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Engineering the ULTra System

Although transport is an essential catalyst for human interaction, transport technologies remain rooted in a previous era. Information technology has fuelled the development of the knowledge society. ULTra provides an opportunity to catch up with the demands of a society which is computer literate but transport moribund.

Background

For many years it has been clear that the world faces a major problem in urban transport. Congestion in major cities has reduced traffic speeds to a crawl.* Congestion is also the principal cause of excess energy use and emissions output by transport. Over the years there has been an extraordinarily large number of analyses of the problem. To date no solution has been found.

It has been suggested that cities are the engine of the economy, and that transport is the oil for the engine. There is a need to consider the benefits of changing the oil.

Historical analysis

Before looking to the future it is wise to look to the past. Figure 1 (presented originally in Lowson, 1998) shows the development of surface transport in the UK over a quarter of a millennium, in terms of the build rate, non-dimensionalised against the maximum for each system.

Figure 1 shows that transport does change. In 50 years time it must be assumed that another surface transport system will be in place. It seems probable that this will make the same contribution to the present century as the car–road system made to the last century and the rail system to the century before.

Some important clues to the likely characteristics of this new system come from further historical analysis.

* In Outer London, the most recent 1998 Journey Times Survey shows that overall A–B speeds at peak are only 8.5 mile/h by car and 5.0 mile/h by public transport . This reduces to 3.0 mile/h by car and 3.5 mile/h by public transport in Central London.

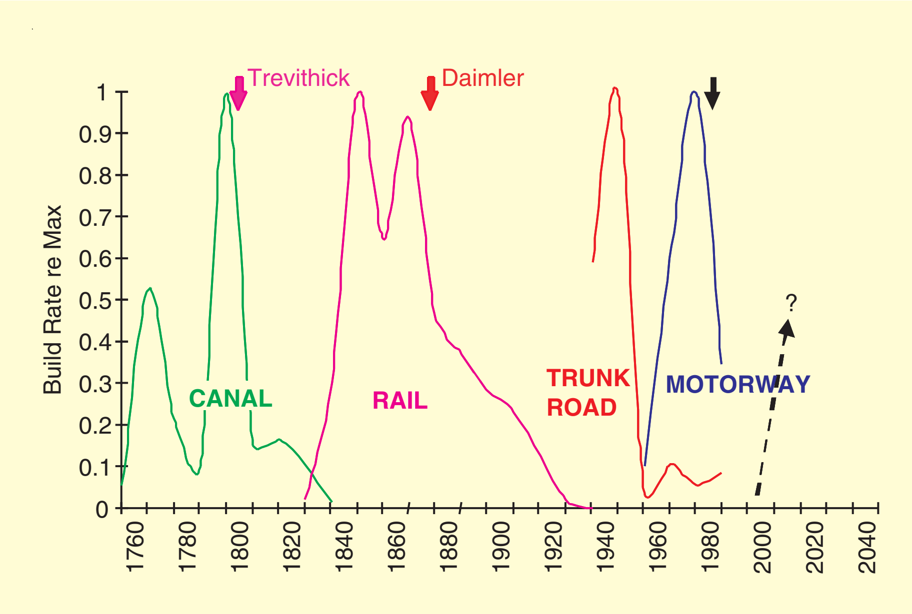

Figure 1: UK surface transport history

Every previous change in surface transport has involved a change of both vehicle and infrastructure. Thus it is logical to examine new systems which feature a change of both vehicle and infrastructure. This has provided new opportunities unconstrained by the limitations of existing systems.

The key technology for the train, Richard Trevithick's high pressure boiler, was invented just after the major peak in canal building. But high pressure steam could provide only marginal gain for the canal system. Similarly the key invention for the car–road system, the internal combustion engine, was invented just after the second major peak in railway building. Again, the application of the internal combustion engine to the railway provides only marginal gain over steam. In both cases, it needed the development of a new transport system, vehicles and infrastructure, to exploit the opportunities offered by the new technology.

We are now past the major peak of motorway building, so, by analogy with the past, it is reasonable to suppose that the key technologies that will drive the next form of surface transport should be available now. Indeed these are almost certain to be modern computing and information technologies. But again by analogy with the past, it can be inferred that application of these technologies to existing transport systems will provide only marginal gain. A new system is needed to exploit the opportunities offered by the new computing technologies.

