaluation of narrow passageway system operations

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Abstract

This study applies a new intelligent transportation methodology for transforming informal operations concepts for narrow passageway systems into system-level designs, which will formal enough to support automated validation of anticipated component- and system-level behaviours. Models and specifications of behaviour are formally designed as labelled transition systems. Each object is the management system is assumed to have behaviour that can be defined by a finite state machine; thus, the waterway management system architecture is modelled as a network of communicating finite state machines. Architecture-level behaviours are validated using the Labelled Transition System Analyzer (LTSA). We exercise the methodology by working step by step through the synthesis and validation of a high-level behaviour model for a vessel passing through a waterway network (i.e., canal).

Keywords: Synthesis; Validation; Verification; Narrow Waterways Management; System Behaviour Model.

Introduction

Narrow passageway systems (e.g., waterway, work zone, tunnel, one-lane bridge and railroad applications) are large multidisciplinary complex systems characterized by geographically distributed system structures, concurrent subsystem-level behaviours, and end-to-end system life-cycles that may last decades. From a performance perspective, sophisticated techniques for engineering analysis are justified by adverse economics of poor system throughput. Within the waterways domain, for example, recent research has focused on assessment of overall system performance, congestion and delays in single and adjacent locks - see, for example, references (DeSalvo and

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Lave, 1968; Dai and Schonfeld, 1998; Zhu et al. 1998; Ting and Schonfeld, 1998; Wang et al., 2006). Unfortunately, performance studies address only part of the problem - with traffic volumes expected to increase significantly into the foreseeable future (Austin and Kaisar, 2002; Maniccan, 2004), the effective management of passageways is needed to mitigate the undesirable impact of bottlenecks (perhaps caused by adverse weather conditions or accidents) on system safety, performance and cost.

As management systems become progressively diverse in their functionality, and solutions increasingly reliant on high technology, the challenge in creating good system-level designs will steadily increase unless new approaches are developed. In past decades, systems have been viewed from an operations point of view, where information and communication have been regarded as services necessary for the system to operate in pre-defined ways. Nowadays, there is a rapidly evolving trend toward large-scale information-dominated systems which exploit commercial off-the-shelf technologies and communications, have superior performance and reliability, and are derived in response to various types of information drawn from a wide array of sources (Austin, 2004). It is well known that concurrent behaviours increase complexity in scheduling activities to improve performance, while avoiding system failure. Nevertheless, there are now a growing number of application domains for which these difficulties are justified because of additional functionality that would not be possible without and ability to gather and work with data/information. For example, Turkey (Bosporus Straights), Korea (Tsushima Strait), and the Suez and Panama Canals have already made large investments to develop traffic management systems for narrow waterways where decision making is guided by GIS and data collected by land (sensors) centres (Paul, 1997; Gribar, 1999; Moore, 2000).

A fundamental tenet of our research is that new methodologies for system synthesis and validation are a prerequisite to software environments for front end system-level design of information-centric transportation management systems. For our purposes, synthesis of engineering systems is a process whereby provisional and plausible concepts are developed to the point where traditional engineering and design can begin. Synthesis is particularly important for systems that are quite unlike their predecessors; engineers need to return to first principles, rethink established ideas, and identify potential problems downstream in the development. The terms system validation and verification refer to two basic concerns, “are we building the right product?” and “are we building the product right?” Satisfactory answers to both questions are a prerequisite to customer acceptance.

To keep system developments on course and to prevent serious design flaws, today we seek validation and verification procedures that are an integral part of the development process (rather than a postscript to development) and support pre-deployment reasoning about system requirements and design. The complexity of design activities can be kept in check with system-level design methodologies that: (1) Strive to orthogonalise concerns (i.e., achieve separation of various aspects of design to allow more effective exploration of the space of potential design solutions) and (2) Employ formal design representation that enable early predictions of behaviour and detection of errors (Sangiovanni-Vincentelli, 2003). Moreover, to minimize the possibility of unforeseen failure we need models of system-level development that will help designers clearly articulate what the system must provide and what must be prevented. Engineers also need to understand the extent to which a system provides functionality beyond what is actually required.

Scope and objectives

Established approaches to behaviour modelling focus on the simulation of complete system descriptions (modelled to a certain degree of abstraction). Typical modelling objectives include performance assessment and identification of cause-and-effect relationships between system inputs and outputs (Cassandras, 1993; Fishwick, 1995). In a departure from this trend, this work focuses on the early stages of development where system descriptions may still be incomplete, but opportunities for improvement to the system design are greatest. Our primary goal is synthesis of high-level models of behaviour that can be used to verify correctness of partial system descriptions and guide the incremental elaboration of system descriptions. We note that while visual modelling languages, such as the Unified Modelling Language (UML, 2003) are useful for documentation and informal analysis, generally, they lack the precise interpretation of scenarios needed for rigorous analysis and formal verification of system compliance. A second problem is the failure of present-day techniques and tools to specify gaps in the specification which, if not detected, could result in costly design errors in the system development downstream.

Using ideas from object-based and systems-engineering development, this paper proposes a methodology for the incremental transformation of informal operations concepts into system-level designs, the latter being formal enough to support automated validation of anticipated component- and system-level behaviours. The methodology is inspired by our work on systems engineering methodologies (Austin, 2004; Kaisar et al., 2004) and, in part, the work of Magee and co-workers (Magee, 1999; Uchitel, 2004) on behaviour modelling for concurrent and distributed software systems.

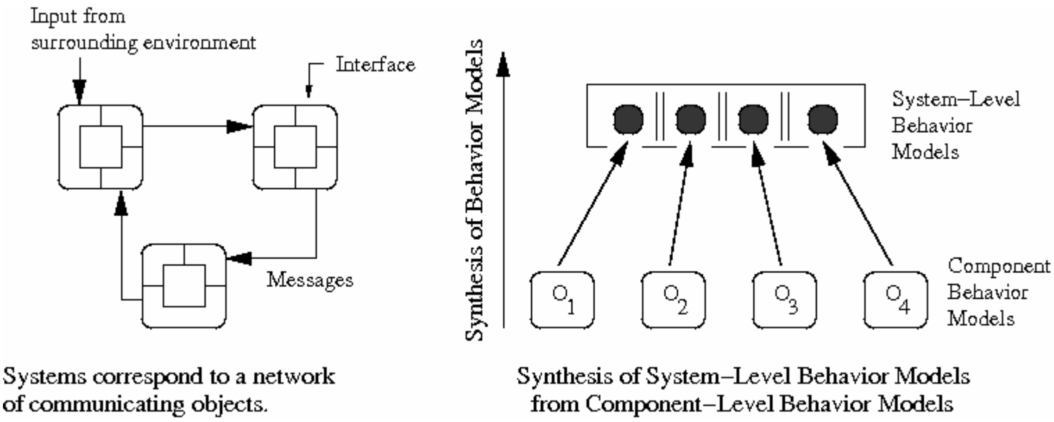

Figure 1: Two Key Elements of Hybrid Object-Oriented/Systems-Development. Objects communicate through message passing (Source: Austin (2004)).

