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Forth Replacement Crossing Study

Report 5 : Final Report

Grant Thornton

TRIBAL

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Authorisation

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EXECUTIVE SUMMARY

INTRODUCTION

Jacobs and Faber Maunsell were commissioned by Transport Scotland to undertake the Strategic Transport Projects Review (STPR). The STPR commission involves identifying the strengths and weaknesses of the Scottish strategic transport network, identifying gaps between the future demand and capacity of the network, producing a prioritised list of interventions for the period 2012-22. The commission also covers a study of the Forth Replacement Crossing. This element of the work is reported as follows:

- Report 1 : Network Performance;
- Report 2 : Gaps and Shortfalls;
- Report 3 : Option Generation and Sifting;
- Report 4 : Appraisal Report; and
- Report 5 : Final Report.

This is Report 5 of the Forth Replacement Crossing Study (FRCS) and summarises the findings of all the work undertaken during the course of the study.

The study has assessed proposals for a replacement crossing for the existing Forth Road Bridge (FRB) if one is required. The possible need for a replacement is due to the lack of certainty that the existing bridge is going to be available in the future. Also, recent reports from the Forth Estuary Transport Authority (FETA) would suggest that the refurbishment of the existing crossing will have severe impacts on traffic flows across the bridge for a period of between 3 and 4 years.

The level of repair/refurbishment carried out on the FRB will be determined by the role that is ultimately intended for that crossing and the level of investment required to support that role. For example, if the FRB is intended only for use by light vehicles in the future then there may be no requirement to replace the main suspension cables. A decision can also be taken on whether the deck should be replaced thereby removing the need for expensive painting and strengthening of the existing deck structure.

The key point is that once the replacement crossing is open there is flexibility and time to decide how best to refurbish and operate the FRB.

The FRCS is, therefore, primarily concerned with determining the form, function and location for a replacement crossing. Further development is required to determine the role that the existing FRB should play once refurbished. However, this is dependent upon the level of investment that is required to achieve a number of different possible outcomes. A final decision may, therefore, have to be left until further information is forthcoming from, amongst others, the FETA Cable Replacement Study.

However if the FRB was to be refurbished and re-opened then consideration would have to be given as to how it could be used in combination with the replacement crossing. This report considers how such a strategy may operate. The guiding principle of the operation of this combination would be that there should be no more than two lanes available for general traffic in each direction. Additional capacity offered by the presence of the two crossings would be reserved for sustainable modes such as public transport or high occupancy vehicles (HOV).

An assessment of the complementary measures has been made. These could be implemented prior to a replacement crossing being constructed and as part of a new crossing. These measures are also considered in the context of a twin crossing strategy in the event that the refurbished FRB is brought back into commission.

EXISTING AND POTENTIAL PROBLEMS

There is likely to be an increased requirement for significant maintenance on the FRB in the future regardless of the problems associated with cable corrosion. This maintenance cannot be undertaken without temporary traffic management measures being put in place which will restrict the capacity of the crossing. Evidence from recent occasions when maintenance on the bridge has taken place at weekends indicates that serious congestion is experienced. Delays of between 60 and 90 minutes have been recorded even when traffic flows are some 30 per cent lower than the corresponding weekend in 2006.

The forecast increases in daily traffic crossing the Forth will exacerbate the high levels of congestion experienced during restrictions or closures on the FRB. It is also envisaged that due to the type of maintenance works expected to be undertaken on the bridge in future, that it will not be possible to limit these traffic management restrictions to weekends as is currently the case.

It is envisaged that in the future road users will be faced with an increased number of occasions when restrictions are placed on vehicles using the bridge on both week days and weekends. Due to the growth in traffic the delays and queues experienced are likely to be greater than those encountered during maintenance periods.

PLANNING OBJECTIVES

Current and emerging policies that are relevant to the STPR and in particular the FRCS have been considered in detail. The recently published National Transport Strategy and associated documents have been particularly important in guiding the development of the study objectives. Those have also drawn extensively on previous work undertaken by both the South East Scotland Transport Partnership (SEStran) and FETA. Consideration has also been given to the consultation that has already taken place in the development of current policy and undertaken directly as part of this study.

Following careful consideration of these two aspects (current/emerging policy and consultation), a number of study specific "SMART" objectives have been developed and tested within the relevant reference groups. This has led to the setting of a final set of study objectives which has guided future work in the latter phases of this project. Specific performance indicators used to identify any gaps and shortfalls between the future performance and the expectations of the transport network in the vicinity of the Forth bridges have been identified.

OPTION GENERATION AND INITIAL SIFTING

A long list of 65 potential options was generated and this was subjected to an initial sifting process. This was undertaken with a view to reducing the list by eliminating options which did not satisfy the objectives of the study or were not technically feasible. Following this process, the approach adopted was to consider the crossing location and whether bridges and/or tunnels would be feasible solutions in following the five corridors:

A – Grangemouth (West of Bo'ness);

B – East of Bo'ness;

C – West of Rosyth;

D - East of Rosyth/West of Queensferry; and

E – East of Queensferry.

Each corridor was assessed for its suitability for a tunnel or bridge crossing. The work undertaken confirmed that Corridors A and B did not meet the objectives of the study and were therefore rejected. It was concluded that these corridors would not be considered further within the study. Corridors C, D and E did, however, perform well to varying degrees against the objectives and these were taken forward to the STAG Part 1 Appraisal, with bridge and tunnel options considered for all three corridors.

STAG PART 1 APPRAISAL

The STAG Part 1 appraisal was undertaken on the basis of the initial alignments developed for Report 3 – Option Generation and Sifting.

The majority of the planning objectives were met by each of the proposals, although it is evident that the degree to which they were met varies across corridors and crossing types.

At that stage the critical issues which emerged related to the Environment objective and the planning objective to "minimise the impact on people, the natural and cultural heritage of the Forth area". The bridge proposals in Corridors C and E performed particularly badly in this regard as both the northern and southern landfalls cross, or come very close to, the Forth Special Protected Areas (SPA) which may lead to loss of SPA habitat. Both were considered to have major adverse impacts on a European designated site and are unlikely to be permitted when viable alternatives exist that have less or no adverse impact. The bridge in Corridor D was considered to avoid this impact.

STAG indicates that any proposal which fails to meet the Part 1 appraisal test should be rejected. In this case, given the importance of the SPA and the likely impact which these bridge proposals would have on it, it was considered that the bridge proposals in Corridors C and E should be set aside and not carried forward to the STAG Part 2 appraisal.

The outcome of the STAG Part 1 Appraisal was that the following proposals were taken forward for further development:

Corridor C – tunnel;

Corridor D – bridge;

Corridor D – tunnel; and

Corridor E – tunnel.

CORRIDOR PROPOSALS

The design detail and construction methodology of each of the four remaining proposed crossings was examined. Also, included for each option was a summary of the network connections required to connect the new crossing to the existing road network. Attention was placed on developing technically and operationally robust and efficient solutions for each option.

The tunnel in Corridor C would be 8.5 kilometres in length and would be constructed through a combination of Tunnel Boring Machine (TBM) and Sprayed Concrete Lining (SCL) tunnelling techniques. It is expected to take 7.5 years to construct with the capital cost of construction estimated to be £2.3 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

There are two types of bridge options suggested for Corridor D. The first is a suspension bridge with a 1375 metre main span and a 40 metre wide deck. It is estimated that this would take 6 years to construct. Its cost is estimated to be £1.7 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

The second type of bridge considered in Corridor D is a cable stayed bridge with two main spans of 650 metres and 40 metre wide deck. This would take around 6 months less to construct than the suspension bridge and is estimated to cost £1.5 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

The tunnel is Corridor D is 7.3 kilometres in length and would also be constructed using a combination of TBM and SCL techniques. It would take 7.5 years to construct and is estimated to cost £2.2 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

Finally the tunnel is Corridor E is also 7.3 kilometres in length and would be constructed using a combination of TBM, SCL and immersed tube techniques. It would take 7.5 years to construct and is estimated to cost £2.4 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

STAG PART 2 APPRAISAL

Implementability

There are currently a greater number of technical risks assumed for the three tunnel options. This is due to uncertainties in relation to ground conditions and the likelihood of hitting dolerite. There is also the possibility of the progress of the TBM being impeded by the presence of unknown obstructions in the glacial deposits such as boulders and large pieces of timber. Construction difficulties are envisaged with the construction of the cross passages between the two bores of the tunnel. Construction techniques would involve working at very high water pressures and would include the use of ground freezing treatment. Corridor E Tunnel also has issues associated with the construction of an immersed tube tunnel. There are fewer technical risks with the Bridge in Corridor D.

Environment

The Environmental Appraisal findings show that environmental impacts for most options would generally be similar, typically minor to moderate adverse. However, the main exception to this are impacts on biodiversity where Tunnel E and Bridge D options may have Major to Moderate adverse impacts.

For Corridor E Tunnel this is due to the proposed immersed tube that would disturb sediments and may impact on the Firth of Forth SPA and Forth Islands SPA, which are protected at the European level, as well as other European protected species such as cetaceans. In addition, approach roads at the southern end of Corridor E Tunnel pass through the Dundas Castle Gardens and Designed Landscapes, which is a national designation.

For Corridor D Bridge there is a significant risk of indirect disturbance to protected species particularly within the Forth Islands SPA but also relating to the Firth of Forth SPA. This may impose significant seasonal constraints during construction, as the Forth Islands SPA protects breeding birds (i.e. spring and summer) whilst the Firth of Forth SPA protects over-wintering birds. In addition, the northern landfall of Corridor D Bridge passes through the St Margaret's Marsh SSSI, protected at national level, and would involve the loss of some areas of ancient woodland.

Safety

Typically the proposals result in marginal reductions for all accident types in all options. Corridor D Tunnel, Corridor E Tunnel and Corridor D Bridge perform similarly, with accident savings valued at around £220 million. Corridor C Tunnel produces benefits at a slightly lower level of approximately £180 million.