This thinking provided the impetus for the present work. There appeared to have been no fundamental reassessment of the requirements of urban travel and how best to meet them. Urban transport was a problem which cried out for re-examination using modern systems engineering principles.

Systems engineering analysis and synthesis

The objective of the systems engineering approach was to identify the ideal system for future urban transport. A requirements analysis for urban transport suggested that the optimum system should offer the features shown in the box to the right.

This requirements specification formed the basis for the synthesis of an urban transport system. The system which emerged has been called ULTra, short for Urban Light Transport.

Available on demand

ULTra is an automatically controlled, personal taxi system of four-seat vehicles that run on their own segregated guideway network. Transport is available on demand at any of a series of stations distributed around the city like cab ranks. The empty vehicle management system ensures that a vehicle is nearly always available at the cab-rank as required. Simulations of the full application in Cardiff at peak periods have shown that nearly all passengers (>90%) would obtain immediate service from a waiting vehicle. Wait times in all applications studied to date are comfortably within the design target of 90% of all trip demands met within a minute.

Non stop

All stations are off-line, so there is no need for vehicles to stop during their journey. As a result, although maximum speed has been limited to 40 km/h (25 mile/h) to enhance safety, trip times are still reduced by a factor of between two and three compared to cars or buses in a congested city centre, or to light rail.

Accessible

ULTra provides car levels of service to non car owners, including the young and the old. In the city centre, or under other congested conditions, this provides a far better transport service

The optimum urban transport system should

- be available on demand
- go non-stop from start to destination
- be easily accessible and offer a full choice of destinations
- be environmentally sustainable
- have a low cost
- have demonstrably high safety, together with personal security
- integrate well with other forms of transport.

than is available from the car, or any current form of public transport. A smart-card system permits any user to request direct transport to any other station on the network.

The system provides significantly increased accessibility for those with a wide range of disabilities. There is no change in level between platform and vehicle floor and the vehicle door has been designed to facilitate entry. Appropriate lifts are provided for high level stations. The vehicle design can accommodate a wheelchair and companion, and wheelchairs can be turned around inside the vehicle. Following discussions with the mobility group of the Department for Transport, special emphasis will be put on providing a system which meets the needs of the partially disabled (e.g. those who are partially sighted or have movement difficulties).

These design considerations also greatly facilitate travel by everyone whose mobility is temporarily restricted by luggage, shopping or children in pushchairs.

Environmentally sustainable

Sustainability issues are critical for 21st century transport. Analysis, shown here in Figure 2, suggested that most forms of transport, public or private, have similar levels of energy use and emissions output. Because the ULTra vehicle is electrically powered there is zero emission in the city, but, in any case, overall energy and emissions are significantly reduced. The average system energy usage is 0.55 MJ per passenger km. This can be compared with figures between 1.2 and 2.4 MJ per passenger km shown for conventional forms of transport in Figure 2. The typical benefit compared with cars is over 70%. Importantly, in peak periods when cars (and buses) are restricted by congestion this benefit rises to nearly 90%.

This energy saving translates directly into reduced carbon dioxide emissions. The system meets the recommendation of the Royal Commission on Environmental Pollution, following the Intergovernmental Panel on Climate Change, that the carbon dioxide emission should be reduced by at least 60%. The RCEP target is set for 2050. ULTra is able to exceed this target in the present decade.

Resource usage is also considerably reduced because of the small scale of the system. Vehicles are reused many times during each day, so each 400 kg vehicle does the job of about forty 1000 kg cars. Infrastructure costs, and resource usage are down by a factor of between six and ten compared with roads or motorways.

Because the vehicles require considerably lower power than other forms of transport there is a significant reduction in noise. Initial measurements during vehicle drive-by at 6 m/s gave noise levels which were indistinguishable at 10 m against a background noise of 35 dBA. This compares with a car, which would make about 65 dBA at the same distance during drive-by.