To exercise the methodology, we work step by step through the synthesis and validation of a high-level behaviour model for a ship passing through a waterway network. We assume that the waterway management system architecture can be modelled as a network of communicating objects, as shown on the left-hand side of Figure 1. Management systems achieve their purpose with object/module having well defined functionality, well defined interfaces for connectivity to other modules and the surrounding environment, and message passing. We assume that each object will have behaviour that can be defined by a finite state machine; thus, the management system will be modelled as an ensemble of interacting finite state machines. Scenario specifications and models of behaviour are formally modelled as labelled transition systems (LTSs) (Alur, 2000; Keller, 1976). At the component level, the nodes of a labelled transition system represent states the component can be in. At the architecture level, labelled transition system nodes represent system-level states, which, in turn, correspond to specific combinations of component-level states. Transitions are labelled with messages that components send to each other. The key advantage of this approach is that models of system-level behaviour can be automatically synthesized through the parallel composition of component-level behaviour models. A symbolic representation of this process is shown on the right-hand side of Figure 1. We validate behaviour using the Labelled Transition System Analyser (LTSA), a verification tool for concurrent systems (LTSA, 2004). In LTSA, processes correspond to sequences of actions. The textual representation is the finite state process (FSP) language. Labelled transition systems (LTSs) are the graphical representation. The properties required of the system are also modelled as state machines. LTSA mechanically checks that the specification of a concurrent system satisfies the properties required of its behaviour.

Frontend development

The methodology follows the step-by-step development procedure shown in Figure 2. Component- and architecture-level models of behaviour are synthesized using a combination of top-down and bottom-up strategies. A top-down decomposition strategy is used to develop component-level models of behaviour from use cases and scenario specifications. Models of architecture-level behaviour are developed through a bottom-up parallel composition of component-level behaviours. Downstream in the development (not covered by the methodology described here), system-level design alternatives are created by linking models of system-level behaviour to the high-level structure, and imposing constraints on performance and operation (e.g., control logic). To identify the major subsystems/objects and the details of message communication that a system-level design will need to support, we systematically work through the following steps: (1) Use cases and scenarios, (2) Basic- and high-Level message sequence charts, (3) System requirements, (4) Component- and architecture-level behaviours, an (5) Model checking and incremental improvement. The details of each step are as follows:

Use cases and scenario

Top-down development of system-level models begins with use cases, and proceeds to fragments of system functionality, expressed as activity and sequence diagrams (i.e., UML-based methods). Use cases are high-level representations of system functionality that do not reveal the details of implementation. Use case diagrams are a convenient way in which a real world actor (i.e., entities that are external to the system) will interact with the system, the use cases with which they are involved, and the boundary of the application. In a departure from established approaches to use case modelling

(Amour, 2001, Kulak 2000), the methodology organizes functionality according to aspects.

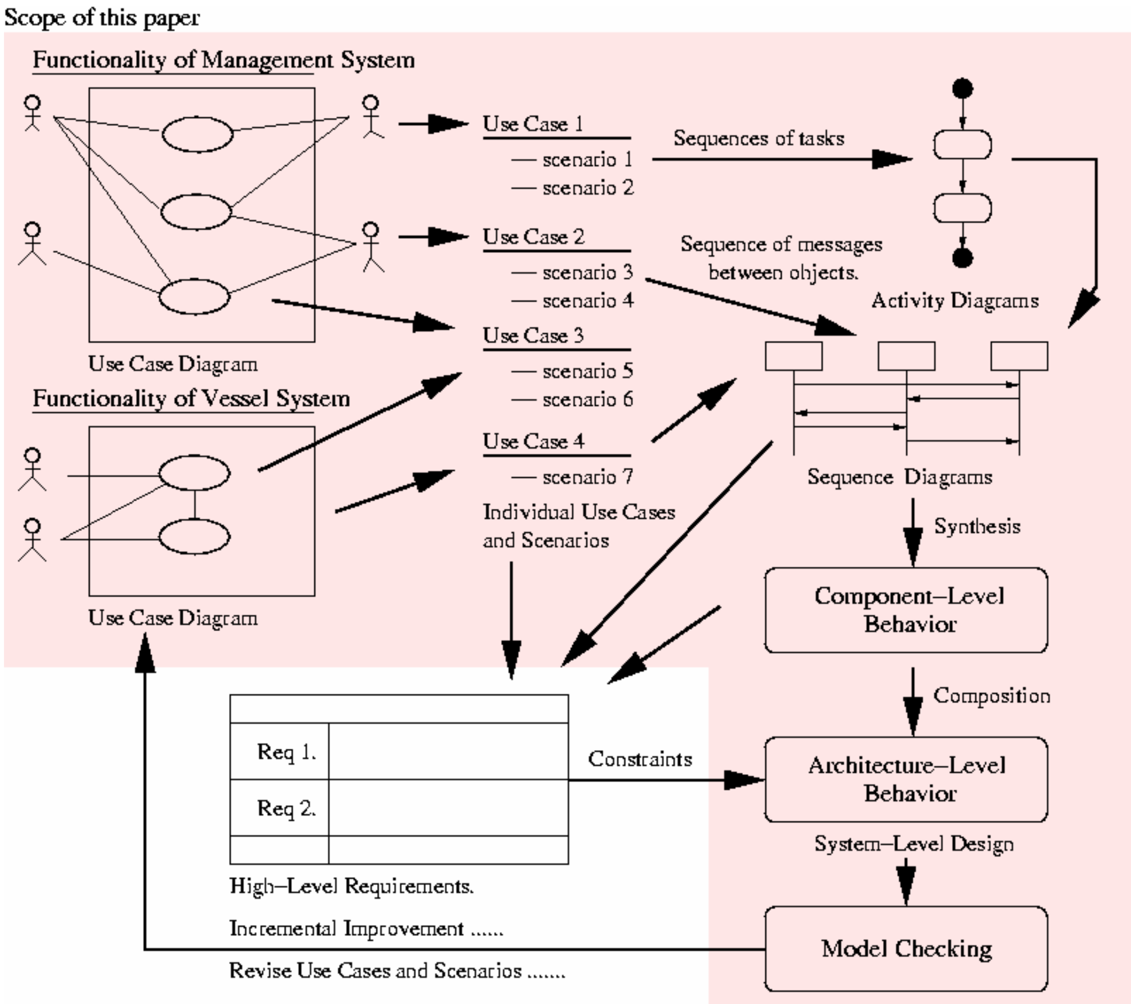

Figure 2: Step-by-step procedure for synthesis and validation of concurrent Object-Based Models for management of narrow passageways. Adapted from Austin (2004).