No specific security issues have been identified which would differentiate between the options. The majority of issues can be managed through best practice in relation to bridge and tunnel operations.

Transport Economic Efficiency

In all scenarios analysed in the Part 2 Appraisal the monetised benefits are greater than the costs. Corridor D Bridge produces the most favourable results, with the lower cost of the cable-stayed variant giving the highest Net Present Value (NPV) and Benefit to Cost ratio (BCR). The most favourable tunnel option in economic terms is that of Corridor E. This option produces the highest level of monetised benefits, but at a significantly higher level of cost than Corridor D Bridge. This results in an inferior NPV and BCR. The higher level of benefits is a consequence of the proximity of the southern connections with routes into the city of Edinburgh. This is contrary to current regional and local policies.

A summary of the results is given in the table below.

Monetised Summary of Costs and Benefits (£millions, 2002 values and prices)

Corridor	C	D	D	D	E
Crossing Type	Tunnel	Tunnel	Cable-Stayed Bridge	Suspension Bridge	Tunnel
Present Value of Benefits (PVB)	4,655.6	5,303.1	6,026.1	6,026.1	6,317.1
Present Value of Costs (PVC)	-2087.4	-1967.7	-1,397.3	-1,574.9	-2,172.2
Net Present Value (NPV)	2568.2	3,335.3	4,628.8	4,451.1	4,144.9
Benefit to Cost Ratio (BCR)*	2.23	2.70	4.31	3.83	2.91

*ratio, not monetary value

Economic Activity and Location Impact

At the national level, the main positive impacts are to be felt on existing businesses. At the regional level, existing businesses and new businesses are forecast to experience positive impacts. At the local level, all the corridors are anticipated to have positive economic development effects with Corridors C and D tending to favour West Lothian while Corridor E tends to favour north and central Edinburgh.

Integration, Accessibility and Social Inclusion

All options perform similarly in relation to Integration. This also applies to the Accessibility and Social Inclusion criteria. This is particularly the case when a replacement crossing is being compared against a scenario where the FRB is closed to all traffic.

TWIN CROSSING STRATEGY

This assessment provides an overview of the possible operational arrangement for the proposed new crossing of the Firth of Forth if a twin crossing strategy were to be introduced after the existing FRB was refurbished and brought back into use.

The key objective was to develop an operational arrangement, which complied with the requirements of the study brief, current national policies, complements the proposed alignments and allows flexibility during abnormal conditions.

Based on the assessment of 160 different operational arrangements the following options are recommended:

- **Option OP1:**
  New crossing: Two lanes for any vehicles;
  Existing Crossing: One bus lane and one HOV lane.

- **Option OP3:**
  New Crossing: One lane for any vehicle and one lane for Bus and HOV;
  Existing Crossing: One lane for any vehicles and one lane for Bus and HOV

The final recommendation for the operational arrangement can be confirmed later in the development of the replacement crossing projects once the future of the FRB is better understood.

COMPLEMENTARY MEASURES

Possible Complementary Measures have been identified that would be used to improve the performance of the network on, and in the vicinity of, the Forth bridges and on any replacement crossing. These measures might be considered interim measures prior to the construction of any Forth crossing but should also be considered in terms of how they might be maintained as part of the final strategy. Measures considered for further assessment include HOV lanes, bus priority measures, park and choose sites, further bus services, additional rail capacity, ferry services, Active Traffic Management and variable tolls. The last option may no longer be available given the likelihood that tolls will be removed in the near future.

RECOMMENDATIONS

The principal factors for differentiating between the options are Implementabilty, Environmental Impact, and Economic Efficiency. Other factors are principally altered by the method of operation, or the suite of Complementary Measures.

It is recommended that Corridor E Tunnel should not be considered further for the following reasons:

- the environmental impacts;
- the implementability risks associated with tunnels;
- the impact of drill and blast construction techniques on Hound Point;
- the mine workings on the south side; and
- the high cost of this option.

Of the remaining tunnel options (C and D), there is little to choose between them. Both are estimated to take 7.5 years to construct and have similar costs (£2.2 - £2.3 billion). The monetised benefits of D are marginally better than C due to its proximity to the existing cross Forth corridor. The environmental benefits of both are similar and do not impact on the SPA. When considered as a replacement crossing the tunnel options would not be able to provide the same facilities as a bridge crossing as pedestrians and cyclists would not be permitted into the tunnel.

However, it is recommended that the bridge in Corridor D be taken forward as the best overall performing option from this study. This is for the following reasons:

- it is significantly cheaper than the tunnel options;
- it can be delivered quicker;
- it has fewer risks associated with its construction; and
- It has the best performing BCR.

Environmentally, however, the bridge options do not perform as well as the tunnel options in Corridors C and D. There are likely to be direct impacts on the St Margaret's Marsh SSSI in the north side of the corridor. There may also be indirect disturbance to protected species within both the Forth Islands and the Firth of Forth SPAs. These may impose seasonal constraints during construction. The full scale of these impacts would not be known until such time that an Environmental Impact Assessment has been carried out.

Of the two types of bridge structure, the cable stayed bridge has advantages over the suspension bridge in that it is the cheaper option and can be delivered around six months earlier. The use of cable stayed techniques would avoid the need for complex foundations on the landfalls, therefore, avoiding the methane risk on the southern side. Cable stayed bridges are modern forms of long span crossings and provide the opportunity to create a vista across the Forth of three different types of bridge construction comprised of the old (Forth Bridge), recent (FRB) and the new (the replacement). The visual impact of this vista is clearly something to be discussed with Architecture and Design Scotland.

Given all of the above factors, it is recommended that the replacement crossing be a cable stayed bridge in Corridor D. This should incorporate two lanes with hardshoulders plus pedestrian walkways/cycleways in each direction. Network connections should be provided principally to join the A90/M90 to the north of the Forth and to the M9 in the south.

1 INTRODUCTION

1.1 BACKGROUND

Jacobs and Faber Maunsell were commissioned by Transport Scotland to undertake the Strategic Transport Projects Review (STPR). The STPR commission involves identifying the strengths and weaknesses of the Scottish strategic transport network, identifying gaps between the future demand and capacity of the network, producing a prioritised list of interventions for the period 2012-22. The commission also covers a study of the Forth Replacement Crossing. This element of the work is reported as follows:

- Report 1 : Network Performance;
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- Report 5 : Final Report.

This is the Report 5 of the Forth Replacement Crossing Study (FRCS) and summarises the findings of all the work undertaken during the course of the study.

1.2 COMMISSION OBJECTIVE

The primary objective of the study was to identify the scope, form and function of any potential replacement to the existing Forth Road Bridge (FRB). The need for a replacement crossing is for the following two key reasons:

- there is a lack of certainty that the existing bridge is going to be available in the future; and
- the repair/refurbishment of the existing crossing has too severe a set of impacts on the east of Scotland economy if it were to be closed (or even severely restricted) for a period of time.

This appraisal, therefore, focuses upon the options for the provision of a replacement crossing if one is required. Once a new crossing is opened then the FRB could be closed for repairs/refurbishment. During the period of closure all traffic would be switched to the replacement crossing.

The level of repair/refurbishment carried out on the FRB will be determined by the role that is ultimately intended for that crossing and the level of investment required to support that role. For example, if the FRB is intended only for use by light vehicles in future then there may be no requirement to replace the main suspension cables. A decision can also be taken on whether the deck should be replaced thereby removing the need for expensive painting and strengthening of the existing deck structure.

The key point is that once the replacement crossing is open there is flexibility and time to decide how best to refurbish and operate the FRB.

The FRCS is, therefore, primarily concerned with determining the form, function and location for the replacement crossing. It has gone onto determining the role that the existing FRB could play once refurbished. However, this is dependent upon the level of investment that is required to achieve a number of different possible outcomes. A final decision on the precise future role of the FRB may, therefore, have to be left until further information is forthcoming from, amongst others, the study into the feasibility of replacing or augmenting the suspension cables on the FRB currently being undertaken by the Forth Estuary Transport Authority (FETA).

However, if the FRB was to be refurbished and re-opened then consideration will have to be given to how it could be used in combination with the Replacement Crossing. This study also examines how an operational strategy could be developed for the two crossings. The guiding principle of the operation of this combination is that there should be no more than two lanes available for general traffic in each direction. Additional capacity should be reserved for sustainable modes such as public transport or high occupancy vehicles (HOV).

An assessment of the complementary measures that could be implemented alongside the development of a replacement crossing is also reported.

1.3 METHODOLOGY

The methodology adopted follows closely the Scottish Transport Appraisal Guidance (STAG) issued by the Scottish Executive in 2003. STAG aims to aid transport planners and decision makers in the development of transport policies, plans, programmes and projects.

The process begins with an analysis of current and future conditions on the transport network within the Study Area (shown in Figure 1.1). This was reported in Report 1: Network Performance and the key findings of this are summarised in Chapter 2. From this assessment the gaps and shortfalls from expected levels of performance and future problems are identified. This then flows into the setting of objectives for the study. This was reported in Report 2: Gaps and Shortfalls and this document is summarised in Chapter 3.

The next part of the STAG process involved the generation of options and the initial sifting. This forms the final stage of the STAG pre-appraisal process and begins with a mapping of constraints in the study area such as environmental or other physical constraints that would influence the development of options to be considered. Once these constraints have been identified a long list of possible options is developed. As will be seen in Chapter 3 the long list includes suggestions for different types and locations for new crossings. Other forms of options (which could be introduced either with or without a replacement crossing) such as public transport and other more sustainable modes of transport are also considered at this stage.

The next step was to sift options into those which may assist in meeting the objectives. This is the final element of the STAG pre-appraisal process. As part of this some general design issues are explored to assist the understanding of how well each of the options might perform. The output from this was a shorter list of options which will be subjected to the appraisal required by STAG.