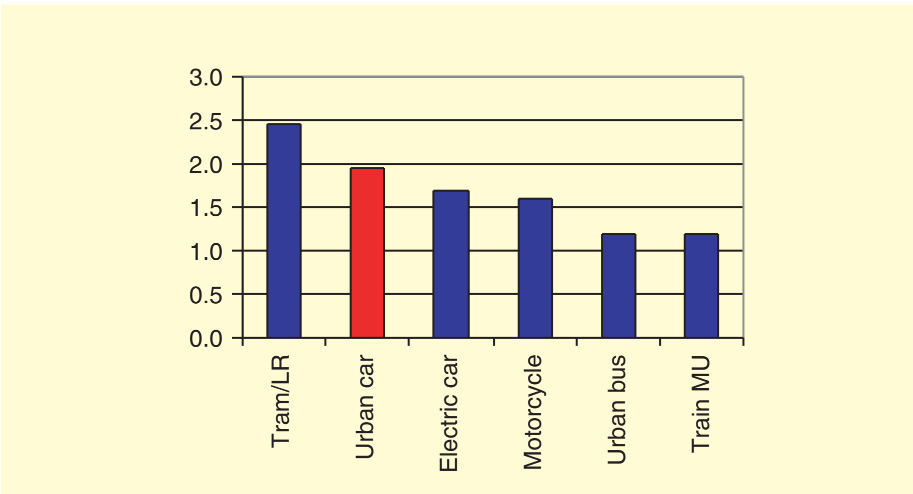

Figure 2: Comparative energy use per passenger kilometre

Low cost

Designs undertaken by Arup show that infrastructure construction costs for the overhead guideway are less than for the equivalent footbridge, and for at-grade track less than the equivalent footpath. This is because the system loadings at around 1500 N/m^2 are less than the pedestrian crush loads required for footway design, i.e. 5000 N/m^2. This also means that the system can be run into buildings designed to existing floor loading codes with no structural change. Complete system cost also includes other infrastructure such as stations, together with vehicles, control systems and support, such as ticketing and closed-circuit television (CCTV). These costs vary considerably with details of the application but typical costs for a complete system in a variety of applications have been around £5M per kilometre of guideway. In a variety of applications studies it has been found that these costs are around one-third of the cost of a light rail system doing a similar task.

Safety and security

Safety is the prime design requirement for any transport system. ULTra is designed to exceed the best safety standards of modern public transport. The detailed concept safety paper developed by Advanced Transport Systems Ltd has received a ‘Letter of No Objection’ from HM Rail Inspectorate. By providing an effective form of transport, which will encourage existing car users to use safer public transport, significant benefits can be projected in terms of fatalities, and serious or slight injuries. For the Cardiff application, analysis of existing statistics suggests that the benefit of the system would be a saving of around 50 accidents a year.

ULTra offers significant benefits in personal security. All trips are undertaken only with companions chosen by the traveller. As noted above, during peak periods 90% of trips are available immediately on demand. Off peak, this figure rises to 100%, since vehicles can be assured to be available at all stations. Thus, the risks associated with waiting for public transport are almost eliminated. Further, all stations will be under continuous coverage by CCTV, with direct links to the controller available from all vehicles and from all stations via help buttons. In addition, in-vehicle CCTV is an option where required.

Integrated transport

The system is complementary to existing forms of transport. By providing a network link, with on-demand access, to major bus and rail stations or to park-and-ride sites, it will improve the attractiveness of these modes. This can contribute to improved transportation, both directly and by enhancing the appeal of other modes. A recent stated preference study in Cardiff suggested that the proportion of people using conventional public transport such as bus and rail would be doubled if there were an ULTra distribution network at the city end of the system.

Personal rapid transit

ULTra is a form of transport generically known as personal rapid transit, or PRT, and has been examined by others. The first study to clearly outline a system which is essentially PRT was by Donn Fichter in the late 1950s. An extensive study was undertaken in the US at the Aerospace Corporation, starting in the 1960s, and considerable detail is provided in the book by Irving (1978). The ideas were further developed by Anderson (1977).

In the UK, a proposal put forward by Blake culminated in the Cabtrack system which was extensively studied in the late 1960s (Langdon (1971)). The principal problems with Cabtrack were the cost and visual intrusion of the infrastructure, which was over 3 m in depth. Cabtrack also used multi-level exchanges, which increased significantly both the cost and visual intrusion of the exchanges. This was exacerbated by the Cabtrack control policy which required acceleration/ waiting/deceleration lanes at every junction. Generally Cabtrack appears to have concentrated on the vehicle issues, and given inadequate emphasis to the problems of the infrastructure, including stations. Compared to Cabtrack, the present system has identified many areas for reduction of cost and visual intrusion.