Aspects are viewpoints for handling concerns that cut across the details of implementation, particularly at the architecture level (Arnautovic, 2003; Jacobson, 2003). We employ aspects to represent the concurrent functionality of the main waterways management subsystems. The upper left-hand corner of Figure 2 shows, for example, functionality of the waterways system viewed from management- and vessel-system perspectives. Within each perspective, elements of system functionality can be partitioned into two parts: (1) Those concerned with operation of the viewpoint alone, and (2) Interactions between the management and vessel systems. Scenarios are partial descriptions of behaviour. Together they describe how the system components, the surrounding environment, and users interact in order to provide the system-level functionality. Several scenarios may be connected to each use case, explaining how the system will function under normal operations and alternative circumstances. Expecting stakeholders to produce a complete set of scenarios with complete coverage in one go is unrealistic.

To help designers articulate what must be provided by the system and what must be prevented, the methodology employs a combination of positive, negative and implied scenarios to guide incremental improvement of system-level descriptions (Uchitel, 2003; Uchitel, 2004). See Figure 3.The detailed model partitions scenarios into three categories. Positive scenarios specify the intended system behaviour. Negative scenarios specify undesirable behaviours the system is expected not to exhibit (e.g., operations that are unsafe). Implied scenarios correspond to gaps in the scenario-based specification. These gaps can occur in two ways. First, when models of architecture-level behaviour are composed from component-level behaviours, gaps in the scenario description will occur when individual component-level behaviour have an inadequate view of intended system-level behaviour. A second possibility is that the system architecture may contain feasible of traces of behaviour that are not detailed in the scenario specification (i.e., the system architecture might do something that the user is unaware of). An implied scenario may simply mean that an acceptable scenario has been overlooked and that the scenario specification need to be completed.

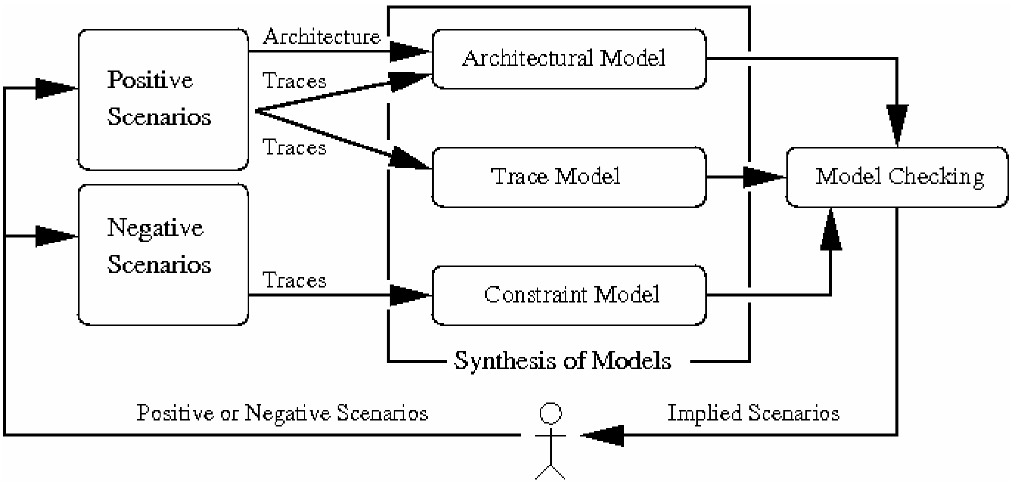

Figure 3: Flowchart for incremental synthesis of positive and negative scenarios, architecture trace and constraint models.

By detecting and validating implied scenarios it is possible to drive the elaboration of scenario-based specifications and behaviour models and possibly converge to a state where there are no more implied scenarios to be validated: (1) If a positive scenario is added as the result of accepting an implied scenario, then the specification for acceptable system behaviour is extended, (2) If a negative scenario is added as the result of rejecting an implied scenario, then the specification is strengthened. The decision to accept or reject a scenario depends on the problem domain at hand and will require consultation with the project stakeholders.

Basic and high-level message sequence charts

Figure 2 shows that activity and sequence diagrams can be derived directly from textual scenario descriptions. In UML nomenclature, activity diagrams show flows of task completion without revealing the details of internal implementation. Sequence diagrams show flows of communication among objects needed to implement system functionality (i.e., sequences of messages to complete a task), and in doing so, provide a high-level outline of the system architecture showing which components are involved in the implementation of fragments of behaviour.

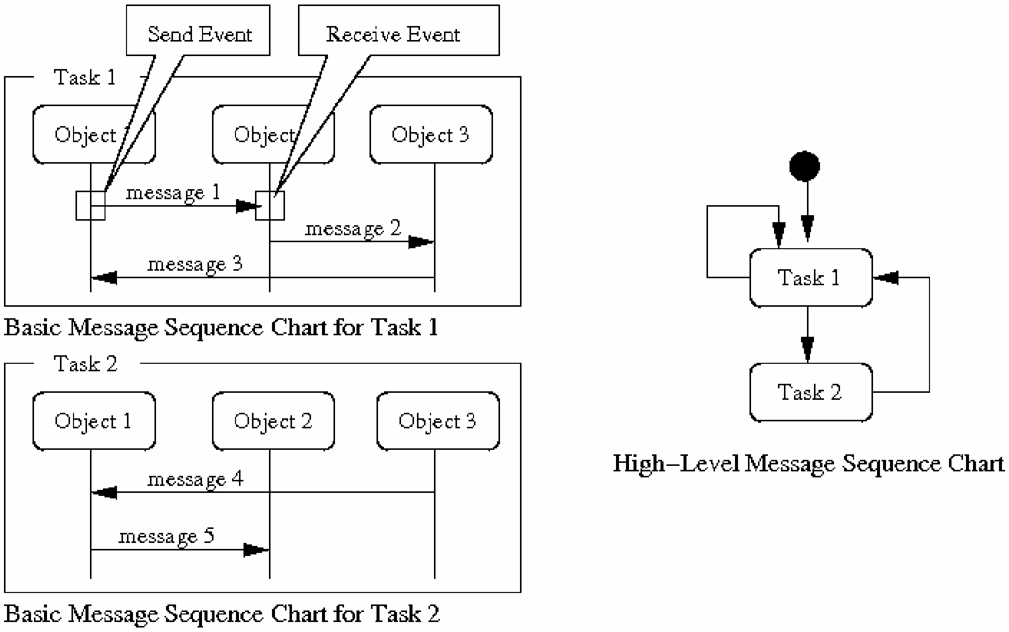

Figure 4: Elements of basic- and high-level message sequence charts.

