THE POTENTIAL USE OF THE CIVIL ROTORCRAFT FOR INTERCITY PASSENGER TRANSPORT SERVICES

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1 Abstract

There are many high-speed rail (HSR) projects in Europe at different stages of development. The feasibility of these projects has been largely based on their capability to capture passengers in the inter-city travel market, both those using private car and air transport, especially in the business market and for trips of less than 600 Km.
The main socio-economic benefits of HSR projects depend on the energetic sustainability of the electric traction rail and on a reduction in delays at congested airports due to the traffic shift. On the other hand, HSR projects absorb very high investment costs take a long time to realise and involve high financial risks.
Based upon these considerations, there is a new interest in the development of innovative air passenger transport systems and services based on civil rotorcrafts.
Both the helicopter and the tiltrotor are taken into consideration. Helicopters belong to a mature vehicle technology, but their use in commercial aviation is still rare. The civil tiltrotor, after more than twenty years of research and development activities, is ready to begin commercial transport passenger services.
The scope of this paper is to assess the potentiality of civil rotorcrafts, as part of the air transport system, to improve the interurban transportation networks at domestic and/or regional level. To this aim some discrete mode choice models have been used to forecast traveller choice behaviour when the rotorcraft is introduced among other competing modes.
Then, based on operating costs and willingness to pay for the service of the different competing transport modes, a financial feasibility evaluation will be conducted, from the vector point of view.

2 Introduction

Air transport liberalization has favoured hub-and-spoke flight network configurations, both in North America and in Europe. In order to be more competitive, airlines often privilege the provision of high frequency services, thus resulting in a reduction in the average size of aircraft. Large airports have longer waiting times than the smaller ones, even though one would expect shorter waiting times given the higher frequencies of services. The consequence is that, generally, passengers must wait at hub airports for their connecting flights for longer than is necessary, since the flight co-ordination is less efficient and minimum connecting time is higher. Besides, not only does this cause congestion on the ground, it also means that far more effort is necessary to control all the aircraft trying to use a limited amount of space [14].
In accordance with the guidelines of the EU White Paper [7] the available airport capacity in Europe will not be able to respond to the predicted growth in air traffic . As the construction of new airport infrastructures is limited to a very few cases, a general rethinking of a more efficient use of airport capacity is needed. To this end the competition between rail and air transport with high speed connections between cities is considered a way of transferring airport capacity to routes, where High Speed Rail (HSR) is not available.
At the moment in Europe there are 3039 km of high speed lines in operation, 2723 under construction and 1875 at the planning stage [8].
The main socio-economic benefits of HSR projects lie in the energetic sustainability of electric propulsion and in the reduction in delays at congested airports due to the traffic modal shift. From the traveller's point of view, HSR is often the preferred transport mode for short haul journeys, as the benefit of very high speed of flights is diminished by the distance of the airport from the origin of the trip, by the congested ground links for gaining access to the airport and by the considerable time spent in check in and check out operations at the terminals or by time penalties incurred on indirect flights via a hub. When travelling by air, the time spent reaching the airport, walking around and waiting at the airport is close to 3 hours. When travelling by rail this time is reduced to about 1 hour, so, even if the

time on board is much longer, under a certain distance, the total journey time is shorter by rail.

On the other hand, HSR projects suffer from several shortcomings, they:

- involve very high investment costs;
- may cause significant environmental impact due to the huge civil works needed;
- require long construction times;
- have high financial risks to be sustained;
- are justified only when a high traffic corridor is well established.

The recent development of innovative air transport systems based on civil rotorcraft used for commercial passenger transport services might contribute to overcoming both the lack in airport capacity and the HSR drawbacks, playing a simultaneous role of cooperation and competition with rail and traditional air modes.

Rotorcrafts belong to a class of vehicle where one or more rotors sustain both the function of aerodynamic suspension and propulsion. They are also called rotating wing aircraft as opposed to traditional fixed wing aircraft where aerodynamic lift is supplied by fixed wings and propulsion by a set of jets or turboprop engines. Rotorcrafts belong to the category of VTOL (Vertical Take Off and Landing) aircraft due to their ability to perform take offs and landings without a runway. It is a category of aircraft to which the helicopter traditionally belongs and, more recently, the tiltrotor. This latter is an aircraft that, using two blade rotors tilting around the transversal axis, can perform with the flexibility of a helicopter during approach, take off and landing phases, while flying at the speed and with the operating costs of a fixed wing during the cruising phase [9].

The current generation of advanced technology helicopters and the new civil tiltrotor aircraft offer the ability of true Class 1 performance operations with continued flight even with one inoperative engine. Thus these vehicles are comparable to operations with fixed wing passenger carrying airplanes [16]. Modern rotorcrafts can generally be used in all weather conditions. Flight cruising speed has increased with modern helicopters in the 240 - 300 km/h range. Civil tiltrotors, such as the Bell Agusta BA609, offer even greater performance with cruising speeds of 500 km/h.

Rotorcrafts play a part in a wide range of aviation activities, including law enforcement, fire fighting, emergency medical services, traffic reporting and corporate transportation, etc.

The scope of this paper is to assess the potentiality of the civil rotorcraft, as part of the air transport system, to improve the interurban passenger transportation networks at the domestic and/or regional level.

The main benefits of civil rotorcrafts may be identified as follows:

- reducing airport congestion and traffic delay, by using on-airport vertiports to drain off short-haul transit travellers, so releasing runway capacity for larger aircrafts; typically, at most major hub airports, 25-30 percent of the total aircraft operations are with regional aircraft seating 50 passengers or less; rotorcraft vertical lift technology offers the potentiality for separating a portion of these operations from the fixed-wing runways to VTOL sites on the airport and allowing more of the larger capacity fixed-wing aircraft to use the runways (see [1] [2], [3]and [9]);
- reducing airport congestion and traffic delay, by using off-airport vertiports for city centre to city centre services, shifting travellers from congested hub airports and from congested ground access road links;
- increasing the economic life of an airport without large investments;
- increasing the effectiveness of the transport supply by providing a door-to-door service with significant time savings for the traveller, also for regional air transport services characterised by a low intensity of traffic;
- guaranteeing the access and mobility rights for smaller communities, such as the minor islands or the internal towns of Sicily, where the lack of airports or of suitable surface transport infrastructures compromises social and economic development.