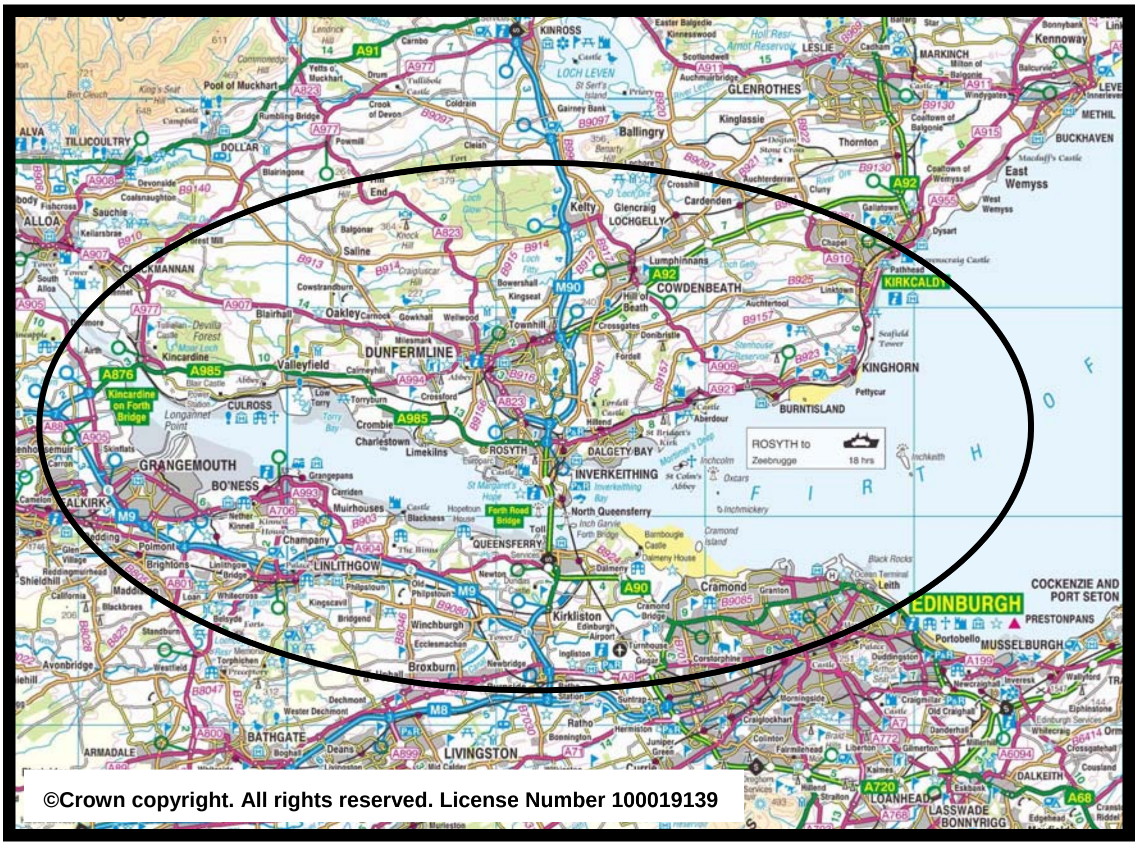
The appraisal of project proposals within STAG has two parts:

- Part 1: this is an initial appraisal and broad assessment of impacts, designed to decide whether a proposal should proceed to the Part 2 Appraisal, subject to meeting the planning objectives and fitting with relevant policies; and

- Part 2: this is a detailed appraisal of proposals that have emerged from the Part 1 appraisal, against the Government's transport criteria, including consideration of cost to government, risk and uncertainty, and proposals for monitoring and evaluation.

In between the two parts, the options emerging from Part 1 are subjected to further development to allow some of the detailed issues to be assessed as part of Part 2.

Figure 1.1: Study Area and Associated Transport Network



1.4 STRUCTURE OF REPORT

Following this introductory Chapter, the remainder of this report is set out as follows:

- Chapter Two – Existing and Potential Problems;
- Chapter Three – Planning Objectives;
- Chapter Four – Option Generation and Initial Sifting;
- Chapter Five – STAG Part 1 Appraisal;
- Chapter Six – Corridor Proposals;
- Chapter Seven – STAG Part 2 Appraisal;
- Chapter Eight – Operation of Twin Crossing Strategy;
- Chapter Nine – Assessment of Complementary Measures; and
- Chapter Ten – Finance, Procurement and Legislative Issues
- Chapter Eleven – Summary and Conclusions.

2 EXISTING AND POTENTIAL PROBLEMS

2.1 INTRODUCTION

This chapter covers the analysis of the existing and forecast future conditions of the transport network in the vicinity of the Forth Road and Rail Bridges. It identifies the problems and opportunities that are likely to be faced in the future. In particular it examines the current and future (2012, 2017 and 2022) conditions of the FRB, Forth (Rail) Bridge and their surrounding networks. It also considers the likely environmental constraints that may be associated with any replacement crossing.

This work is outlined in greater detail in Report 1[1].

2.2 EXISTING CONDITION OF THE FORTH ROAD BRIDGE

When opened in 1964, the FRB was the longest suspension bridge outside the USA and the fourth longest in the world. The bridge has a main span of 1006 metres and the side spans are each 408 metres long. The main towers are 156 metres in height above water level. The eleven span south viaduct is 438 metres long and the six span north viaduct is 253 metres long. The bridge is managed by FETA and has a dedicated maintenance unit which carries out routine inspection and maintenance activities. The bridge is listed by Historic Scotland as Grade A.

Although the FRB has been maintained throughout its lifetime, it is showing signs of deterioration, mainly as a result of the growth and increase in weight of traffic together with the influence of the weather and climate.

During the early life of the bridge, the amount of goods moved by road in the UK almost doubled and the number of goods vehicles with a gross weight over 28 tons rose from an insignificant number to 90,000. This has lead to the frequent occurrence of convoys consisting of closely spaced HGVs which has resulted in loading effects greater than that originally anticipated.

In addition to the growth in traffic loading set out above, the growth in traffic using the bridge has increased at a relatively steady rate of 2-3 per cent each year. At present the bridge carries over 24 million vehicles per annum or on average over 66,000 vehicles per day.

The FRB is at a relatively northerly latitude and is subjected to high winds blowing in from the west. In addition, the presence of the North Sea to the east results in the Forth being a relatively cold body of water. This leads to foggy weather during the spring and summer months with high relative humidity. With the presence of salt water this helps to contribute to highly corrosive conditions and also reduces the length of the painting season. The conditions make maintenance of the bridge a challenge to FETA's maintenance team.

[1] Forth Replacement Crossing Study – Report 1- Assess Existing, and Forecast Future, Conditions of the Transport Network within the Vicinity of the Forth Road and Rail Bridges, Transport Scotland/Jacobs/Faber Maunsell – February 2007

Since the bridge opened several major capital projects have been carried out to replace, strengthen, or improve elements of the structure. These projects were necessary due to deterioration, changes in traffic loading, design code changes and a risk assessment of shipping impact. These projects have included the strengthening of viaduct box girders, main tower wind bracing strengthening, main tower strengthening, hanger replacement and construction of pier defences.

Maintenance of the FRB is an ongoing exercise and a summary of FETA's Capital Plan maintenance of principal items and the programmed schedule for these are shown below in Table 2.1.

Table 2.1 Summary of Capital Plan maintenance

Maintenance Activity	Time Period for Completion
resurfacing main/side span north	2007-15
resurfacing main span south	2012-20
resurfacing viaducts and north approaches	2007/2008 and 2014/2016
viaduct painting	2008-13
main tower painting	Present – 2010
main cable dehumidification (installation)	2007-09
parapet and barrier replacement	Present – 2010
main tower deck joints and cycle track joints	2008/2009
truss end linkages	2009/2010
bearing replacement viaducts and side spans	2009-12
suspended span painting	2010-21

Over the life of the bridge regular maintenance of the main suspension cables has been undertaken, which has included periodic repainting. Regular external inspections have been carried out with no significant deterioration or egress of water noted. FETA took a decision to carry out a first internal inspection of the cables in 2004.

Following this inspection, severe corrosion was discovered and the cables were estimated to be working with a loss of strength of 8 to 10 per cent. The current cable factor of safety is between 2.2 and 2.3. Predictions indicate that, at the present rate of corrosion, the factor of safety could fall below the acceptable value of 2.0 in 2013/2014. It is not possible to reduce dead weight on the FRB and, therefore, it is envisaged that live load restrictions would need to be phased in. This can be done, for example, by firstly restricting HGVs in order to maintain a minimum factor of safety of 2.0 in the main cable. However, the rate of deterioration is such that further restrictions on light vehicles could be required within a further five years. Acoustic monitoring equipment has been installed to detect the failure of further strands in the cables.

A dehumidification system is currently being installed which, if successful, would arrest the rate of deterioration and delay the need to introduce vehicle restrictions. The complete system will not be fully operational until the middle of 2009 and the outcome will not be known until approximately two years after this.

Whilst FETA is optimistic that the proposed dehumidification will halt the corrosion of the cables, there is no absolute guarantee that this will be the case. Therefore, FETA had to give consideration to replacing or augmenting the main cables should it become necessary in the future. However, there are several significant engineering difficulties as follows:

- the main towers, including existing cable saddles, have already been strengthened and new load paths need to be identified at the tower tops;
- potential problems with the integrity of the existing anchorages, and the need to investigate methods of determining the condition of the post-tensioned strands in the anchorages;
- new anchorages would be required. It is noted that development on land to the north and south of the bridge make the provision of additional anchorages difficult; and
- the existing truss is overstressed and would also require to be strengthened.

A critical question is the extent of the carriageway restrictions that would be required to carry out replacement or augmentation of the main cables.

Given the above, FETA decided that a feasibility study should be carried out and a consultant was commissioned to undertake this work in late 2006. The preliminary report of the feasibility study, published in early June 2007, found that the replacement or augmentation of the cables presents significant engineering challenges but is achievable. It identified three possible options for undertaking the work. The preliminary report reviewed the principal construction sequences of the options and estimated the consequent traffic impacts. The contract duration would be between 5.5 and 7 years depending upon the option pursued.