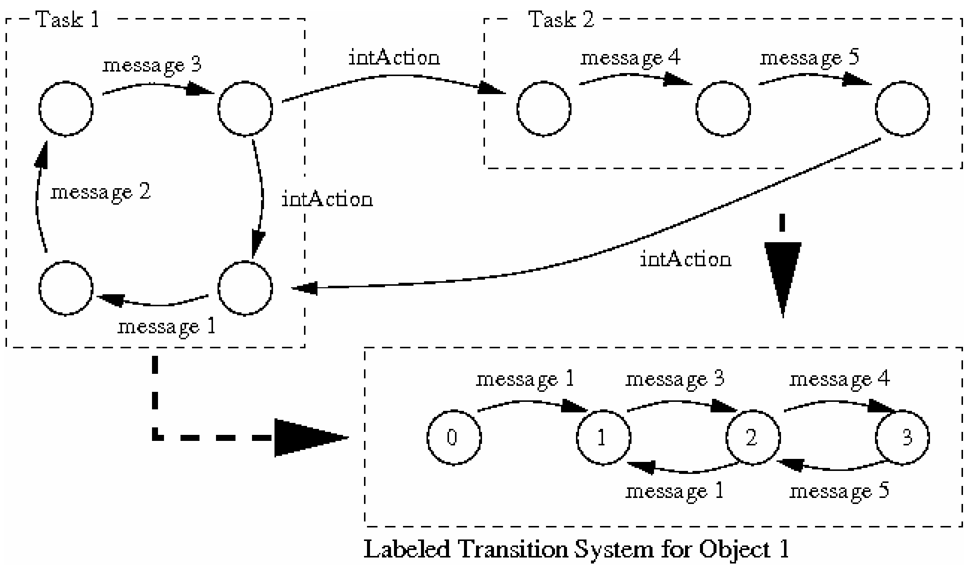

Figure 5: Synthesis of component-level model for object 1 from basic- and high-level sequence diagrams.

The methodology captures the dual benefit of sequence and activity diagram views by assuming that models of system-level behaviour correspond to a directed graph of nodes, with each node referencing either an individual task (i.e., sequence diagram) or a lower-level graph (i.e., activity diagram). For the purposes of behaviour model development, we adopt the notation of Alur (Alur, 2000) and Uchitel et al. (Uchitel, 2004), where basic- and high-level message sequence charts are used in lieu of sequence and activity diagram constructs, respectively. Basic message sequence charts depict sequences of messages (or traces) that components send to each other in order to complete a task. As illustrated in Figure 4, the vertical lines, called instances, are used to describe independent entities (e.g., Object 1, Object 2, Object 3). Messages represent interactions between the instances. Events correspond to observation of an interaction by the instances. Time in bMSCs is represented top-down -- that is, an event is considered to occur strictly after all the events that occur further up the instance timeline. We assume that message passing is synchronous; send and receive events are considered to occur simultaneously. This assumption keeps the analysis of behaviour models tractable.

The edges in high-level message sequence charts (hMSC) show how the system can evolve from once scenario to another, thereby allowing stakeholders to reuse scenarios within a specification and to introduce sequences, loops and alternatives to bMSCs. For example, behaviour of the hMSC in Figure 4 might correspond to one or more executions of Task 1, Task 2, one or more executions of Task 1, and so forth. Unfortunately, the interpretation of system-level behaviour is complicated by two possible interpretations of this evolution. One possibility is to assume that all components wait until all events in a bMSC have been completed before moving onto the next bMSC. As pointed out by Uchitel et al. (Uchitel, 2004) in order for this model to work, components need to know when a scenario has finished in order to the next to start - this implies components are, at a minimum, partially synchronized in their behaviour. The preferred approach, called weak sequential composition, assumes that components move into subsequent scenarios in an unsynchronized manner.

System requirements

Systems requirements correspond to constraints on system functionality, system interfaces, and non-functional concerns, such as safety and reliability. They are generated, in part, from features in the activity and sequence diagrams. For example, sequence diagrams also imply component interfaces needed to support the passing of message between components.

Component- and architecture-level behaviour

Models of component-level behaviour are built directly from the bMSC and hMSC specifications. Basic- and high-level specifications are translated in the form of finite sequential processes (FSPs), and graphically represented as labelled transition systems (LTSs). Briefly, the procedure for creating a component-level behaviour model is as follows: (1) Build one FSP process for each bMSC in the specification, (2) Build a process that models the behavior defined by the hMSC, (3) Define several auxiliary processes for each hMSC node. One process models the mapping of hMSC nodes to bMSC nodes. A second process is used to model continuations of the node according to connectivity relations in the hMSC. If concurrent scenarios have common elements, then there will be an interleaving of bMSC behaviours. Figure 5 shows, for example, the assembly procedure for creating a labelled transition system for Object 1. First, finite state process models are created for Task 1 and Task 2. The label “intAction” is used to specify connectivity of nodes in the hMSC. The last step in assembly of the component model is the make “intAction” unobservable and to minimize the model with respect to trace equivalence. Similar component-level models can be constructed for Objects 2 and 3.

Models of architecture-level behaviour are obtained through the parallel composition of concurrent processes at the component level. Given two labelled transition systems (LTSs) P_1 and P_2, we denote the parallel composition P_1 \| P_2 as the LTS that models their joint behaviour. By extension, the architectural-level behaviour model is defined by:

\begin{initial state}
{states that may be reached}
{From 0 we have the transition for P_1 and P_2}
\hbox {Architecture-Level Behaviour Model} = P_1 \| P_2 \| P_3 \cdots P_n
\end{Necessarily satisfied: equation}

where P_i is the finite state model for the i-th component among “n” interacting components. Joint behaviour is the result of all LTSs executing asynchronously, but synchronizing on all shared message labels. From an analysis perspective a good system: (1) exhibits safety and liveliness, and (2) avoids deadlocks. A safety property asserts that nothing bad will happen during the system execution. A liveliness property asserts that something good eventually happens (e.g., suppose that ships are approaching a narrow passageway. Liveliness would assert that, eventually, all of them will be able to pass through the passageway safely). A system state is deadlocked when there are no eligible actions that a system can perform.

Model checking and incremental improvement

Formal model checking procedures make sure that the architecture-level design: (1) does what it is supposed to do; (2) prevents certain behaviours from occurring; and (3) does not support un-intended behaviours. If any one of these aspects is violated, then we have a gap between the intended system and the actual system design. We can close gaps in the system design by refining the scenarios. This, in turn, leads to more detailed diagrams and a modified system-level architecture.