At that time there were also several other studies. In addition to the US study mentioned, other systems include Aramis in France, the subject of a book by Latour (1996), CabinenTaxi in Germany, and CVS in Japan. None of these reached fruition. It is interesting that many of these systems went through the same metamorphosis, moving from personal rapid transit to group rapid transit. Unfortunately any form of group rapid transit brings with it the fundamental difficulties of collective travel, i.e. waiting and, because of the need for stops, the problem of either low speed or inadequate accessibility. Automated group rapid transit with small vehicles raises the further problem of a possible enforced ride with undesirable travelling companions. This issue would be a fundamental barrier to acceptance today.

The reason for this metamorphosis can be traced to the selection of the incorrect application for the system. The present system can be highly effective for travel over the whole of modest scale cities such as Bristol, or in the outer areas of very large cities such as London. The system as currently configured is not well matched to the problems of the centres of the largest cities, where conventional solutions such as an underground railway are reasonably effective. Unfortunately Cabtrack, Aramis and Aerospace took, respectively, London, Paris, and Los Angeles as their principal target cities. This significantly distorted the conclusions, and led to minitram type approaches, which discard the key conceptual advantage of personal transport. With Aramis, the designers were always committed to a corridor system, and so excluded the major transport advantages of a network approach from the start.

One system with many technical features in parallel with the present ideas is that at Morgantown in the United States. This has fully automatic cabs on a dedicated guideway. It has been running successfully for 20 years and has now carried 50 million passengers without incident. Although called PRT, the cab capacity is 20, and it is in reality a collective-corridor system linking two parts of a university campus. Nevertheless, it does demonstrate that a fully automatic demand responsive system can be technically successful.

Generally it seems that PRT studies undertaken in the 1960s and 70s were ideas which were ahead of their time. We have been able to make significant improvements over these systems, and eliminate a number of the technical weaknesses of old solutions, especially in the approach to infrastructure. Also, today we are able to exploit a wide range of new technologies, especially computing.

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The ULTra system

Vehicles

The prototype ULTra vehicle is illustrated in Figure 3. It is based on conventional automotive technologies, and is electrically powered with four conventional rubber wheels.

Figure 3: Prototype vehicle

Principal parameters are given in the box. The vehicle is equipped with two permanent and two flip-down seats and has a level entry from the station. Thus, there is plenty of room for wheelchairs, shopping or pushchairs (Figure 4). Doors are automatic and have a novel patented opening action.

Because the vehicle is light and travels only at low speed, power requirements are low. This means that battery power with opportunity recharging is practicable. Tests have shown that it is practicable to recharge a 5 minute trip in 1 minute. Battery pack weight at 64 kg is only 8% of gross weight, compared to many electric vehicles which require up to 50% of gross weight for batteries. This could make electric vehicles practicable.

ULTra vehicle: Principal parameters	
Gross weight	800 kg
Empty weight	400 kg
Maximum speed	40 km/h
Length	3.7 m
Width	1.45 m
Height	1.6 m
Passengers	4
Continuous power	2 kW

Questionnaire studies in Bristol and Cardiff show that 98–99% of respondents believe the vehicle interior and exterior to be good or excellent. This is very encouraging.

Guideway

The track has been designed in conjunction with Arup. Details are given in the box. The track is low cost, as mentioned above, and the structural cost and performance predictions have been confirmed in the build of the prototype system. Columns are designed to be truck proof. Considerable attention was given to minimising visual intrusion during the design. Thus, it was very pleasing to find in questionnaire studies that over 90% of people were very happy with the appearance of the track and fewer than 1% felt that it would be an unacceptable intrusion in their city.

ULTra guideway: Principal parameters	
Overhead or at-grade alternatives	
Width	2 m
Overhead	
Depth	0.45 m
Height above roadway	5.7 m
Column spacing	18 m

Network and control system

ULTra runs on its own guideway network with off-line stations. Typically, the network is arranged in a series of loops serving key transport locations around the city. These loops are combined by merge/diverge sections.