To assess the potential market of rotorcraft passenger services, we need a tool which is able to forecast traveller choice behaviour between different competing modes. We will refer to discrete mode choice models, based on the random utility economic theory, to estimate the share of the passenger market which could be attracted by a commercial civil rotorcraft service.

Then, based on the operating costs and on the willingness to pay for the service of the different competing transport modes, a financial feasibility evaluation will be conducted, from the vector point of view, in terms of direct operating costs.

3 Literature Review

According to recent studies [18], the market for high speed rail is stronger in countries where distances between large cities are approximately in the 300-600 km range. The construction of high speed lines is likely to be less difficult in sparsely populated countries. From this point of view, France, Spain and Japan are ideal countries for HSR networks; German and Italy have a number of cities in the right range, but many other cities are sufficiently close together for a conventional rail mode to be competitive, so, only the need for additional capacity can justify the construction of high speed lines. In countries like Australia, the biggest cities are generally so far apart that high speed rail could not compete with air travel.

Other studies focus on the possibility of cooperative integration of high speed rail and air transport. The European Commission research COST 18 [24] points out that high speed rail traffic can successfully compete with air traffic; air traffic, on the other hand, offers good development possibilities where the demand is not too high; within the framework of a system, high speed travel rail and air traffic can complement each other well, they are usually also competitors; attractive rail connections with airports allow access costs to be minimized with respect to both waiting times and external costs.

A U.S. study [25] found that magnetically levitated (maglev) vehicles and tiltrotor aircraft are among the technologies that could improve passenger mobility at large terminals and in the most crowded intercity corridors in the United States in the long term. However, like all new transportation systems, both the tiltrotor and maglev will be expensive to develop and establish, and some form of government support will be necessary. Furthermore, complementary policies, programs and standards must be developed and implemented, if these technologies are to help resolve any of the congestion problems besetting transportation.

Many research approaches deal with passenger behaviour, as regard their modal choice between air and other transportation modes, paying particular attention to the impact high-speed train services may have on the air transportation market in Europe (see [6] for a complete literature review).
The problem of the modal choice is maybe one of the most important issues in transportation planning.
One might think there is not much to discuss: when transport choices are given, distances and journey times are known, passengers will choose the fastest transport, which is a reasonable conclusion based on the rationale of time saving. But there is much more to a journey than a simple equation of time, distance and speed. Many other dimensions and attributes affect the choices of travellers, whose awareness and responsiveness to price, time, comfort, service availability, etc, vary considerably among different categories of customers.

Transport planners and transport companies are greatly interested in understanding how people choose between different transport modes when making a journey. A knowledge of traveller behaviour allows transport planners to programme the right set of infrastructural, organizational and institutional operations to match a sustainable mobility demand and allows transport companies to adopt the most effective and efficient management strategy for catching travellers when competing with other vectors.
Discrete choice models belong to a well consolidated technique, widely used today for this scope. They are based on the Random Utility Theory and enable the calculation of the probability of individuals choosing a given option as a function of their socioeconomic, characteristics and of the relative attractiveness of the options [10]. A comprehensive scientific literature on choice models can be found in [11] and [12].

The main hypotheses of discrete choice models are:

- each decision-maker has a finite set of mutually exclusive alternatives that constitute the choice set and that can be explicitly listed;
- each decision-maker selects the alternative with the highest utility among those available;
- utility is modelled by a function of observable independent variables, called attributes, and unknown parameters, these latter being estimated from a sample of observed choices.

Some attributes are generic to all alternatives and some are alternative-specific. Random utility models attempt to capture the complexity of human behaviour: the decision rule is assumed to be rational and deterministic (the decision-maker always chooses the alternative with the highest utility), but utility is represented as a random variable. In mathematical terms, this is obtained by separating the total utility U^i_j that the decision maker *i* associates to the choice of the mode *j*, into a deterministic component V^i_j called systematic utility, and a random component ε_j, called random disturbance.

$$U^i_j = V^i_j + \varepsilon_j$$

The random disturbance captures different sources of uncertainty, such as unobserved attributes which influence the decision, unobserved taste variations among different categories of individuals or measurement errors of the values of attributes.
When random utility theory is used, the model is not able to calculate which alternative will be chosen but the probability of each alternative

being chosen. Of course, the probability is a monotone decreasing function with the associated utility. The probability of any alternative *j* being selected by person *i* from a choice set I_i is the following:

$P^i(j/I_i)=P(U^i_j > U^i_k)\ \forall\ k\neq j,\ k \in I_i$

or

$P^i(j/I_i)=P(V^i_j - V^i_k > \varepsilon_k-\varepsilon_j)\ \forall\ k\neq j,\ k \in I_i$

If the random terms of the utility functions are independently distributed, identically distributed and Gumbel distributed with parameter α, the probability may be calculated by a Multinomial Logit model as:

$$P^i(j)=\frac{e^{\alpha V^i_j}}{\sum_{k\in I_i} e^{\alpha V^i_k}}$$

4 Methodology

Hereafter we will refer to a set of mode choice Logit models specified and calibrated for the Eurocontrol CARE project ([6]). They are based on a sample of 25 European city-pairs which are significant for traffic air/rail competition.
The attributes considered as explanatory variables are:

- travel times;
- fares;
- service frequency;
- dummy variables;
- alternative specific attributes.

Travel time. Time is the most critical choice attribute, both for business and leisure travellers. As already pointed out, the main advantage of the high speed train (HST) is the short station access time with respect to airports which are often sited far away from the city. The total travel time for all the modes between each city pair has been considered.
Both air and rail travel time consist in:

- access and exit time to reach and leave the terminals;
- terminal time for check in and check out operations;
- on board time.

Fare. As is well-known, price elasticity is influenced by the scope of the travel: it is substantially higher for leisure travellers. But the main complexity in dealing with travel fares, especially by air, lies in dealing with a large number of ticket categories, determined by revenue management strategies adopted in the liberalized air transport market.