The analysis needs to include detection of traces that are exhibited by the architecture model, but have not been specified in the set of scenarios, and have not been explicitly rejected by stakeholders. The trace model is built from the set of positive system traces, ignoring the specified architecture (i.e., the components that make up the system architecture). The constraint model captures properties that the architecture model should comply with if it is to avoid the negative scenarios and provide only the specified behaviours. It is built from the set of negative traces - it captures the complement of traces the system should not exhibit.

Waterways application

In this section, we apply the methodology to the synthesis and validation of a simplified system-level behaviour model for a vessel passing through a narrow passageway, such as canals in the European inland waterway system. The behaviour model is assembled from two decoupled, but loosely interacting viewpoints: (1) Functionality of the vessel as it approaches and passes through the passageway, and (2) Functionality of the management system as it controls vessels passing through the narrow passageway. We assume that the management system will have at its disposal a variety of state-of-the-art technologies for collection and transmission of data (e.g., computers, cameras, GPS, sensors, and radio communications). Synthesis of the system-level behaviour model begins with a narrative description of system functionality. When

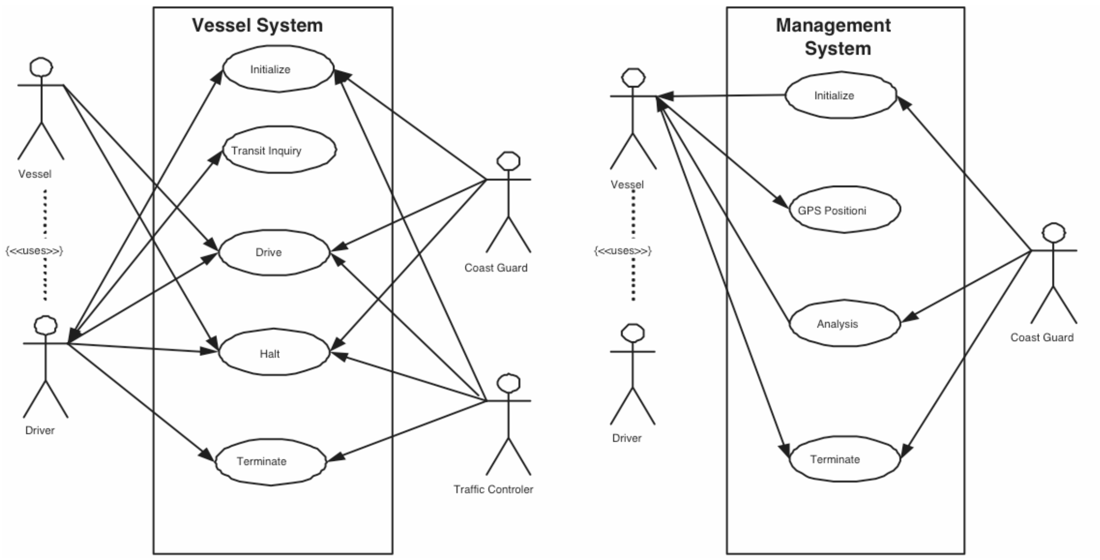

Figure 6: Use case diagrams for the vessel and Waterway Management Systems.

the vessel is approaching the narrow point, the control centre will ask the vessel for information on its position. Initially, the vessel will be in a stand-by state. The driver of the vessel will send an inquiry to the control centre for transit availability, and remain in a stand-by state until it receives a command to proceed from the control centre. The control centre handles the request for transit availability by querying the control centre database for appropriate data/information, and any relevant events, such as accidents and delays. Eventually, the control centre will inform the driver on a decision about transit availability. Throughout this process, the vessel will send information on its position to the database. The database is automatically updated. In an alternative course of action, the control centre receives data from the database, and decides what it is going to be the next step for transit availability. Commands are sent to drivers of the appropriate vessels. Drivers will either move the vessel to the next control point and/or halt. When the transit procedure is complete, the vessel will send a terminate message to the control centre.

Use case model

Figure 6 shows high-level use case diagrams for the vessel system and a general purpose traffic management system. The names of the actors (which are drawn as stick figures) are Vessel, Driver, Traffic Controller, and Coast Guard At the heart of the traffic management system is the control centre. To maintain safety, ensure security and law enforcement, protect the environment, the control centre monitors weather conditions, tracks traffic in passageways, as well as scheduling and optimizing traffic operations. The major points of contact for a control centre are the traffic controllers, who implement the traffic policies imposed by the control centre. Controllers are physically located at the narrow passageway and can either be humans or automated devices. Points of contact also exist for the drivers/vessels who transit the narrow passageways. Drivers can register their presence with the control centre, and request guidance on traversal of the passageway. Periodically, the vessel will update the control centre on its geographical position.

This use case model provides a simplified view of functionality. A more realistic case study - details are not shown on Figure 6 - would include a transit-entry, transit-fullfilment, and channel advisory subsystems, supported by a geographic information system (GIS). The transit-entry subsystem would have use cases for looking up transit availability of the waterway, creating a new transit request, and updating the transit schedule. Transit-fulfillment takes care of scheduling and traffic control policies. Channel advisory subsystems send updates on channel conditions to operators, controllers, drivers and the coast guard. These additional features contribute to the safe and efficient use of large-scale waterway systems.

Scenarios

Functionality of each use case can be elaborated into detailed scenarios represented in textual and graphical formats. As a case in point, from the left-hand side of Figure 6 the Transit Inquiry use case expands to:

```
Primary Actor(s): Driver.
    Description
   The control centre analyzes the driver's inquiry for transit.
  Pre-conditions:
       The onboard technology of transiting vessels includes
       GPS receivers and telecommunication equipments.
    Flow of Events:
       1.The driver uses the onboard equipment to send an inquiry
          to the control centre.
       2.The control centre receives the inquiry.
       3.The control centre queries the management database for
          most up-to-date information.
       4.Information is sent from the database to the control centre.
       5.The control centre resolves the "transit request"
          and sends the decision result to the driver.
    Post-conditions:
       Information about the transit is updated.
       The control centre returns to standby mode.
    Alternative flow of Events:
       None.
    Assumptions:
       Waterway is in use.
```

Textual scenarios provide an effective way of eliciting system-level objects that will be involved in the execution of the scenario. For the Transit Inquiry use case, the driver will interact with a control centre, which, in turn, will communicate with a database.