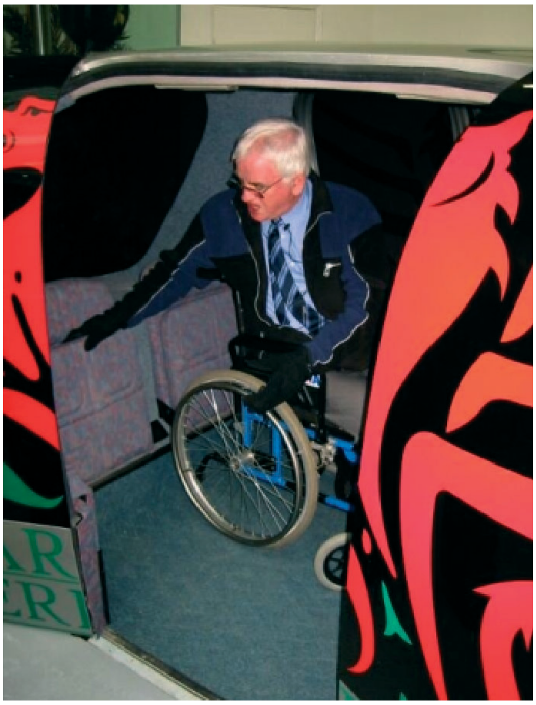

Figure 4: ULTra vehicle interior

In combination with off-line stations this provides non-stop travel. Track is passive, and switching is achieved by in-vehicle steering using an electronic guidance system. Stations have spacings similar to bus stops. The network form allows the guideway to be one way, providing important benefits in cost and visual intrusion. A variety of application studies has been completed and it is typically found that, to provide reasonable accessibility, individual tracks need to be spaced at around 500 m separation, or about every sixth side road.

Operation of the network is based on a synchronous system with fixed 'slots' for each vehicle at the prescribed headways. This requires free routes to be identified from start to destination through all merges before launch of a trip from the station. Extensive simulations have been done to optimise the synchronous control process, including development of effective empty vehicle-management algorithms. It is found that around 65% of the available line capacity can be used. However, in nearly all applications the critical factor on overall system capacity is found to be the stations rather than the line. Small multi-berth stations permitting a throughput of up to 500 vehicles per hour have been devised.

A mature headway of 1 second is planned. This will permit meeting-brick-wall stop criteria. Early applications will have a considerable margin over this for safety reasons. The mature headway permits a typical passenger load during the peak hour of over 2000 passengers per route kilometre, assuming an average 1.4 passenger per vehicle load. This is a larger capacity than actually delivered by any UK light rail system, so that ULTra has an effective mass transit capability.

Figure 5: ULTra vehicles on the Cardiff test track

It is ironic that, although around 85% of all trips over 1 mile in the UK are in fact done by small vehicles, i.e. cars, conventional wisdom is that effective public transport must require some super-scale vehicle for 'mass transit'. Except in the largest cities such as London, this view is false. In manufacturing, it is widely recognised that mass production should be replaced by just-in-time methods. This realisation has not yet reached transport. ULTra can be regarded as a just-in-time transport system. A highly simplified analysis is given below.

Current project position

The ULTra system is currently undergoing prototype testing on two tracks: a simple track in Bristol and a more complex 1 km guideway with overhead sections in Cardiff. Initial results have been very encouraging. Vehicle and track have been successfully integrated and over 1000 circuits of the complex guideway have been completed under fully automatic control.

Figure 5 shows a recent picture of the 'A' and 'B' vehicles on the Cardiff Test track. The new 'B' vehicle is fully fitted out for passenger carrying, and includes several developments. An emergency hatch has been incorporated in the windscreen. Fully automatic doors are included and the interior has been lengthened by 120 mm, following comments from Cardiff disabilities groups.

The National Assembly of Wales has approved a bid by Cardiff County Council which will allow the council to support the first stage in implementing ULTra. This will enable the system to be operated between the Bute Street railway station and the Inner Harbour, Wales Millennium Centre, National Assembly of Wales and County Hall. Progress on the link between the Bay and the city centre will be progressed in parallel, possibly as a public/private partnership project. It is envisaged that vehicles could be operating in the Bay area by early 2005, with the city centre being connected during 2005 if the partnership approach is successful. The estimated costs of the complete 7.7 km scheme are £39M. Projected passenger levels are five million per year.