Service frequency. The number of train or flight departures for each city pair has an explicit effect on the modal share, as it reduces the so-called frequency delay, which represents the elapsed time between an individual traveller's preferred time and the time of a scheduled departure [13]. The variable used for this attribute is:

$$PER=\frac{60\cdot 19}{N}\ \text{(min)}$$

being *N* the number of daily flights or trains between a selected city pair and 19 is the virtual number of daily service hours, taking into consideration the absence of HSR service during the night. The model uses the variable $\ln(PER)$, to consider that travellers show higher demand elasticity when the frequency is high.

Alternative specific attributes. The Alternative Specific Attribute (ASA) or modal preference is used to include in the utility function the influence of all the characteristics of the alternative, such as comfort, reliability, and others, that are not observed or that are difficult to determine. It expresses the preference for one transport mode when all other attributes are identical for each alternative.
We will refer to four different model specifications, whose parameters are indicated in Table 1. The general systematic utility function for the generic transport mode has the following expression:

$$V_{MODE} = \beta_{TIME}\,TIME_{MODE} + \beta_{FARE}\,FARE_{MODE} + \beta_{PER}\ln(PER_{MODE}) + \beta_{MODE}MODE$$

Table 1 – Model attributes and relevant parameters

	Estimated parameters			
Attribute	*Model 1*	*Model 2*	*Model 4*	*Model 5*
TIME	-0.012	-0.012	-0.007	-0.008
FARE		-0.004		-0.003
ln(PER)			-0.586	-0.521
ASA	-0.840	-0.660	-0.760	-0.631
	General tests			
R2	0.769	0.793	0.848	0.851
Ftest	84.275	48.798	72.019	46.571

With regards to the relative importance of attributes, the results show that users are more responsive to travel time than to fare. This is a common output in the mode choice process, especially for business travellers. Models 1 and 4 do not consider fare as a choice variable, models 2 and 5 show a low parameter of the fare variable. This is probably caused by two coexisting reasons. The first is the dominance of business trips for the selected city-pairs, which are mainly oriented to travellers who do not pay for their ticket themselves. The second is that fares are not easily handled as a clearly perceived variable, due to the large number of ticket categories with different, changeable price levels, related to yield management techniques applied, above all, by airlines. Several studies that used aggregate fare measures failed to obtain the expected signs for the fare variable [20].

5 Case Study

The thesis we wish to pursue is the following: HSR services may divert traffic from air mode on short haul routes as the lesser train speed is compensated by the saving in terminal access/exit times. In fact, the significant distance of airport terminals from cities, to reduce the impact of air traffic noise, is still increasing as low cost carriers often choose peripheral terminals to pay less in airport charges.

This traffic modal shift is bringing benefits as it alleviates the problems caused by the lack of capacity at airports; we want to assess if the same benefits may be obtained using rotorcrafts, which takeoff and land in small terminals (vertiports) sited in the centre of cities without interfering with traditional air traffic, with rapid access/exit to/from the terminals, as for train stations, while not requiring the huge infrastructure costs of HST lines.

We will use four mode choice models described in paragraph 4, in order to analyze different competing transport mode scenarios and to assess to what extent civil rotorcrafts are capable of competing for the market share over different distance journeys.

To perform the choice model, an equilibrium iterative procedure is applied: this means that the number of travellers who will choose one transport mode among the available alternatives is affected by the service frequency and this is set by the company as a function of the traffic to be served. So the iterative procedure begins by calculating the number of passengers shared by each mode, using a starting value of the service frequency, then frequency is recalculated as a function of the value of each mode and a new value of the modal share is obtained. The algorithm goes on until the convergence is reached.

With reference to the choice model, we may say that the market share of mode j is d_j and that it is calculated as

$$d_j = P_j \cdot d$$

being d the total demand between the origin and the destination selected, and P_j the probability that mode j will be chosen. In accordance with the choice model, P_j depends on the utility associated to mode j which is influenced by the service frequency (the *PER* attribute of the model), but the transport operator selects the service frequency as a function of the traffic demand to be served. In formulas:

$$d_j = P_j\, [V_j(PER(d_j))] \cdot d$$

The fare variable also affects this equilibrium procedure as it is calculated as equal to the unit direct operating cost per passenger-km, being itself influenced by the market share obtained by the transport mode.

The technical specifications and performances for the vehicles selected for this study and which are relevant to the choice model are now reported.

In the helicopter category, the AB139 medium twin-turbine helicopter developed by Bell Agusta Aerospace and Agusta Westland has been considered; it has both the JAA European and FAA certification; the AB139 is available in civil configuration, and is capable of carrying up to 15 passengers.

The engines give a maximum cruising speed of 310 km/hour and a maximum range (without reserves) of 1000 km. Due to the power reserve of the engines, safe flight is ensured even with one engine inoperative at maximum take-off weight ([5] and [17]).

As regards the tiltrotor we refer to the BA609, developed by Bell Agusta Aerospace and Agusta Westland; it is the world's first commercially available tiltrotor aircraft. It has a two-person crew and can carry up to 9 passengers. Dual certification (FAA and European) is planned for 2008. BA609 has a composite fibre-placed fuselage with an aluminium internal structure, a pressurised composite cabin and two composite three-bladed prop rotors on swivelling nacelles. With its nacelles in the vertical position, the tiltrotor is able to take-off, land and hover like a traditional helicopter. With the nacelles in the horizontal position, the tiltrotor is able to fly with the high speed and range of a turboprop fixed wing aeroplane. The BA609 is pressurised to fly at altitudes of up to 7620 meters and its anti-ice/de-icing capability with heated rotor blades allows flight in known icing conditions. It can cruise at 510 km/hr with a range of 1,390 km ([4] and [17]).

In the field of conventional fixed wing aircraft, the Boeing 737-300 has a cruising speed of 800 km/h, a maximum range of 2970 km and capacity for 128 passengers. It has been selected for the study as it is the most common narrow-bodied aircraft, typically used on short haul flights.

For the rail mode, the Italian ETR500 high speed train has been considered, with a passenger capacity of 450. It has two edge traction units, each equipped with asynchronous three-phase electric engines, supplied by a 3000 V d.c. electric line. The engines are driven by a two stage system: the first is a chopper converter used to lower and stabilise the line voltage, the second is a three-phase inverter which feeds the permanent bridging connected motors. Total power is 4400 KW and maximum speed is 300 km/hour on 1.8% grade.