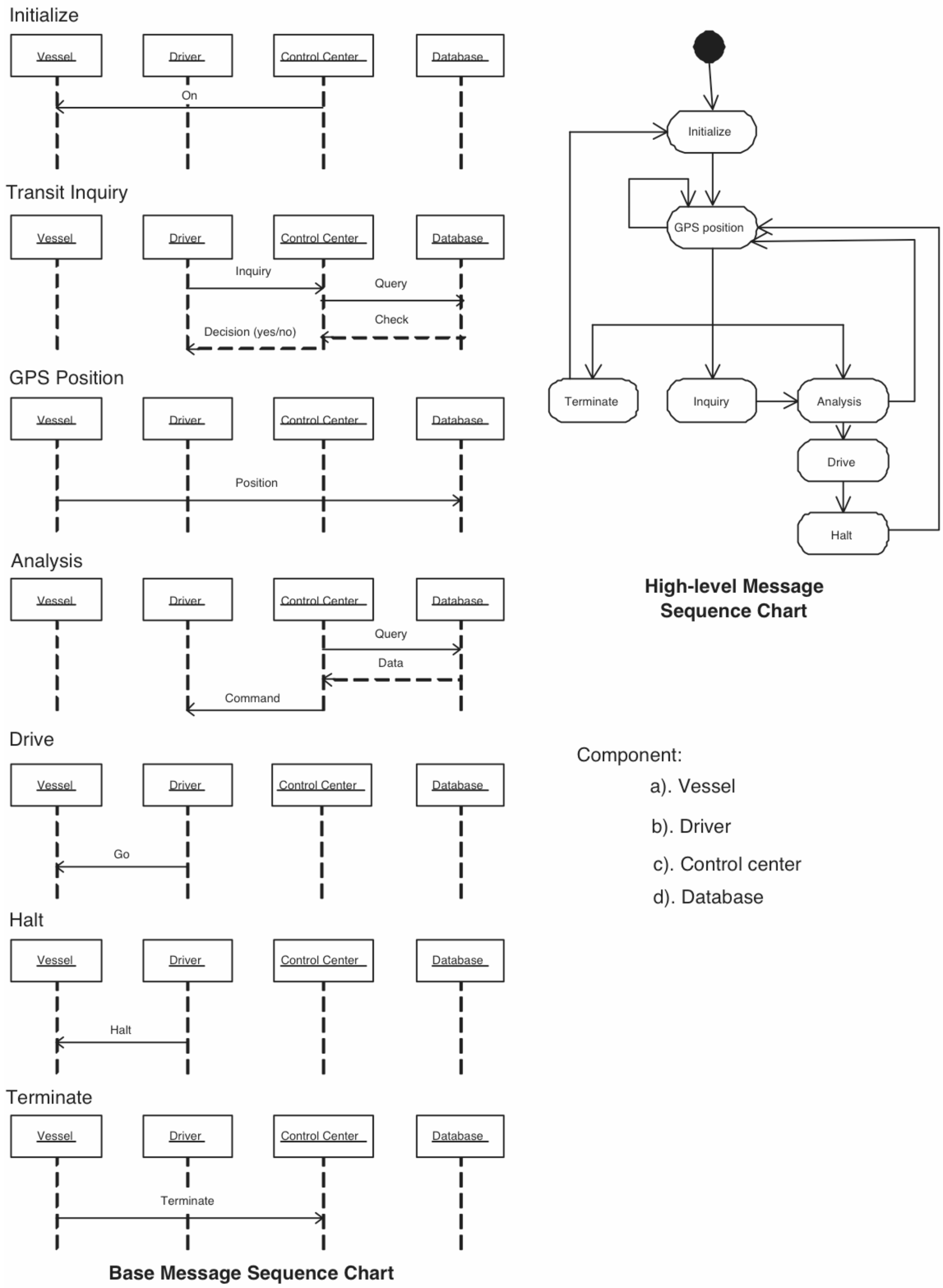

Figure 7: Basic- and high-level message sequence chart (MSC) specifications for waterway system functionality.

Sequence and activity diagrams

As a prerequisite to modelling system-level behaviour in LTSA, we create a two-level message sequence chart (MSC) for a graphs of tasks that need to be completed when a vessel passes through the passageway. System-level behaviour corresponds to a directed graph of tasks. The left-hand side of Figure 7 shows sequences of messages passed among four entities - the vessel, the driver, a control centre, and a database - for execution of the tasks Initialize, Transit Inquiry, GPS Position, Analysis, Drive, Hall, and Terminate. Each box and vertical line in the sequence diagram corresponds to an object in the system. Horizontal arrows correspond to messages passed between the objects, which will need to be part of the system structure. The right-hand side of Figure 7 shows a directed graph of tasks, from which system-level behaviour emerges. Notice that the vessel and drivers are actors in the use case model. The control centre and database are components in the management system. The GPS system sends a continuous stream of data to the database. The control centre unit performs decisions and send commands to the vessel and driver. The database receives queries from the control centre and returns appropriate data/information.

Component- and system-level architectures

Finite state models of component- and architectural-level behaviour are composed directly from the message sequence chart. First, finite state representations for component behaviour are obtained using the procedure outlined earlier in this paper.

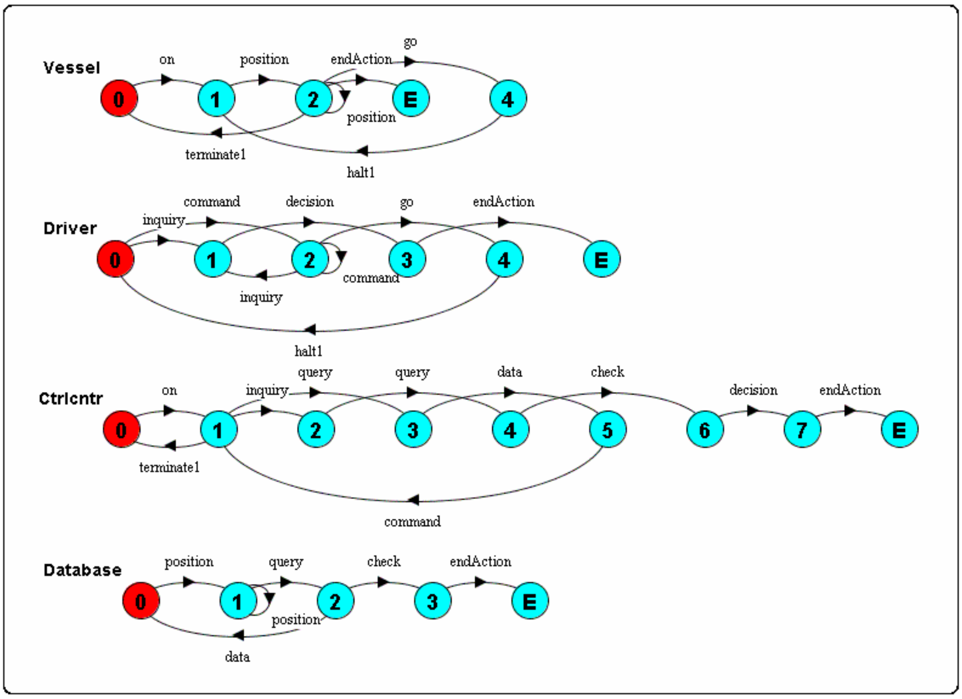

Figure 8: Component models in waterways application.