Cardiff is particularly suited to the ULTra system because regeneration has totally changed the transportation requirements. The docks area, a former industrial zone, is now a prestigious business and residential centre but one which is, at present, disconnected from the main city centre. Journeys between the two centres are already causing a variety of difficulties. Analysis shows that ULTra offers an effective solution, both directly and by complementing existing public transport. Based on the recent stated preference studies, the addition of a network link in the Bay area would lead to 1 800 000 additional trips per year on

Simplified analysis of theoretical capacity

50 seat bus	every 5 minutes provides	600 seats/hour
200 seat light rail	every 10 minutes provides	1200 seats/hour
4 seat ULTra	every 3 seconds provides	4800 seats/hour

conventional rail and bus transport supported by the ULTra network.

Other applications

Substantial interest has been expressed in the system worldwide. In-depth studies, supported by the EC under the EDICT programme, have started on potential applications in four European cities: Cardiff, Eindhoven, Stockholm and Rome. These will examine the potential of the system in a variety of different European scenarios.

Considerable interest has also been shown in the system for application not only in cities, but also in:

- **Airports:** especially for 'landside' applications serving the parking and rental car areas. In effect, ULTra brings remote areas within minutes of the main terminal and thus offers significant commercial gain. Detailed studies are in progress on an application to Heathrow.
- **Institutions:** for example industrial, commercial or academic campuses and also major visitor attractions.
- **New developments:** this is perhaps the most exciting opportunity. Because of the intimate link between the community and its transport infrastructure, change to the transport system brings with it the opportunity to examine new forms of urban living, enabling space devoted to cars to be returned to use by people. A study is in progress on the opportunities offered by application to a new development in Corby.

Conclusions

Meeting the challenge of providing sustainable mobility will require consideration of innovative solutions. Existing forms of public transport are mismatched to the form of present cities, which have been shaped by the capabilities of the car. There is a need to examine public transport which can equal or better the convenience of the car, but at considerably reduced environmental impact.

The ULTra system has been conceived to meet this requirement. It can be regarded as an automatic personal taxi system, since it responds to individual demands and passengers share trips only with chosen companions. This makes it uniquely attractive as a public transport system. Because the system retains many of the qualities of car-based transport – privacy, immediate access, non-stop travel – it can appeal to users who are unwilling or unable to change to current modes of public transit. Transport choice models supported by questionnaire analysis suggest that 25–30% of current car users would be prepared to transfer to an ULTra system. It is also a system which is complementary to existing forms of public transport. By providing a network link, it can improve the attractiveness of existing modes.

Evaluations show that ULTra can be integrated into the urban environment at densities which provide a useful service but also minimise adverse impacts. In particular, the use of existing transport rights of way allows a significant proportion of track to be placed at grade, with little added severance, thereby providing cost and visual intrusion benefits. Studies show that ULTra can provide an immediate benefit for use on routes being considered for tram systems. It is projected to be fully financially viable.

The system has many novel features for urban transport that relate directly to improving the quality of urban life. It is currently undergoing engineering tests with a view to first application in Cardiff in 2005.

In essence ULTra replaces the old mass transit paradigm for transport with a new paradigm based on just-in-time transit.

These ideas have frequently been seen in science fiction. But what is described here is science fact. The ULTra system of personal transportation can be delivered using technology which is available off the shelf today.

Further details can be found at www.atsltd.co.uk. ■

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References

Anderson, J.E. (1977) *Transit Systems Theory* Lexington Books: Mass.

Irving (1978) *Fundamentals of Personal Rapid Transit* Lexington Books: Mass.

Langdon (1971) 'The Cabtrack urban transport system' *Traffic Eng & Control* Vol 12 pp 634–638

Latour, B. (1996) (Translation: C. Porter) *Aramis or the Love of Technology* Harvard UP

Lowson, M.V. (1998) 'Surface Transport History in the UK – Analysis and Projections' *Proc Inst Civil Eng Transp* Vol 129 Feb pp 14–19

Lowson M.V. (2002) Sustainable Personal Transport *Proc Inst Civil Eng Municipal Engineer* (5) Issue 1 pp 73–82

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