6 Case Study results

Under 400 km the HST is competitive with the airplane, corresponding approximately to a 3-hour door-to-door journey by HST; this is a threshold below which a passenger can make a return trip and still have a productive day, while above this threshold he incurs overnight hotel costs. So the extension of the high speed network may be justified by the traffic generated on short segments than on end-to-end journeys (Figure 1).

If the journey time by HST is more than 5 hours, the aeroplane is highly competitive, while between 3 and 5 journey hours by train, the passenger's choice is greatly affected by qualitative issues other than time, such as mode network connectivity, service frequency, fare, ground access, etc.

If passenger transport by rotorcraft were introduced, the tiltrotor would always be the fastest alternative. The HST and helicopter enable journeys over short and medium distances to be made quicker than fixed wing aircraft. The helicopter offers advantages also over medium-high distances, while the conventional aircraft is the best alternative only for very long journeys, outside the range of the graph.

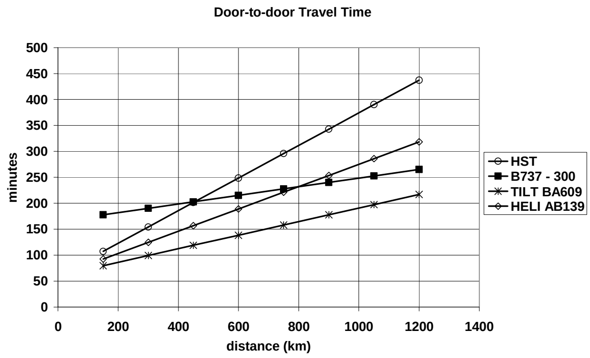

Figure 1 - Door to door travel time

The presence of the helicopter over distances under 450 km seems to eliminate the ability of the HST to compete with the aeroplane in terms of door-to-door travelling time. When journeys are more than about 800 km, the fixed wing aircraft is faster and, moreover, the helicopter is outside its technical range. The competitive rail markets become more niche-focused (night services, car transport service, etc.). Of course, the exact range of journeys over which each mode is competitive, at least in terms of journey time, varies depending on assumptions about time required for terminal access, check-in, etc.

Figure 2 shows the performances of the different modes in terms of overall speed, calculated including check-in and check-out times, but excluding access and exit times. For every transport mode, overall speed increases with the distance, but the rate of gain is slight for the HST and helicopter when the distance is over 400 km, over 800 km for the tiltrotor, while airplane overall speed continues to grow also for long range journeys.

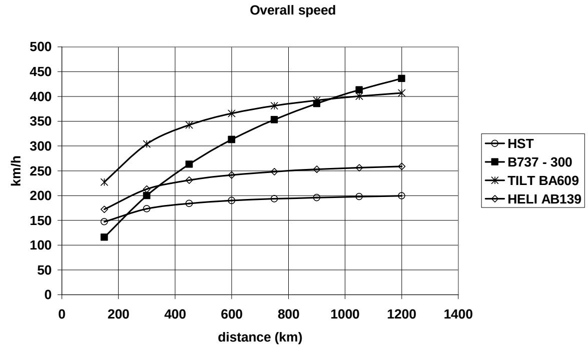

Figure 2 – Overall speed of airplane, train and rotorcraft

Market share as a function of travel distance has been estimated using four different choice models described in paragraph 4. We have left unchanged the numeration of the models taken from the Eurocontrol CARE research [6], labelled in the following as model 1, 2, 4 and 5.

Figure 3 shows the choice model 1 market share forecast, when the helicopter competes with the HST and airplane. Model 1 is a very simple model, considering only time as a choice attribute, and the helicopter holds a market share of close to 30% with a maximum of 35% over distances of about 600 km. Most of the helicopter market is shifted from the HST, which is still the leader mode for short and medium distance. When distances reach 700 km the three modes share approximately the same market quotas. As distance increases, the HST service rapidly loses attractiveness with respect to the airplane.

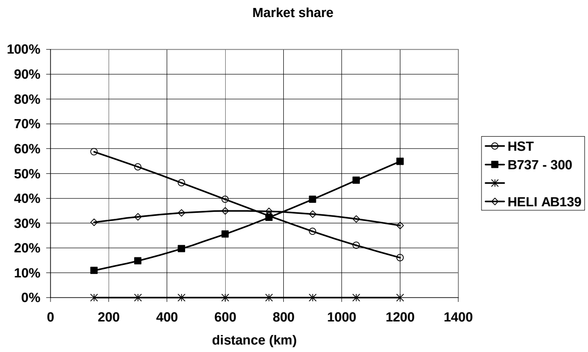

Figure 3 – Market share with helicopter per model 1

As the fare attribute is introduced by choice model 2 (Figure 4), the helicopter continues to subtract passengers from the HST in the short range, but as distance grows, it loses passengers due to the high fare levels needed to balance its high operating costs. It's lost market is gained by the airplane, which also captures train passengers thanks to time savings over medium and long distances.

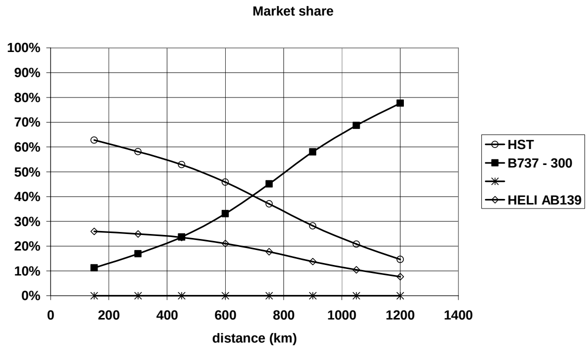

Figure 4 - Market share with helicopter per model 2

Model 4 results in Figure 5 show an extraordinary performance of the helicopter which is regularly chosen by 85% of travellers, slightly loosing some percent only for very long distances. This quite surprising result is the effect of choice model 4, considering a very high sensitivity to service frequency and giving no influence to fares. This trend is however confirmed by Wei [21], whose study, based on a nested logit model, found that airlines can obtain higher returns in market share from increasing service frequency than from increasing aircraft size.