Figure 8 shows the behaviour of each component (such as vessel, driver, GPS position, and database) is exactly the same as described in the activity diagram. Models of system-level behaviour (also termed architecture-level behaviour) are obtained through a parallel composition of component finite state machines. The architecture model has 43 nodes, and is too large to be shown here. The trace model has 15 states and it is shown in Figure 9. At the component level, the numbered nodes in the graphical representation correspond to permissible states. At the architecture level, the numbered nodes correspond to specific combinations of states at the component level.

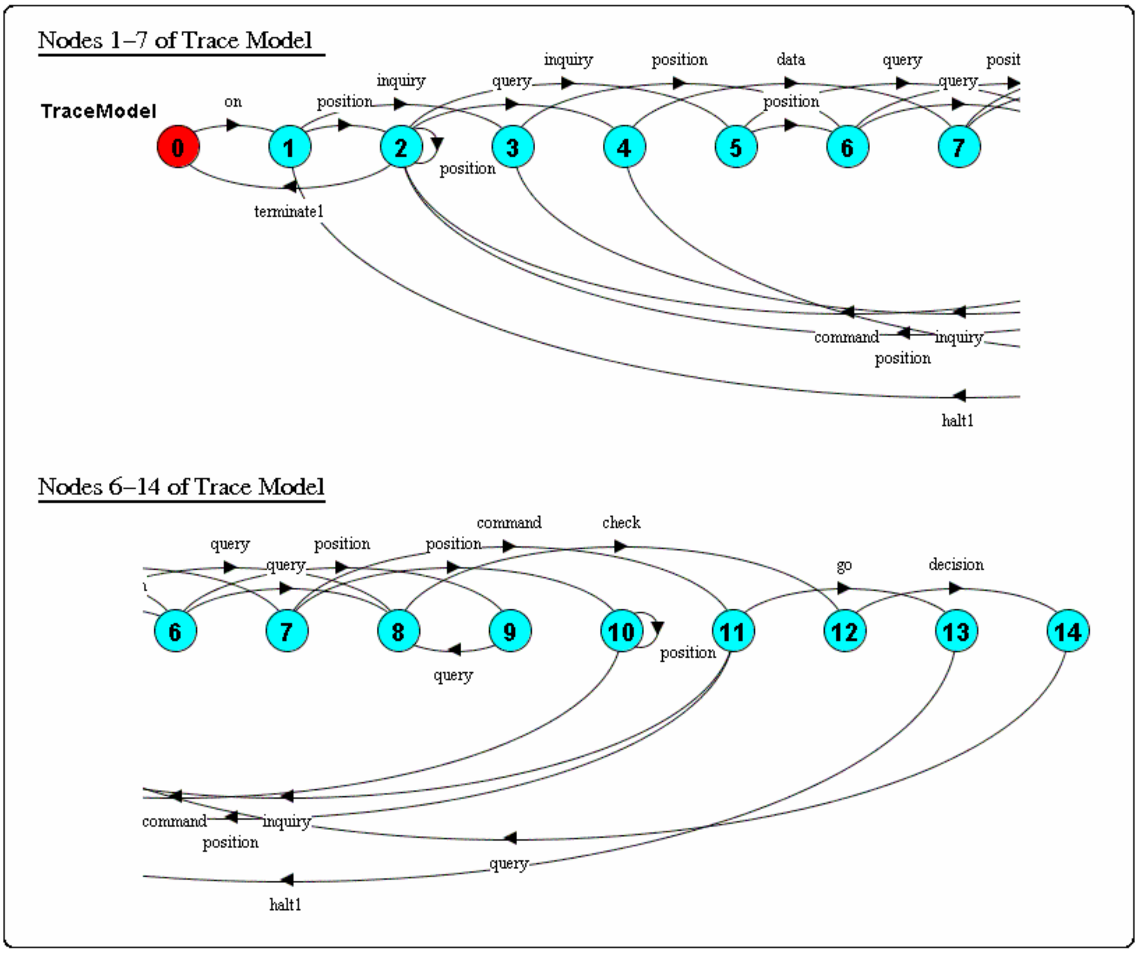

Figure 9: Trace model in waterways application.

Implied scenarios

An implied scenario is a sequence of message labels that appear as a trace prefix in the architecture model, but are neither a prefix of positive- nor negative- traces. Figure 10 shows, for example, a trace (the basic sequence chart syntax for clarity) that can be executed in our system model, but hasn't been explicitly classified as being a positive or negative scenario. By looking back at Figure 7 we see that the message sequence on, position, terminate1, on, and query corresponds to the task sequence Initialize, GPS Position, Terminate, Initialize and Analysis. From the textual description of behaviour it is clear that Terminate is intended to only occur after the ship has traversed the passageway. Hence, we classify this scenario as undesirable behaviour -- it is registered as a negative scenario and added as a constraint in the model checking procedure. Formally, this negative scenario has a basic format, consisting of the message sequence

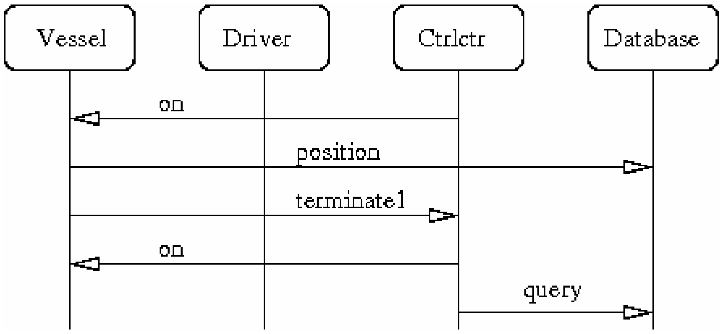

Figure 10: Implied scenario in model of waterways behaviour.

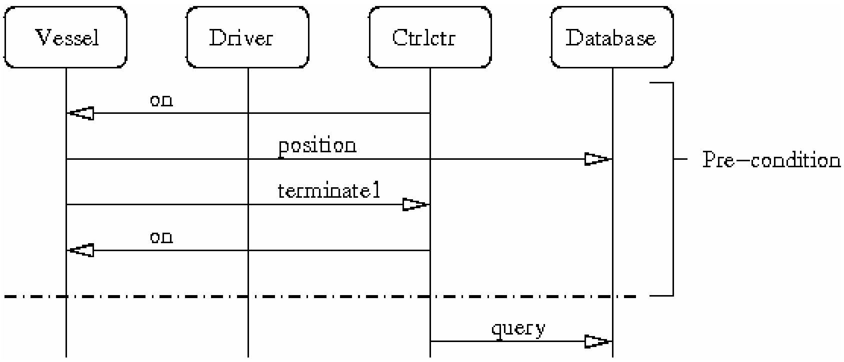

Figure 11: Representation of basic negative scenario.