The first option would result in around 50 complete weekend closures of the bridge and 3 separate blocks of 32, 12 and 24 weeks (spread over 4 years) of carriageway closures requiring contra-flow traffic operation. The second option again would have around 50 weekend closures of the bridge and 2 separate blocks of 32 and 24 weeks (spread over 3 years) of carriageway closures requiring contra-flow operation. The third option would possibly be carried out during two separate blocks of 32 and 24 weeks (spread over 3 years) of carriageway closures requiring contra-flow operation.

The report also considered the option of closing the bridge completely to carry out the work. This would require a continuous closure over a period of some 3.5 years with an overall contract duration of 4.5 years.

It is emphasised within the preliminary report that it is an interim report and the traffic restrictions are indicative only and would be subject to further consideration in the next phase of the work. The report is due to be completed in April 2008.

However, the impact of these closures and contra–flow working should be viewed in the light of the recent weekend contra-flow operations at the FRB for carriageway resurfacing. Delays of between 60 and 90 minutes are being recorded despite the traffic volumes being 30 per cent down on the corresponding weekends in 2006.

As indicated in the preliminary report, it is envisaged that contra-flow working would be required during week days when average traffic flows are around 30 per cent higher than the weekend. It follows, therefore, that, unless traffic flows can be reduced considerably below current levels, delays to motorists could be substantially greater than those currently measured.

The preliminary report does go on to state that measures such as increased public transport provision and the introduction of HOV Lanes would need to be introduced to bring demand down to manageable levels. This will be examined in the next phase of FETA’s work as will the likely economic impact of the traffic management measures through a survey of businesses.

In addition to the above, strengthening is required to the stiffening truss. Although fatigue has not been an important issue to date it is likely that the fatigue sensitive details in the main deck will require major maintenance in the future.

Also, resurfacing and painting are extremely disruptive operations and both need to be carried out regularly to maintain the integrity and life of the structure. In common with all bridges, the support bearings need to be replaced several times through their lifetime. The existing parapets do not comply with current standards and would need replacing.

Ongoing painting of the bridge is required whatever the live loading applied to the bridge. The volume and weight of the live load has a critical effect on the surfacing, deck, main cables, hangers, joints and bearings.

The bridge continues to carry an average of 66,000 vehicles per day. There are still many years of life in the bridge but with high ongoing maintenance liabilities, provided that the deterioration of the main cables can be arrested.

In summary, there will be an increased requirement for disruptive maintenance in the foreseeable future, due to increases in traffic levels, HGV proportions (and weight), and remedial measures that required to be undertaken on the bridge structure itself.

2.3 SUPPORTING ROAD NETWORK

2.3.1 Southern Bridgehead

In the southern bridgehead the two main roads supporting the FRB are the A90 and the A8000. The A90 provides direct linkage with Edinburgh whilst the A8000 provides connection with the trunk road and motorway network. These two routes in turn connect to the A8/M8, A720 Edinburgh city bypass, M9, and A89.

A major construction project is currently underway which will extend the M9 spur motorway to connect with the A90 which, in turn, will be widened as far as the bridge toll plaza. This work stared in June 2006 and completion is expected by the summer of 2007.

The opening of this new road is expected to lead to an increase in traffic using the FRB of 3 per cent.

2.3.2 Northern Bridgehead

The northern bridgehead road network is primarily the A90/M90 corridor together with its principal feeder routes, the A92, A921, A985 and A823 (M). Dunfermline, the major town to the north west of the FRB, can be accessed from the M90 through two roads: the A823 from the south and the A907 from the east.

A Route Action Plan Study of the A985 trunk road is currently being undertaken by Atkins on behalf of Transport Scotland. The A985 runs along the north side of the Firth of Forth linking the Kincardine Bridge and the FRB. The A985 is heavily trafficked with a high proportion of HGVs. The existing alignment does not comply with current trunk road design standards and exhibits few overtaking opportunities. The Route Action Plan is looking at ways to provide additional overtaking opportunities and safety schemes along its length. It is essential that the Route Action Plan takes account of further HGV traffic that may be displaced onto the A985 as a consequence of any HGV ban that is imposed upon the FRB in the future (see 2.3.3 below).

2.3.3 Upper Forth

The Upper Forth area provides further options for crossing the Firth, via the Kincardine Bridge and the A91. The Kincardine Bridge crosses the Forth 15 miles upstream of the FRB. It carries one lane in each direction and is the diversionary route for traffic should any closure (partial or full) of the FRB be required.

A new crossing of the Forth at Kincardine is currently under construction. The new line is to the west of the existing bridge and will form a connection from the upgraded A876 to the A977 south of Gartarry Roundabout. The bridge is due to open towards the end of 2008. As part of the overall strategy for Kincardine, the 'Eastern Link Road' was built to provide relief from traffic using the A985.

Anecdotal evidence suggests that the diversion of traffic from the FRB due to maintenance, or high winds, causes very significant congestion on and around the FRB, and at Kincardine.

The possible introduction of a complete ban on HGV's on the FRB could have an important part to play in extending the operating life of the FRB. However, the consequence of any ban would be an immediate and noticeable increase in HGV traffic using the Upper Forth Crossings and adjacent main roads (A977 and A985) on the north side of the Forth of Forth. The impact on the south side is less noticeable as the increase in traffic on the M9 is partially lost in the higher levels of traffic already using the motorway.

2.4 FORTH (RAIL) BRIDGE

The recently published Network Rail (NR) Route Utilisation Strategy (RUS) highlights that improved use of rail capacity is a central element of the Scottish Executive's plans for effective delivery of its rail transport objectives. The key requirement is to make effective and efficient use of the current route capacity.

Rail passenger demand has increased significantly in the last few years reflecting increased employment, especially in Edinburgh, and as a consequence of increasing road congestion especially over the Firth of Forth.

One of the key issues to be addressed is the rail capacity through the Forth Bridge corridor where significant overcrowding is experienced on peak hour trains. Current passenger services include:

- Fife inter-urban - First ScotRail express services terminating at Aberdeen, Dundee, Markinch and Perth;
- Fife Circle - Operated by First ScotRail; and
- Intercity - GNER/Virgin services to Dundee and Aberdeen.

There are presently 10 trains per hour crossing the bridge between 0730 and 0830 i.e. five on the Up line and five on the Down Line

The railway infrastructure on the Forth Bridge consists of double track with signalling which allows five minute headways. The bridge is also the longest section with regard to signalling between Edinburgh and Inverkeithing and this limits its capacity. There are also difficulties in accommodating the current mix of express services and all station stopping services.

NR has estimated the life of the bridge to be in excess of 100 years. However, this is dependant upon NR's inspection and refurbishment works programme for the bridge being carried out year on year. The bridge is a Grade A listed structure.

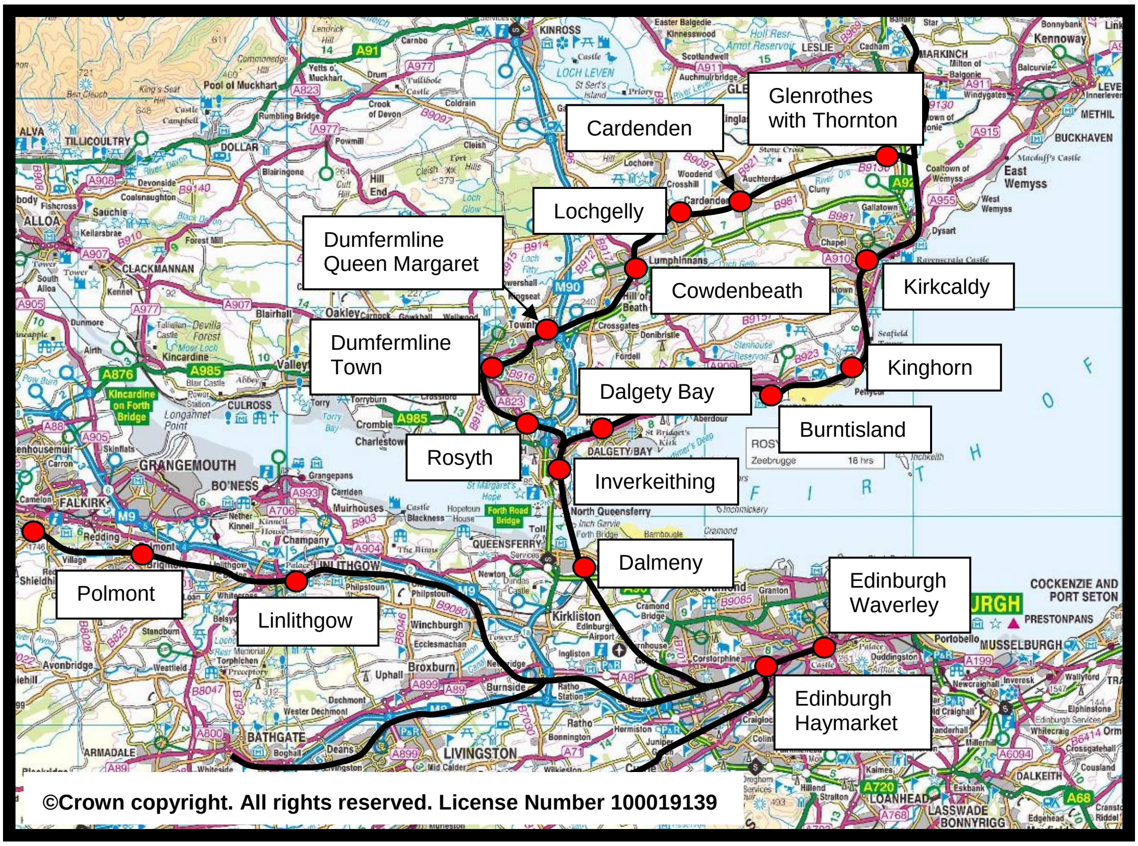
NR is currently carrying out small signalling improvement works to improve signal overlaps between Edinburgh and Inverkeithing. This would not allow further train paths but should improve performance of the existing services. This work is being done in three stages with completion anticipated for 2010-11. The results of these improvements will be a reduction in headway time from five minutes to three minutes.