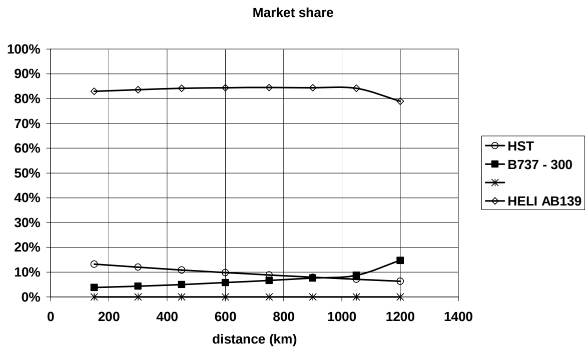

Figure 5 - Market share with helicopter per model 4

Both service frequency and fare are considered in model 5, whose results are presented in Figure 6. The helicopter is the choice of 75% of passengers for short journeys, mostly coming from the HST, and rapidly loses its market position over 500 km, when the conventional aircraft is preferred rather than HST services.

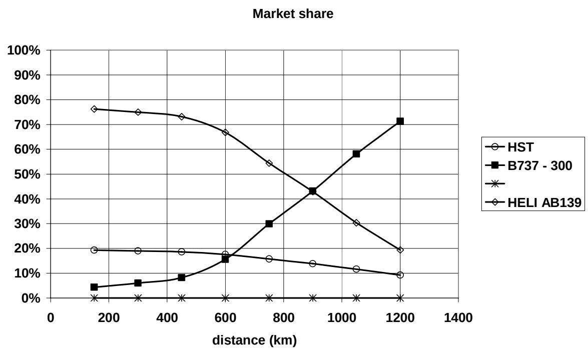

Figure 6 - Market share with helicopter per model 5

If an operator's revenue is calculated as the product of the number of passengers choosing the transport mode and the break-even point ticket price and the result is divided for global demand, the graph of Figure 7 is obtained. It is worthwhile noticing how airplane and train revenues are almost identical for short and medium distances and helicopter revenue has a maximum which is far from the maximum market share distance, and which corresponds to the best combination of the two factors, that is market share and the fare to be applied.

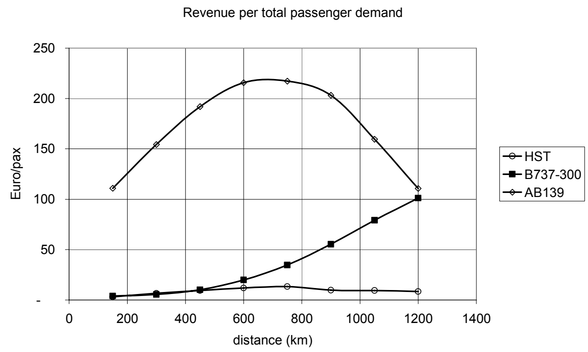

Figure 7 – Revenue per total passenger demand per model 5

The next figures show what happens when the tiltrotor is introduced as a substitute for the helicopter. With regards to performance, the main advantages of a tiltrotor versus a helicopter are

- range before refuelling is further;
- top speed is faster;
- payload might be bigger;
- ceiling is higher
- operating costs may be lower.

Figure 8 shows the model 1 predicted market share. As the tiltrotor is faster than the helicopter, it gains market share as the distance increases, resulting always the best choice as compared to the airplane and for distances greater than 400 km when compared to the HST.

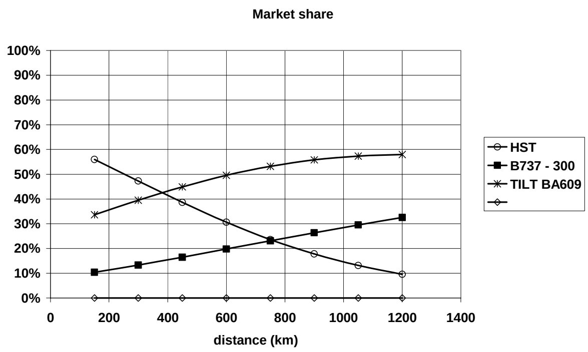

Figure 8 - Market share with tiltrotor per model 1

When the fare attribute is introduced by choice model 2 (Figure 9), travellers show a choice behaviour very similar to the case of the helicopter (Figure 4).

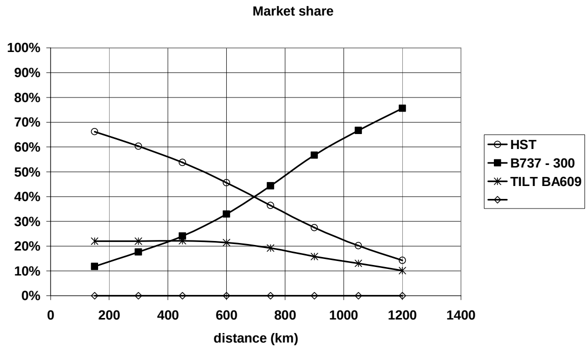

Figure 9 - Market share with tiltrotor per model 2

In Figure 10 model 4 results show an even better performance of the tiltrotor compared to the helicopter, maintaining its market position also for very long distances.

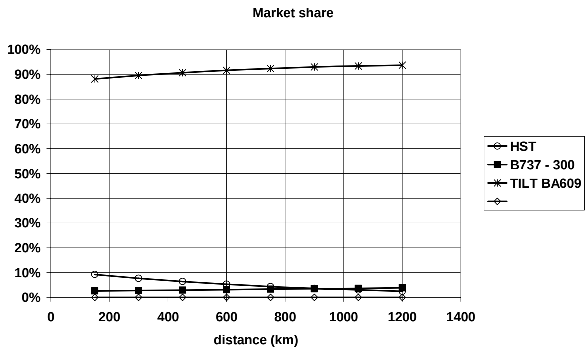

Figure 10 - Market share with tiltrotor by model 4

The results presented in Figure 11, when model 5 is used, are very similar to those of Figure 6, but the decrease in traveller probability choice is shifted about 200 km forward with respect to the helicopter.