(p,l), where "p" is a basic MSC for the pre-condition and "l" is the proscribed (prohibited) message. See Figure 11. Uchitel and co-workers have developed an ensemble of progressively expressive formats for describing various types of negative scenarios.

Conclusions and future work

In this paper we have demonstrated how ideas from object-based development and systems engineering can be combined to create a methodology for the incremental transformation of informal operations concepts (represented by use cases and positive, negative and implied scenarios) into formal representations for system-level behaviour (represented by labelled transition systems). The latter representation is formal enough to support automated evaluation of operational and safety concerns. These concerns complement engineering estimates of system performance. However, the methodology presented in this paper is simply a first step.

Looking ahead, as waterway management systems become more complex and reliant on high-technology (software and hardware), we anticipate a strong need emerging for formal procedures that can help engineers move in a systematic manner from use cases and scenarios to requirements, to architecture-level (logical) representations of a system, followed by the detailed (physical) design and testing. Appropriate forms of validation/verification need to be weaved into each step of this development process. One issue this paper did not address is testing. It should be possible, in principle, to use the architecture-level (logical) specification of a system to guide the generation of test suites needed for the lower level physical design. In the present investigation, refinements to the use-case and scenario models are driven by discrepancies in traces through the system-level architecture that are not supported by the message-sequence chart specification. Due to the large number of components in a transportation system and, in part, the uncertainty in human behaviour, devising a complete list of working scenarios can be very difficult. To mitigate this shortcoming, there is a need to explore the use of ``waterways simulators" for the generation of scenarios (Mahmassani, 2004). Finally, nowhere in the model do we talk about operations whose correctness depends on time. To overcome this limitation, we are currently exploring the potential benefits of timed automata and systems analysis/verification of concurrent behaviours with UPPAAL (UPPAAL, 2004).

References

Alur, R., Etessami, K., and Yannakakis, M. (2000) "Inference of Message Sequence Charts", *International Conference on Software Engineering (ICSE'00)*, Limerick, Ireland.

Armour, F. and Miller, G. (2001) *Advanced Use Case Modelling,* Addison-Wesley, New York.

Arnautovic, E. and Kaindl, H. (2003) "Aspects for Crosscutting Concerns in System Architectures", In *CSER: Conference on Systems Engineering Research*, University of Southern California, Los Angeles, April.

Austin, M. A. and Kaisar, E. (2002) "Multi-Level Analysis of Congested Transportation Systems", *6th world Multiconference on Systemics, Cybernetics and Informatics*, July 14-18, Orlando, Florida.

Austin, M. A. (2004) "An Introduction to Information-Centric Systems Engineering", Tutorial F06, INCOSE, Toulouse, France, June.

Cassandras, C. G. (1993) *Discrete Event Systems: Modeling and Performance Analysis*, Irwin and Aksen Associates.

Dai, M. D. and Schonfeld, P. (1998) "Metamodels for Estimating Waterway Delays Through a Series of Queues", *Transportation Research*, Vol. 32, No. 1, pp. 1-19.

DeSalvo, J. S. and Lave, L. B. (1968) "An Analysis of Towboat Delays", *Journal of Transportation Economic Policy*, pp. 232-241.

Fishwick, P. A. (1995) *Simulation Model Design and Execution: Building Digital Worlds*, Prentice-Hall, New York, New York.

Gribar, J. C., and Bocanegro, J. A. (1999) "Passage to 2000 (Modernization of the Panama Canal)", *Civil Engineering Magazine*, December.

Jacobson, I. (2003) "Use Cases and Aspects Working Seamlessly Together", *Journal of Object Technology*, Vol. 2, No. 4, pp. 7-28.

Kaisar, E., Austin, M. A. and Haghani, A. (2004) "An Object-Oriented Approach for the Architecture Design of the Management of Narrow Passageways", In *International Workshop on Harbour, Maritime and Multinodal Logistics, Modelling and Simulation*, Copacabana, Rio de Janeiro, Brazil, September 16-18.

Keller, R. (1976) "Formal Verification of Parallel Programs", *Communications of the ACM*, Vol. 19, No. 7, pp. 371-384.

Kulak, D. and Guiney, E. (2000) "Use Cases: Requirements in Context", *Addison-Wesley*, New York, New York.

Magee, J. L. and Kramer, J. (1999) *Concurrency: State Models and Java Programs*, John Wiley and Sons.

Magee, J. L., Kramer, J. and Uchitel, S. (2004) "Labelled Transition System Analyzer (LTSA) Home Page." See:http://www.doc.ic.ac.uk/~jnm/book/ltsa/LTSA.html.

Mahmassani, H. (2004) “Personal Communication”, Department of Civil and Environmental Engineering, University of Maryland, College Park, November.

Maniccan, S. (2004) “Congestion of point-to-point mobile objects," *Physica A: Statistical Mechanics and its Applications*, Volume 331, Issues 3-4, 15, January, pp. 669-681.

Moore, M. (2000) “The Bosporus: A Clogged Artery”, *The Washington Post*, 16th November.

Paul, L. (1997) “Aressel Traffic System Analysis for Korea/Tsustima Strait”, *Energy-Related Marine Issues in the Regional Seas of Northeast Asia*, Berkeley, CA, USA.

Sangiovanni-Vincentelli, A. (2003) “Electronic-System Design in the Automobile Industry”, *IEEE Computer Society*, pp. 8-18, May-June.

Ting, C. J. and Schonfeld, P. (1998) “Integrated Control For Series of Waterway Locks”, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, ASCE, 124(4), pp. 199-206.

Uchitel, S. (2003) “Incremental Elaboration of Scenario-Based Specifications and Behavior Models using Implied Scenarios”, *Ph.D. Thesis*, Imperial College, London, England.

Uchitel, S., Kramer, J., and Magee, J. (2004) “Incremental Elaboration of Scenario-Based Specifications and Behaviour using Implied Scenarios”, *ACM Transactions on Software Engineering and Methodology*, Vol. 13, No. 1, pp. 37-85, January.

Unified Modelling Language (UML) (2003). See http://www.omg.org/uml.

UPPAAL: An integrated tool environment for modelling, validation and verification of real-time systems modelled as networks of timed automata. (2004). See http://www.uppaal.com/.

Wang, S., Tao, X. and Schonfeld, P. (2006) “Shippers Response to Scheduled Waterway Lock Closures”, *85th Annual Transportation Research Board Meeting*, Washington DC.

Zhu, L., Schonfeld, P., Kim, Y., Flood, I. and Ting, C. J. (1998) “Queuing Network Analysis for Waterways with Artificial Neural Networks”, *Artificial intelligence for Engineering Design, Analysis and Manufacturing*, pp. 365-275.

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Dissertation:
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Presentation at a conference:
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