There are a number of areas to be explored to improve performance and/or increase train paths. Listed below are some of the options that are included in "Scotland's Railways"[2] as interventions to be pursued and can also be explored as part of the main Strategic Transport Project Review commission:

- review of the allocation of timetable slots to different classes of trains;
- re-signalling the route between Edinburgh Waverley and Inverkeithing to improve signalling headways by introducing additional signals;
- longer platform lengths at stations;
- improve differential in train speeds/acceleration of trains;
- flighting of services to ensure that all trains have the same operating pattern approaching and leaving the bridge;
- revise train stopping patterns to optimise train paths over the bridge;
- the impact of the proposed Edinburgh Airport Rail Link and the Stirling – Alloa - Kincardine and Waverley projects;
- electrification of the route would improve train performance through better acceleration. However it is acknowledged that the bridge may prove to be a constraint to the provision of electrification; and
- track upgrade on the Fife Circle, particularly between Thornton and Inverkeithing via Dunfermline (see Figure 2.1), to permit higher line speed which could allow additional capacity over the route.

[2] Scotland's Railways, Scottish Executive, December 2006

Figure 2.1: Railway Stations on Fife Circle and between Edinburgh and Falkirk



2.5 ENVIRONMENTAL CONSTRAINTS

The environmental constraints on the Study have been examined under the following headings:

- Ecology and Conservation;
- International Protection of Sites;
- International Protection of Species;
- National Protection of Sites;
- National Protection of Species;
- Other Ecological Designations;
- Landscape;
- Nationally Protected Sites;
- Locally Protected Sites;
- Archaeology and Cultural Heritage;

- Scheduled Ancient Monuments**;**
- Listed Buildings;
- Conservation Areas / Heritage Conservation; and
- Countryside Policy Areas.

All designated areas have been identified and these are discussed further in Chapter Four.

One of the key areas is ecology and nature conservation. The Firth of Forth supports a wealth of important wildlife which lives alongside large centres of population, the petrochemical and other industries, such as at Grangemouth, and Rosyth Naval Base. Direct impacts through history, such as land take and disturbance, and indirect impacts, such as pollution, have lead to great pressure on the natural resources of the Firth, which are now controlled under various conventions and legislation.

The Firth of Forth supports habitats and species which are designated at a national and international level in recognition of their contribution to the UK and European biodiversity resource. The highest level of protection is afforded to the Natura 2000 sites, which are legislated by The Conservation (Natural Habitats, & c.) Regulations 1994, and comprise Special Protected Areas (SPAs), Special Areas for Conservation (SACs) and Ramsar sites[3]. The latter are designated under the Ramsar Convention as opposed to the Habitats Directive, under which SACs and SPAs are designated. Ramsar sites have been adopted as part of the Natura 2000 network by the UK government. The Firth of Forth supports sites belonging to all these types of Natura 2000 sites.

There are three Natura 2000 sites situated within the Firth of Forth or having connections with the Firth of Forth. These are the Firth of Forth SPA, the Forth Islands SPA and the River Teith SAC. All would heavily influence the corridor selection for any Forth Replacement Crossing option.

At a national level, areas are protected by being designated as Sites of Special Scientific Interest (SSSIs) under the Wildlife and Countryside Act (1981) as amended by the Nature Conservation (Scotland) Act 2004. Other areas are protected by the local planning system, such as Local Nature Reserves, Ancient Woodland, and areas of local nature conservation importance. The Firth of Forth also has several nature reserves owned/managed by non governmental organisations

[3] Ramsar sites are designated under the Convention of Wetlands of International Importance. The Convention was adopted in Ramsar, Iran, in 1971 and ratified by the UK Government in 1976.

2.6 EXISTING TRANSPORT DATA

The FRB has had tolls in place since it opened in 1964. This has enabled data to be collected for traffic crossing the bridge over the 42 years it has been in place. In 1997, the southbound toll booths were removed to facilitate tolling in the northbound direction only. Traffic in the southbound direction from this date has not specifically been counted, and hence estimates of total flow across the bridge are derived from the northbound flow. Traffic data by both directions is available up until 1997 and since then for the northbound direction only is available from FETA.

Figure 2.2 below displays the pattern of growth in the northbound direction on the FRB since 1965. In 2005 (the latest year for which data is currently available[4]) just over 11.9 million vehicles crossed the bridge in the northbound direction. Of this 90.7 per cent were cars or light good vehicles and 6 per cent were HGVs. The remainder were either buses, motorcycles or vehicles which were exempt from paying the toll, such as those driven by blue badge holders.

Figure 2.2: Forth Road Bridge – Annual Northbound Traffic Flow (1965 – 2005)

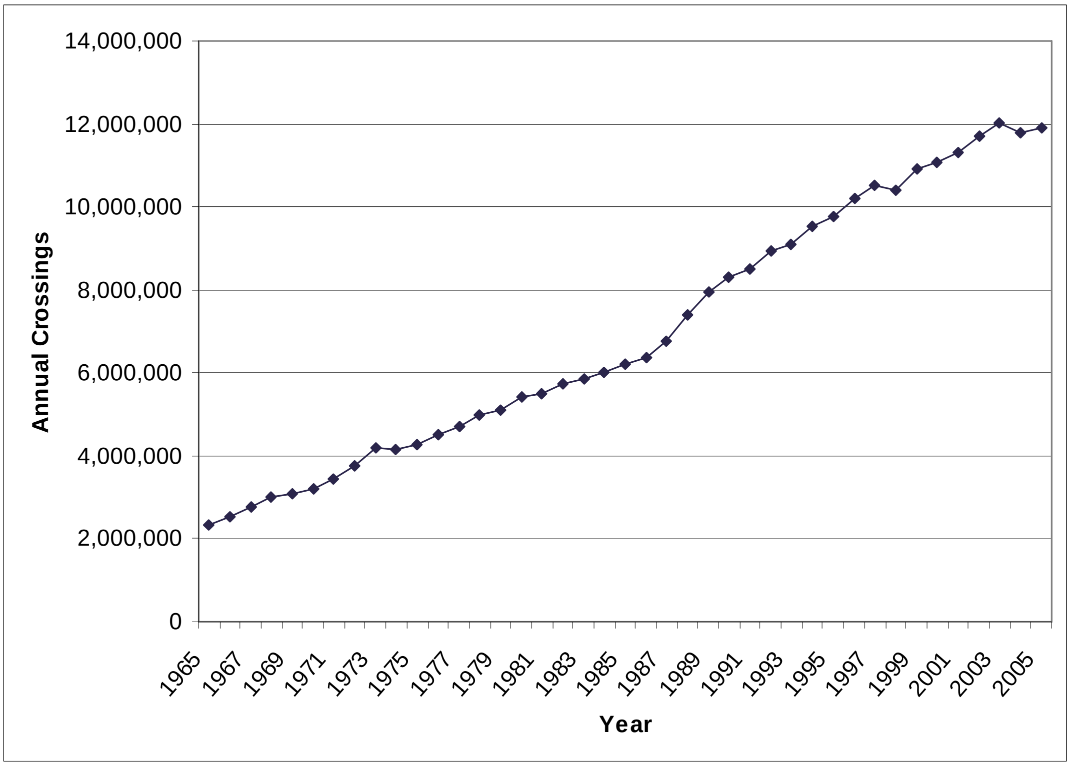


Figure 2.3 below shows the indexed comparison of traffic growth between the FRB and Great Britain. Since 1966 traffic levels on the FRB have increased to approximately 4.7 times that of the 1966 level, while in the GB the levels are just under three times their 1966 levels. This again reflects the above average increase in traffic on the FRB when compared with national traffic growth.

[4] News Release - Analysis of Bridge Traffic & Revenue, Forth Estuary Transport Authority, September 2006.

Figure 2.3: Indexed Traffic Growth 1966 to 2005 – Forth Road Bridge and Great Britain (1966 =1.00)