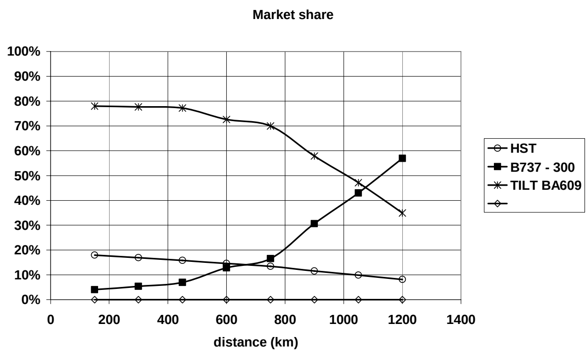

Figure 11 - Market share with tiltrotor per model 5

Though the use of different choice models determines a high variability of the estimated market shares, an almost constant outcome is that rotorcrafts may play a role as a civil passenger transport mode on medium range intercity links.
The different choice behaviour outlined by the models is a consequence of two main reasons:

- the models use different choice attributes;
- the introduction of rotorcraft in a choice model to simulate the competition only between fixed wing aircraft and high speed trains induces the model to a large range of variation of fares and frequency up to values very far from those used when the choice models have been specified and calibrated.

The limited seating capacity suggests that rotorcraft based passenger services may be adequate only on low demand corridors.
The high service frequency and the high fare required too, make rotorcraft journeys very attractive to business and executive demand.

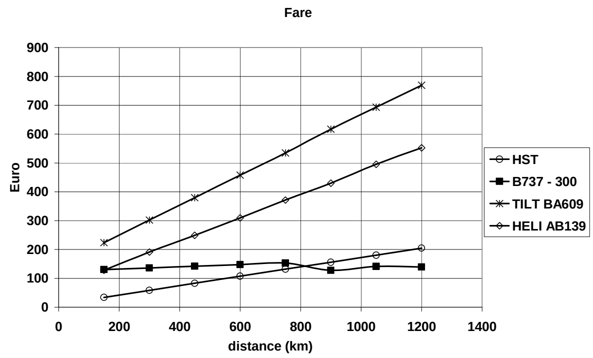

Figure 12 – Required average cost fare for the different transport services

Subsequently, the main drawbacks of rotorcraft are the fares that should be applied for the financial sustainability of the service (see Figure 12) and the maximum transport capacity.

With regard to fares, it should be outlined how the historical concept of the intrinsic high fares of air transport with respect to the corresponding railway services has today been overturned by some main factors:

- the low cost airlines developing in the liberalized market have demonstrated that air transport can be an economic way to travel;
- the need to recover and to shift from general taxation to users the huge investment costs of the high speed railway infrastructure;
- a serious difficulty for rail operators to practice cost effective management, many of whom have historically faced little pressure to contain their costs;
- the ability of rotorcraft to reduce congestion costs in hub airports might be compensated by public subsidies.

With regards to transport capacity, railway signalling systems can usually handle approximately one vehicle every 5 minutes, so the more important performance difference is transport capacity. With up to 1000 seats per train on a double TGV duplex unit, a high speed rail line can, in theory, carry the same number of passengers as a Boeing B737 every 38 seconds or as an AB139 helicopter every 5 seconds. Therefore the HST is justified not only for journeys over a particular range of distances, but also the demand must be very large. In addition it is clear that many countries have constructed or are constructing high speed lines to provide extra capacity, rather than speed, as in the case of the Tokyo-Osaka, Paris-Lyon or Rome-Naples links.

7 Financial analysis

Now that the market share potentiality of rotorcraft has been evaluated, we will carry out a straightforward financial analysis to compare the cost of operating the service using each mode and to calculate which fare is to be applied to obtain the break-even point. In order to correctly confront the differences in vehicle capacities between the train, the fixed wing and the rotor wing craft, the appropriate unit of comparison is the seat, and when considering different distances, the seat-km or the passenger-km.
The financial analysis is performed following the point of view of an airline which must decide if replacing conventional aircraft with HST or rotorcraft on short-medium haul services would be convenient. The analysis will then be limited to operating costs; the investments required to begin the business are not considered, but the costs of providing HST or airport infrastructure are implicitly set in the charges that airlines and railways pay for the right to use the infrastructure.
Operating costs are usually divided into direct operating costs and indirect operating costs, the former being easily assigned to a specific flight or train journey, while this does not apply for the latter. Direct costs include crew salaries, fuel (flight), electricity (train), airport and route charges (flight), track charges (train), vehicle maintenance, vehicle insurance, depreciation and amortisation. Indirect costs include expenses related to ground staff, terminal buildings, handling fees, crew assistant salaries, passenger insurance, ticketing, sales, promotion and general administration.
As indirect operating costs are hard to assign to a specific flight or train and as a large part of them are shared both by rail and by air transport systems, or are in any case sustained by the operator, they are not included in the financial analysis.

The methodology used to perform the analysis is based on the following general data:

- *d* [pax] is the daily demand of passengers;
- d_j [pax] is the daily demand of passengers on mode *j;*
- *dist* [km] is the Euclidean distance between the origin and destination of the journey;
- $dist_j$ [km] is the actual distance covered by mode *j*;
- $V_{op}(j)$ [km/h] is the operating speed, set to 70% of the cruising speed for trains and 90% for flights, both by airplane and by rotorcraft;
- *Cap(j)* is the number of seats available per mode *j;*
- $L_f(j)$ is the load factor of mode *j;*

Following are the choice attributes.

- $FARE(j)$ [€/pax] = $f_{un}(j) \times dist_j$ is the fare applied to passengers per mode j for each journey. The value of f_{un} [€/pax-km] is set equal to the total direct operating cost per Revenue Passenger-Km (DOC_{RPK}) to reach the financial equilibrium.

- *PER [min]* is the time between two flights or trains and is calculated as shown in paragraph 4, while the number of daily runs on mode j is

$$N(j) = d_j / [Cap(j) \times L_f(j)]$$

- TIME [min] = $T_{acc} + T_{egr} + T_{chek\text{-}in} + T_{check\text{-}out} + T_{board}$ is the total travel time

The following times have been considered:

Table 2 – Terminal related journey times

	HS train (min)	*Airplane (min)*	*Rotorcraft (min)*
Access	20	50	20
Exit	20	50	20
Check-in	15	45	15
Check-out	5	20	5

On board time is calculated as

$$T_{board} = (60 \times dist_j) / V_{op}(j).$$

The next step of the financial analysis is to compute the demand to be served by each mode, as the product of the global demand and the choice probability that each mode is selected (according to the choice model methodology shown in paragraph 4) .