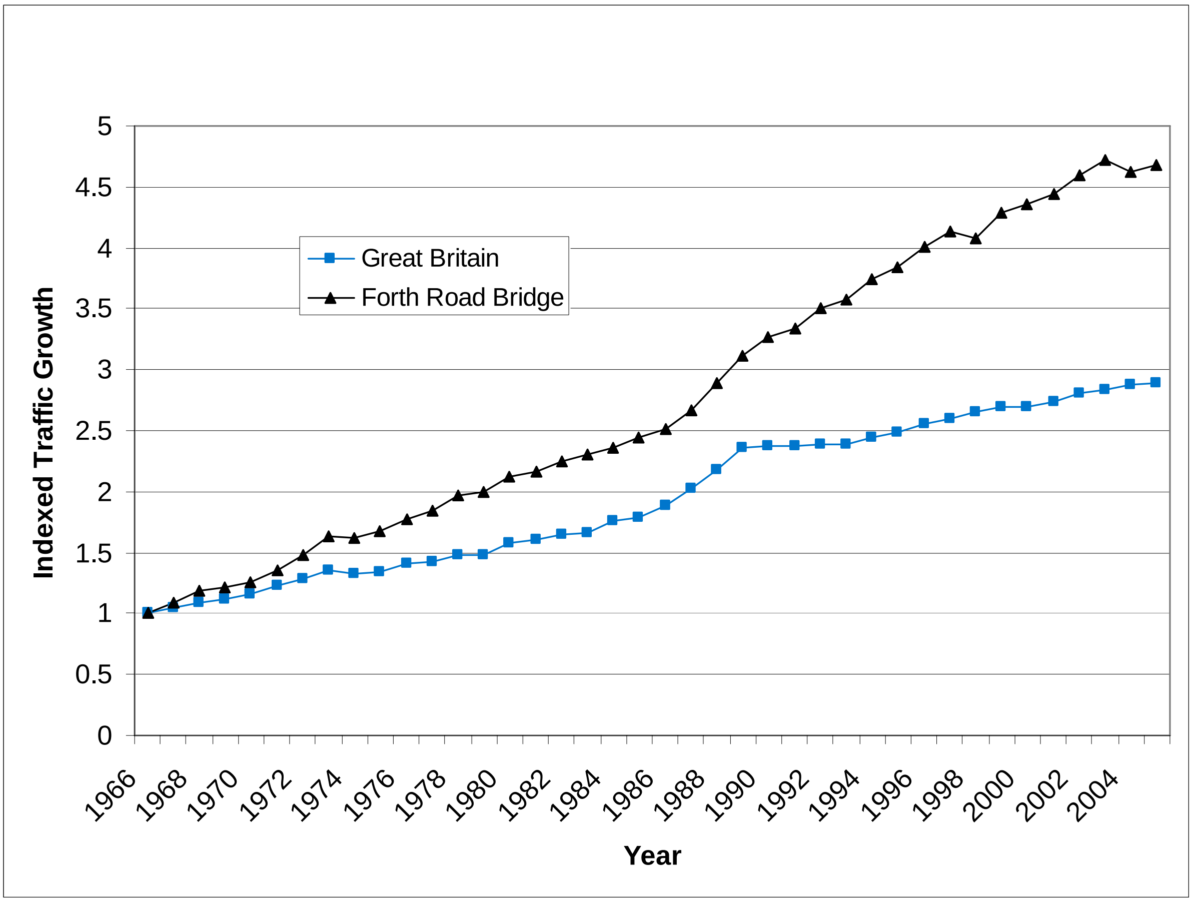


Figure 2.4 below shows the origins of traffic using the FRB, travelling southbound in the morning peak. The data for this, and Figure 2.5, is taken from a roadside interview survey undertaken in 2001. As such, it is a snapshot of a single day, and cannot be taken to apply to all situations encountered on the FRB, such as weekends or holiday periods. However, since this data was originally presented in Report 1, a similar survey was undertaken on the FRB in March 2007. Analysis of this more recent survey validated the findings given below and indicated that the distribution of journey origins and destinations has not changed significantly during this period.

Figure 2.4 shows that the highest proportion of the traffic originates from Dunfermline, with a lower proportion from Kirkcaldy/Glenrothes, Inverkeithing, Dalgety Bay and Aberdour, and Perth and Kinross. Traffic from Rosyth makes up only 5 per cent of the total traffic using the FRB. Note that the figures sum to only 98 per cent due to rounding.

Figure 2.4: Forth Road Bridge – Origins

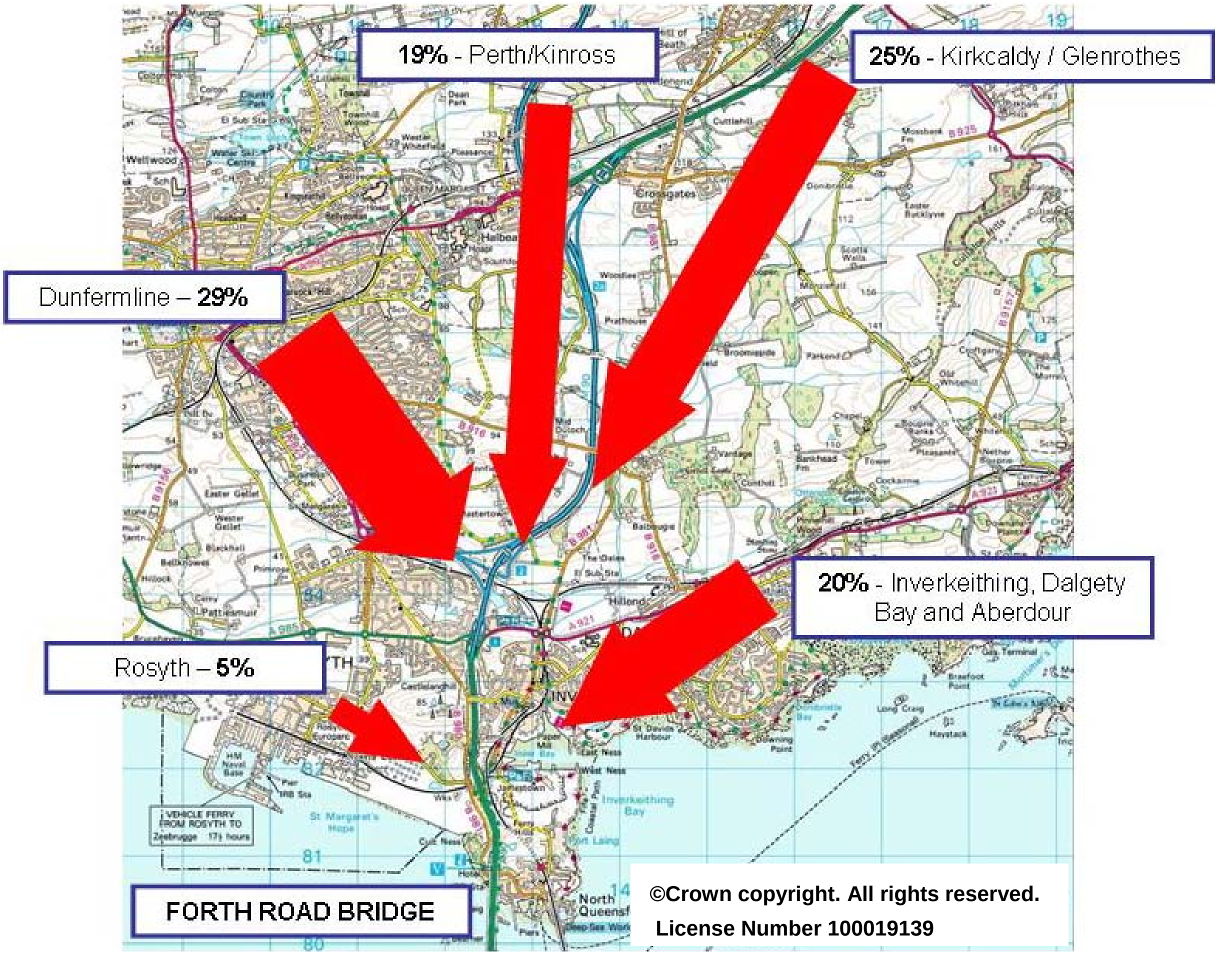
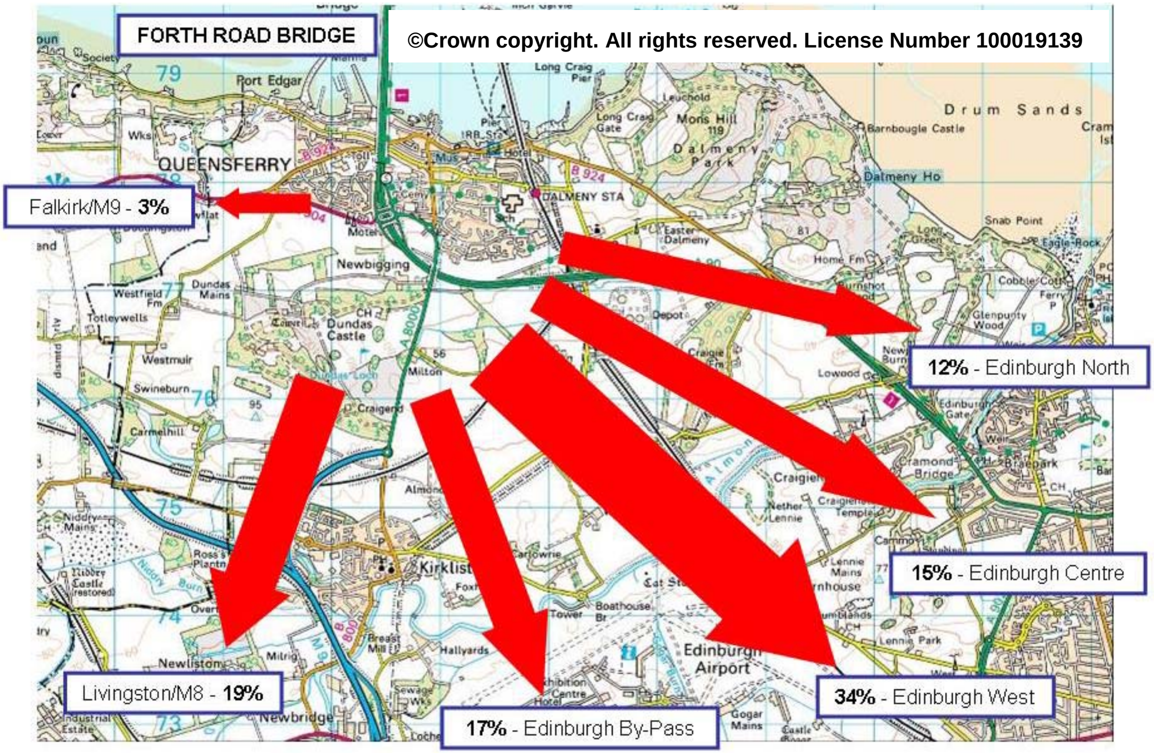


Figure 2.5 below shows the destinations of traffic using the FRB. It shows that only 15 per cent of traffic is destined for Edinburgh City Centre. It should also be noted that 19 per cent of the traffic is destined for Livingston and the M8.

Figure 2.5: Forth Road Bridge – Destinations



Details of car occupancy surveys undertaken on 12th October 2006 at the FRB are included below in Table 2.2. At the time of completion of Report 1 this was the most recent survey information of car occupancy rates crossing the bridge. For comparison, results from a similar survey undertaken at the northbound toll booths in 2000 and reported in FETA's – 2005 Local Transport Strategy are reproduced alongside the 2006 data.

Table 2.2: Forth Road Bridge Car Occupancy Levels – October 2006

Time Period	Car Occupancy Rate – Southbound 2006	Car Occupancy Rate – Northbound 2006	Car Occupancy Rate – Northbound 2000
AM Peak (6 to10am)	1.23	1.17	1.18
Off Peak (10am to 4pm)	1.50	1.43	1.40
PM Peak (4 to 7 pm)	1.35	1.36	1.28

Comparing the 2000 results with 2006 would indicate very little change in the morning and off peak occupancy rates. However, there is a small but noticeable rise in occupancy rates in the evening peak between 2000 and 2006.

Report 1 contains further extensive details of road traffic patterns, volumes and growth trends. It also contains a summary of information collected from public transport modes. Although that information is not as comprehensive as that relating to journeys made by private vehicles, the key points found were as follows:

- It is estimated that there are between 1300 and 1600 people travelling southbound across the Forth using rail in the morning peak hour;
- The average train crossing the Forth Bridge during the morning two hour peak period is around 90 per cent full with seated passengers;
- In the morning peak the Ferry Toll Park and Ride site is serviced by buses bound for Edinburgh with a maximum headway of 10 minutes;
- Around a third of all southbound bus passengers originate from Ferry Toll Park and Ride during the morning peak period; and
- Over 80 per cent of these passengers end their trip within Edinburgh city centre.

The following Performance Indicators have been selected for use in subsequent analysis:

- total vehicle traffic across the FRB and any new crossing. This can be presented by direction and time of day, and split by mode, particularly HGVs;
- road congestion indicators (number of vehicle-hours in excess of that experienced at free-flow speed);
- journey times of selected routes for bus and car;
- average speeds by geographic area, and on a link by link basis;
- mode share of public transport;
- select link analysis, to show the origins and destinations of journeys using a particular link;
- Carbon Dioxide (CO_2) emissions;
- other transport related pollutant emissions;
- public transport flows;
- public transport mode share, as a proportion of total trips;
- bus journey times; and
- crowding levels on rail services crossing the Forth Bridge southbound in the morning peak.

2.7 BASE AND FORECAST MODELLED TRANSPORT CONDITIONS

The Transport Model for Scotland (TMfS) was used to compare the network conditions in 2005 with forecast conditions in 2012, 2017, and 2022 for scenarios with only those infrastructure projects that are likely to be in place by those dates. The conclusions reached are as follows:

- there is very little growth in traffic on the FRB in the peak hour periods, indicating that it is already very close to capacity;
- the inter-peak period experiences the highest rates of growth;
- forecasts of congestion indicators show that congestion is predicted to worsen significantly;
- road journey times in the peak to Edinburgh significantly increase in duration, though this is largely due to congestion in Edinburgh itself;
- road journey times in the peak across the FRB to non-Edinburgh locations do not worsen significantly, indicating that it is already operating at or near capacity in the peak hours;

- average road speeds across the South East Scotland Transport Partnership (SEStran) region are forecast to decrease, with Edinburgh experiencing a drop of over 20 per cent by 2022;
- there is forecast to be little change in the pattern of origins and destinations of those using the FRB;
- $C0_2$ emissions from transport in the SEStran region are forecast to increase by 23 per cent by 2022;
- growth in rail patronage is forecast to be modest;
- bus patronage is forecast to decline; and
- bus journey times will increase as road congestion worsens.

A series of sensitivity tests were undertaken to test the responses of the TMfS to changes in travel costs and land use. Scenarios that varied the cost of private road vehicle fuel, public transport fares, the FRB Toll, and economic growth were undertaken.

The model has been shown to behave in a predictable and logical fashion:

- changing the FRB toll has the greatest impact on the use of the bridge;
- changing the public transport fares has the greatest impact on modal split;
- changing private road vehicle fuel prices has the greatest impact on distances travelled (vehicle kilometres) and vehicle hours, and, hence, on transport related pollutant emissions.

The model is therefore a suitable tool for predicting and assessing the results of changing transport costs on the aggregate behaviour of users of the transport system.

2.8 OVERALL CONCLUSION

This chapter demonstrates that there will be an increased requirement for significant maintenance on the FRB in the future. This maintenance cannot be undertaken without temporary traffic management measures being put in place which would restrict the capacity of the crossing. Evidence from recent occasions when maintenance on the bridge has taken place at weekends indicates that serious congestion is experienced. Delays of between 60 and 90 minutes have been recorded even when traffic flows are some 30 per cent lower than on the corresponding weekend in 2006.

The forecast increases in daily traffic crossing the Forth would exacerbate the high levels of congestion experienced during restrictions or closures on the FRB. It is also envisaged that due to the type of maintenance works expected to be undertaken on the bridge in future that it would not be possible to limit these traffic management restrictions to weekends as is currently the case.

It is envisaged that in the future there will be an increased number of occasions when restrictions are placed on vehicles using the bridge on both week days and weekends. Due to the growth in traffic, the delays and queues experienced are likely to be substantially greater than those encountered during maintenance periods to date.

3 PLANNING OBJECTIVES

3.1 INTRODUCTION

This chapter focuses specifically on establishing the high level expectations for transport network performance on and in the vicinity of, the Forth Road and Rail Bridges, over the ten year period from 2012. This process takes cognisance of the emerging Government policies and action plans together with associated consultation. These high level expectations have been used to determine strategic transport network objectives and consequently identify disparity between desired and forecast performance levels, such that potential interventions can be identified and prioritised.

This work is outlined in greater detail within Report 2[5]

3.2 CURRENT AND EMERGING POLICIES

A comprehensive review of current and emerging policies and action plans at national, regional and local levels was undertaken. At a national level, Scotland's Transport Future (Scottish Executive, June 2004) outlines an overall aim "to promote economic growth, social inclusion, health and protection of our environment through a safe, integrated, effective and efficient transport system".

The **National Transport Strategy (NTS)** (Scottish Executive, December 2006) considers Scotland's transport needs and the needs of travellers over the medium to long-term. It sets the framework for the STPR and will determine the Scottish Executive's future infrastructure investment. Three key strategic outcomes are identified within the NTS:

- **improve journey times and connections**, to tackle congestion and the lack of integration and connections in transport which impact on our high level objectives for economic growth, social inclusion, integration and safety;
- **reduce emissions,** to tackle the issues of climate change, air quality and health improvement which impact on our high-level objective for protecting the environment and improving health; and
- **improve quality and accessibility and tackle affordability,** to give people a choice of public transport where availability means better quality public transport services and value for money or an alternative to the car.

Published at the same time as the NTS are the following associated documents, which provide additional focus on certain aspects of Scotland's transport network; these have been produced in the form of a series of Action Plans.

[5] Forth Replacement Crossing Study – Report 2 - Determining Network Performance , Transport Scotland/Jacobs/Faber Maunsell – February 2007

Moving Into The Future: An Action Plan For Buses in Scotland sets out the Scottish Executive's aims and objectives in relation to bus services in Scotland and specifies measures required to support and improve bus services throughout Scotland. The Action Plan sets out the high-level expectations as follows:

- to improve bus services through effective transport planning;
- to support the development of the bus industry in Scotland; and
- to support effective implementation of the Regulatory Regime.

Scotland's Railways sets out the Scottish Executive's aims and objectives for the rail industry in Scotland.

It is recognised that rail has a central role within the NTS and, as such, the vision for the railway in Scotland is that it should provide *"a safe, reliable customer-focused service that supports our economy and delivers wider social inclusion and environmental aspirations."*

Potential developments or enhancements to the rail network would contribute to the delivery of the strategic outcomes identified in the NTS as follows:

- improving journey times and connections;
- reducing emissions; and
- improving quality, accessibility and affordability.

It is recognised that by investing in the rail network, a contribution can also be made to reducing road congestion and harmful emissions and also reducing the impact of transport on the environment.

Preparing for Tomorrow, Delivering Today: Freight Action Plan For Scotland sets out the Scottish Executive's aims and objectives for the freight industry in Scotland. The Action Plan supports the NTS and, in turn, the Framework for Economic Development in Scotland, Scotland's Sustainable Development Strategy, Scotland's Climate Change Programme and the Air Quality Strategy.

The Freight Action Plan for Scotland highlights the importance of freight, stating that *"the efficient and competitive movement of goods through the entire supply chain is therefore a key element in meeting consumer demand and supporting and enabling economic growth."*

The Freight Action Plan identifies the following high level expectations:

- to enhance Scotland's competitiveness;
- to support the development of the freight industry in Scotland;
- to maintain and improve the accessibility of rural and remote areas;

- to minimise the adverse impact of freight movements on the Environment in particular through the reduction in emission and noise; and
- to ensure freight transport policy integration.

The NTS and associated documents are considered to be particularly relevant to this study, together with the regional and local policies.

Broadly similar high level objectives were concurrent through all policy levels: to promote economic growth, social inclusion, health and protection of the environment through a safe, integrated, effective and efficient transport system. Key priorities were identified to promote modal shift and raise awareness of the need to change; promote new technologies and cleaner fuels; manage demand; reduce the need to travel; deliver reliable journey times for all road users; improve services for all transport users; and enhance movements of freight by non-road modes.

In the Regional Transport Strategy (RTS) developed by SEStran, there were specific requirements for a new crossing to include: provision for future tram or heavy rail use; a maximum of two lanes in either direction for single occupancy vehicles (i.e. matching the existing capacity); new lanes dedicated to buses, HOV and HGV's; flexibility to enable full vehicle carrying capacity during maintenance periods; and demand management measures to ensure traffic levels in Edinburgh remain below those forecast without an additional crossing.

3.3 CONSULTATION

The FETA Local Transport Strategy (LTS) and SEStran RTS were the subject of a detailed consultation process. This informed major stakeholders and members of the public about the draft documents and proposals and it provided the opportunity to comment in a variety of ways.