By knowing the market share it is possible to determine the minimum fleet size necessary for the service as the approximation to the superior integer of the ratio

$$FS(j) = (T_{turnaround}/PER) = (2 \times T_{board} + T_{park})/PER$$

being $T_{turnaround}$ the turnaround time, computed as the sum of twice the time on board plus a parking time for the handling operations to the vehicle before the return run. This was assumed as 60 minutes for the airplane, 45 minutes for the train and 30 minutes for the rotorcraft. Fleet size for each mode has been increased to consider the unavailability of vehicles due to maintenance.

Then an account management analysis has been conducted to evaluate the total direct operating costs per available seat kilometres (DOC_{ASK}) to compare the financial performance of the different modes, as follows.

$$DOC_{ASK} = VVC_{ASK} + IC_{ASK} + VFC_{ASK}$$

being

- VVC_{ASK} the vehicle variable costs per available seat kilometre;
- IC_{ASK} the infrastructure costs per available seat kilometre;
- VFC_{ASK} the vehicle fixed costs per available seat kilometre.

Vehicle Variable Costs. They include crew salaries, fuel and maintenance; they are affected by the length of the block time, from the closing to the opening of the doors, and by the length of the parking time between each run. Givoni [15] made a detailed accounting analysis and comparison of HST and flight operating costs on the London Heathrow to Paris Charles De Gaulle route and found for the HST a VVC_{ASK} of 0.058 Euro/seat-km. He estimates for the B737-300 a VVC_h per block hour of 2400 $/h in 2001 corresponding to about 2000 €/h with the current exchange rate (1 € = 1.2 $). Then the unit vehicle variable cost is

$$VVC_{ASK} = VVC_h / (V_{com} \times Cap)$$

V_{com}, being the commercial speed, calculated as the ratio between the length of the journey and the sum of on board and parking times.

With regard to the AB139 helicopter the manufacturing company brochure declares an hourly operating cost of 747.00 €/h that must be added to the crew salaries. These were estimated at 350.00 €/h considering two pilots, four daily shifts, an increasing factor of 1.5 for holidays and illness absences, a daily service of 19 hours and an annual cost of 200 000.00 € per pilot.

Analogously, variable vehicle costs are calculated for the BA609 tiltrotor.

Infrastructure Costs. These consist of route and airport charges for each flight or track charges per train run.

In the UE a route charge is levied for each flight performed under IFR (Instrument Flight Rules) in the FIR (Flight Information Region) falling within the competence of the Member State. The route charge depends on the distance flown and, less proportionately, on the aircraft weight, according to a unit rate determined for specific periods by each State. A VFR (Visual Flight Rules) flight may be exempt from the payment of route charges. Airport charges consist of three elements:

- a landing fee related to the weight of the aircraft;
- a passenger charge levied on the number of disembarked passengers;
- and a parking charge levied on the duration of the parking time.

Route charges for each flight have been calculated as follows:

$$Route\,charge = CRCOdist\,\frac{t}{100}\sqrt{\frac{MTOW}{50}}$$

being

- *CRCOdist* the great circle distance flown;
- *MTOW* the Maximum Take Off Weight in metric tons;
- *t* the unit rate; an average European member state unit rate of 57.40 € has been assumed both for the rotorcraft and airplane [26].

Airport charges have been estimated at 766.00 € for each flight, as an average of the main European airport charges for a B737-300 aircraft [26]. No airport charges have been considered for rotorcraft.

Track charges are calculated according to the relevant European rules and national laws. In Italy the track charge depends on the railway line performance, on the characteristics and performance of the train which affects the degradation of the line and on the energy consumption. According to Givoni [15], a track charge of 16 €/km has been assumed for HST services.

Vehicle Fixed Costs. These include the rent and insurance costs sustained for each vehicle available and necessary for the transportation service. A monthly rent rate equal to 0.8% of the purchasing price of the vehicle and a yearly insurance rate equal to 0.5% of the purchasing price have been considered both for trains and aircraft.

Figure 13 is the graph of unit direct operating costs per available seat-km as a function of the journey distance, when the helicopter competes with the airplane and the train. As expected, direct operating costs decrease with distance and are quite dissimilar for the three transport modes, especially for short distances.

The airplane shows a steeper decrease of unit costs than other modes as the travel distance grows because of the incidence of terminal costs and because the corresponding increase in the overall speed reduces the fleet size and all the related costs.

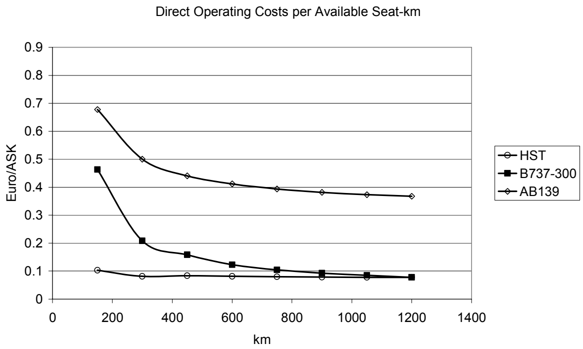

Figure 13 – Direct Operating Costs per Available Seat-km

Seat-km costs are particularly significant on short haul journeys [22]. Not only is the cost per seat-km higher for shorter stage lengths, but the demand is highly elastic (price sensitive), since alternative modes of transportation, are relatively attractive over shorter distances. To attract traffic in the short haul market, fare levels must be kept low, but to cover seat-km costs, they must be kept high. A way to reduce seat-km costs is to use large aircraft, but this involves lower service frequency and consequently a lower market share. One solution to the short-haul problem might be the use of regional aircraft (turboprop or jet) that can operate at lower cost on short hauls than the larger jet aircraft. When the demand is more time-sensitive than price-sensitive, the rotorcraft may play an important role, as its higher costs may be balanced by higher service frequency and consequently higher load factor and overall speed. In fact, when we compare unit costs in terms of passenger-km in place of seat-km, the distance among airplane, train and rotorcraft is reduced. For instance, the graph in Figure 14 is the unit direct operating per revenue passenger-km and is obtained applying a load factor of 50% to the train, 70% to the airplane and 80% to the helicopter.

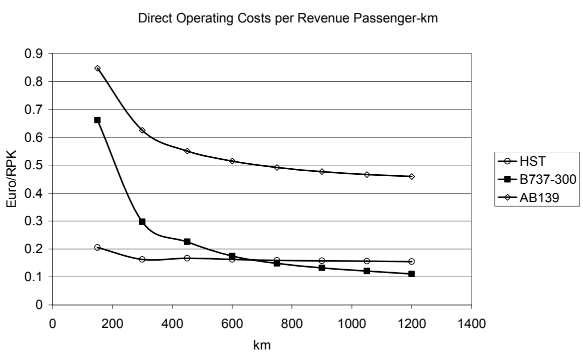

Figure 14 – Direct Operating Costs per Revenue Passenger-km

8 Conclusions

Discrete choice mode models applied for this study indicate that HST infrastructures and services are justified only for short range (under 400 km) and high traffic intensity transport links. When the traffic is lower and the distance is higher, for point-to-point air transport links, small capacity and high frequency services provided by low cost airlines with narrow body or regional jets are very competitive in terms of journey times and fares.

When travellers are less price sensitive and more time sensitive, the rotorcraft seems to have the chance to play an important role in commercial passenger services. As the rotorcraft does not need an airport runway, the helicopter can compete with the HST over small and medium distances and the tiltrotor can compete with fixed wing aircraft over medium and long distances.

After all that, why does the potentiality of rotorcraft not create a market demand for the rotorcraft manufacturing companies?

According to some analysts [16], the problem is that communities perceive vertiports as noisy, unfriendly neighbours, caused in part by an ATC system that forces vertical flight aircraft to operate at lower than optimal altitudes, to avoid the flow of the less manoeuvrable fixed-wing traffic.

Customers imagine rotorcraft as being unsafe, but actually vertical flight aircraft are inherently safer, since they do not require a runway to land, only a relatively small obstacle-free area.

They are perceived by airlines as expensive to purchase and operate. True, rotorcraft may be more expensive than fixed-wing aircraft, but they are much more useful when permitted to operate in a simultaneous, non-interfering ATC system, complementary to fixed wing traffic.

They are perceived as only able to operate in good weather. Actually, modern advanced vertical flight aircraft possess the full capability of the fixed-wing models, with every system available to airplanes, including flight management systems and de/anti-icing capability, as well as weather radar and collision and terrain avoidance systems.

As a result, at the present we may conclude as follows.

When the journey distance is in the range between 400 and 800 km, rotorcraft are able to compete both with high speed train and fixed wing air passenger transport services, especially for point-to-point traffic and not intense demand.

The rotorcraft is more expensive to operate and the higher operating costs must be reflected in the fares paid by passengers.

Convenience, reduced access time and access cost, high frequency and network connectivity, are the discriminating attributes that will make people choose rotorcraft transportation over the other available modes, even if ticket prices may be higher than competing modes.

Due to the high fare level, at the beginning rotorcraft will mainly allow the development of executive and business point-to-point passenger services, as the cost of fares is sustained by companies, part of it being recovered as tax reductions and compensated for by avoiding long journey times and overnight hotel cost reimbursements.

If rotorcrafts are used for short haul flights as hub-to-spoke and spoke-to-hub feeder services, the fare yields and hence the ticket price will not be merely established by the cost of the aircraft used. Then the ticket price might be lower to integrate a variety of factors, including hub size, level of competition and network revenue management policies adopted by airlines.

The rotorcraft passenger services might be subsidised by public administration, at least when the following circumstances occur:

- their contribution to the alleviation of congestion costs at main hub airports is recognised;
- their role in avoiding the costs of rail line construction or improvements is proved;
- they contribute to the operation of transit services at local level, as an essential obligatory public service, as specified by recent Italian reform of local public transport, which explicitly considers a programming and patronizing function attributed to the regional body to provide ground, sea and air transport services at local level;
- Council Regulation (EEC) No 2408/92 authorizes the imposition of public service obligations in respect of scheduled air services for routes serving disadvantaged European regions, as in the case of Sicily and Sardinia in Italy, if land integrity and continuity must be assured.

Really, rotorcraft can greatly increase widespread access to air transport: as outlined by Olcott [17], General Aviation provides access to nearly 5,200 locations in the USA. Scheduled airlines serve less than 500 airports. Most convenient scheduled flights are to less than 50 hub locations. Nearly 100 percent of the U.S. population lives within 40 miles of a GA airport. In Italy more than 80% of the total commercial air traffic is concentrated in less than 25% of the available airports, and more than 50% of the traffic is served by the airports of Milan and Rome, while their districts contain only 13% of the Italian population. This means a high level of airport and ground congestion and a scarce level of accessibility of the population to air transport services. The problem is emphasized by the uniform distribution of the Italian population and of the corresponding air transport demand, which is not concentrated in few metropolitan areas as is usual in other European and North American countries.

Rotorcraft passenger services might be the only alternative for linking areas with scarce accessibility to main airports and that often demand the construction of an airport which is not justified by the potential traffic, but only due to ground transport infrastructure deficiencies.

Rotorcraft passenger services might be the only alternative for serving small communities sited on little islands that do not permit a conventional airport to be built.

A vertical flight system might base its success on civil rotorcraft conceived as a series of train stations or subway stops, but spread out over greater distances, with high frequency connections, relatively low numbers of people travelling in a much more efficient way from point to point, avoiding ground traffic and contributing to the reduction of airport congestion.

However, even with falling prices, subsidising and improved operating performance, the demand for rotorcraft could be dampened by the lack of adequate landing facilities, as operators often find themselves unable to convince communities that a vertiport can be a good neighbour [23].

Technological advances could possibly stimulate rotorcraft usage. The Global Positioning System (GPS) (or the equivalent European Galileo system) and other free flight enabling technologies offer the promise of freedom for all aircraft, including rotorcraft, to use efficient direct routing and manoeuvring to their destinations. These technologies may also enable rotorcraft to fly routes that are less noticeable to people on the ground, increasing community acceptance and further enhancing the utility of rotorcraft operations.

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