The results of the consultation identified a perception that many transport problems in the area originate from a lack of integration between land use and transport planning and between health and transport policies. A number of barriers to cross-Forth public transport use, attributable primarily to lack of direct services and reliability, speed and cost were identified. Top priority measures included public transport investment; implementation of multi-modal crossing; increased public transport integration and a requirement for queue management / tolling regime.

3.4 DEVELOPMENT OF OBJECTIVES

Identification of the high level expectations from emerging and current policies and action plans, together with the key issues arising from relevant consultations, enabled the development of a number of specific transport planning objectives for the FRCS, as follows:

- maintain cross-Forth transport links for all modes to at least the level of service offered in 2006;
- connect to the strategic transport network to aid optimisation of the network as a whole;

- improve the reliability of journey times for all modes;
- increase travel choices and improve integration across modes to encourage modal shift of people and goods;
- improve accessibility and social inclusion;
- minimise the impacts of maintenance on the effective operation of the transport network;
- support sustainable development and economic growth; and
- minimise the impact on people, the natural and cultural heritage of the Forth area.

3.5 GAPS AND SHORTFALLS

Performance Indicators identified in Report 1 were examined and linked to the appropriate transport planning objective.

The TMfS was then used to measure how the base and forecast conditions in 2005, 2012, 2017 and 2022 performed against each transport planning objective. The scenarios included only those infrastructure projects that are likely to be in place by those dates. It should be noted that these predicted conditions do not take account of many of the proposals put forward by the SEStran RTS as these are not committed.

The Performance Indicators selected in Report 1 of this study were reviewed and the most appropriate selected as quantitative measures for each objective. The use of these indicators identified any gaps and shortfalls between the future performance and expectations of the transport network in the vicinity of the Forth bridges in 2012, 2017 and 2022. The results are presented in Report 2 and are summarised in the Table 3.1 below.

Table 3.1 Summary of Assessment

Objective	Measurement	Assessment
Maintain cross-Forth transport links for all modes to at least the level of service offered in 2006	Road journey times	Not met
	Bus journey times	Not met
	Rail crowding cross-Forth	Not met
Connect to the strategic transport network to aid optimisation of the network as a whole	Average road speeds	Not met
Improve the reliability of journey times for all modes	Number of vehicle hours between J4 of the M90 and Echline Roundabout below free-flow speed	Not met
Increase travel choices and improve integration across modes to encourage modal shift of people and goods	Public transport mode share across the Forth	Not met
Improve accessibility and social inclusion	Road journey times between areas of deprivation and major employment centres	Not met
	Public transport journey times between areas of deprivation and major employment centres	Not met

Table 3.1 (continued) Summary of Assessment

Objective	Measurement	Assessment
Minimise the impacts of maintenance on the effective operation of the transport network	Total annual average weekday flow on the FRB	Not met
	Annual average weekday HGV flow across the FRB	Not met
Minimise the impact on people, the natural and cultural heritage of the Forth area	Pollutant emissions from transport in the SEStran area.	Not met (CO_2)
Support sustainable development and economic growth	Pollutant emissions from transport in the SEStran area.	Not met (CO_2)
	Annual average weekday HGV flow across the FRB	Not met
	Public transport mode share across the Forth	Not met
	Total annual average weekday flow on the FRB	Not met
	Number of vehicle hours between J4 of the M90 and Echline Roundabout below free-flow speed	Not met

It can be concluded, based on the appraisal within this study that without intervention in the transport network over and above that currently planned, the objectives of the FRCS will not be met.

3.6 CONCLUSION

This chapter has considered the current and emerging policies that are relevant to the STPR and in particular the FRCS. The recently published NTS and associated documents have been particularly important in guiding the development of the study objectives which have also drawn extensively on previous work undertaken by both SEStran and FETA. The report also considers the consultation that has already taken place in the development of current policy and that undertaken directly as part of this study.

Following careful consideration of these two aspects (current/emerging policy and consultation) a number of study specific "SMART" objectives have been developed and tested within the relevant reference groups. This has led to the setting of a final set of study objectives which would guide future work in the latter phases of this project.

The chapter concludes by presenting specific performance indicators used to identify any gaps and shortfalls between the future performance and the expectations of the transport network in the vicinity of the Forth bridges. It concludes that without intervention in the transport network over and above that currently planned, the objectives of the FRCS will not be met.

4 OPTION GENERATION AND INITIAL SIFTING

4.1 INTRODUCTION

The objective of this element of the study was to generate robust options for a potential replacement Forth Crossing. This has been done by utilising the outputs from the first two reports generated by this study together with other information taken from previous studies. All options generated have been sifted against the objectives developed for this purpose in accordance with the principles of STAG.

The long list of options include different types of crossing, locations of crossing, the accommodation of different modes, connections to the existing transport network and the use of the existing road bridge for other transport users.

The FRCS brief calls for all aspects of the new crossing to be examined including:

- alignment of the crossing and its approaches;
- capacity;
- type/form of structure;
- type/form of solutions;
- ground condition; and
- environmental impact.

Construction and maintenance considerations have been examined together with associated risks. An assessment of the procurement and finance issues, together with the likely programme and timescales for the construction have been examined. Legislative issues have also been addressed.

This work is outlined in greater detail within Report 3[6]

4.2 CONSTRAINTS MAPPING

This section presents the various constraints which exist within the Firth of Forth. These constraints are important considerations in the development of the option(s). Within this chapter, an overview of the constraints is presented.

The various environmental constraints are summarised on Figures 4.1 and 4.2 which show the nationally protected sites and the locally designated sites. Of the nationally designated sites the most influential constraints are the combined effect of the Special Protection Areas (SPA), Ramsar and Sites of Special Scientific Interest (SSSI) areas. These cover most of the intertidal areas between Kincardine and to the east of South Queensferry.

[6] Forth Replacement Crossing Study – Report 3 – Option Generation and Sifting, Transport Scotland/Jacobs/Faber Maunsell – February 2007

Figure 4.1: Environmental Baseline - Nationally Protected Areas

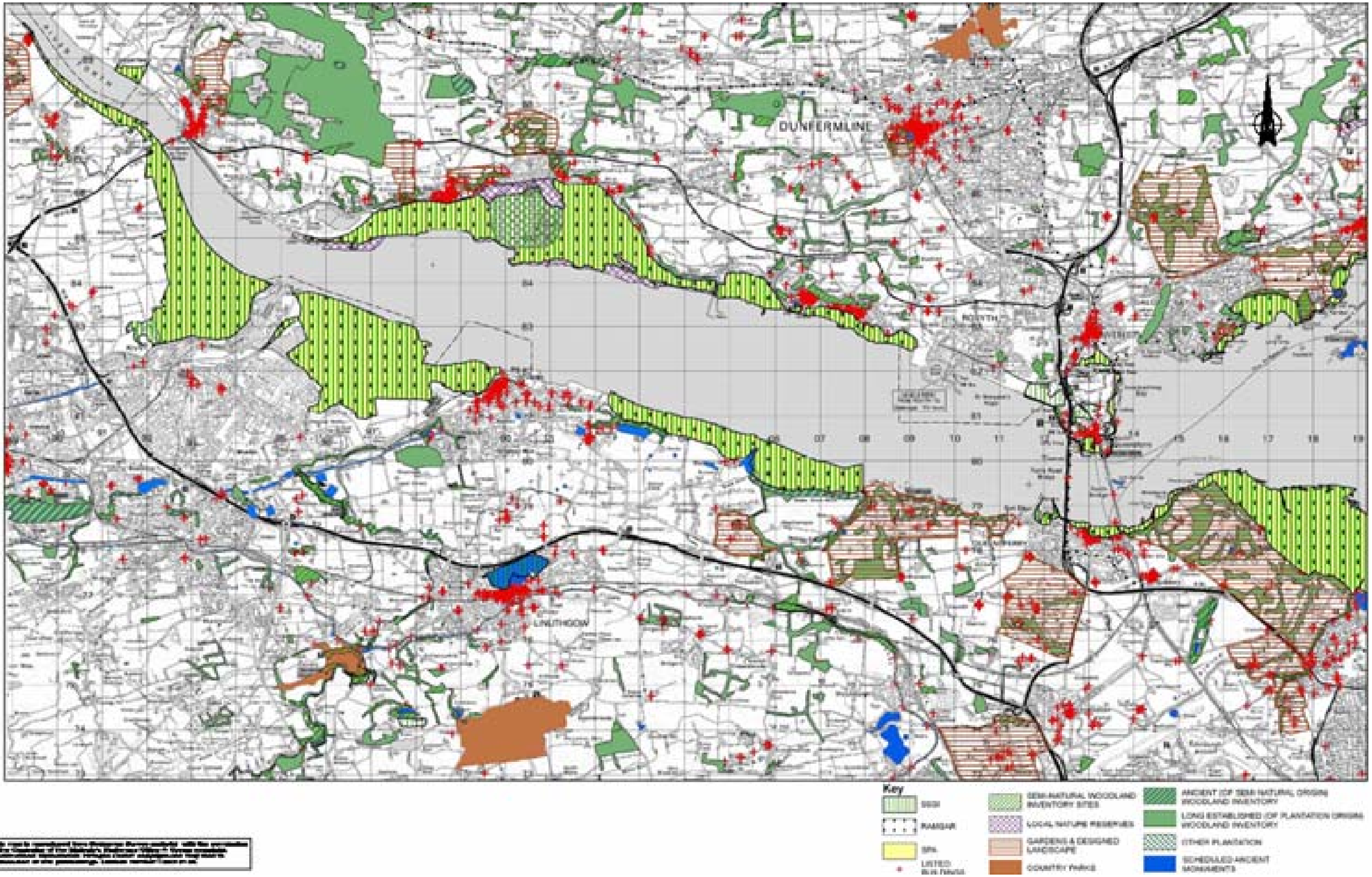
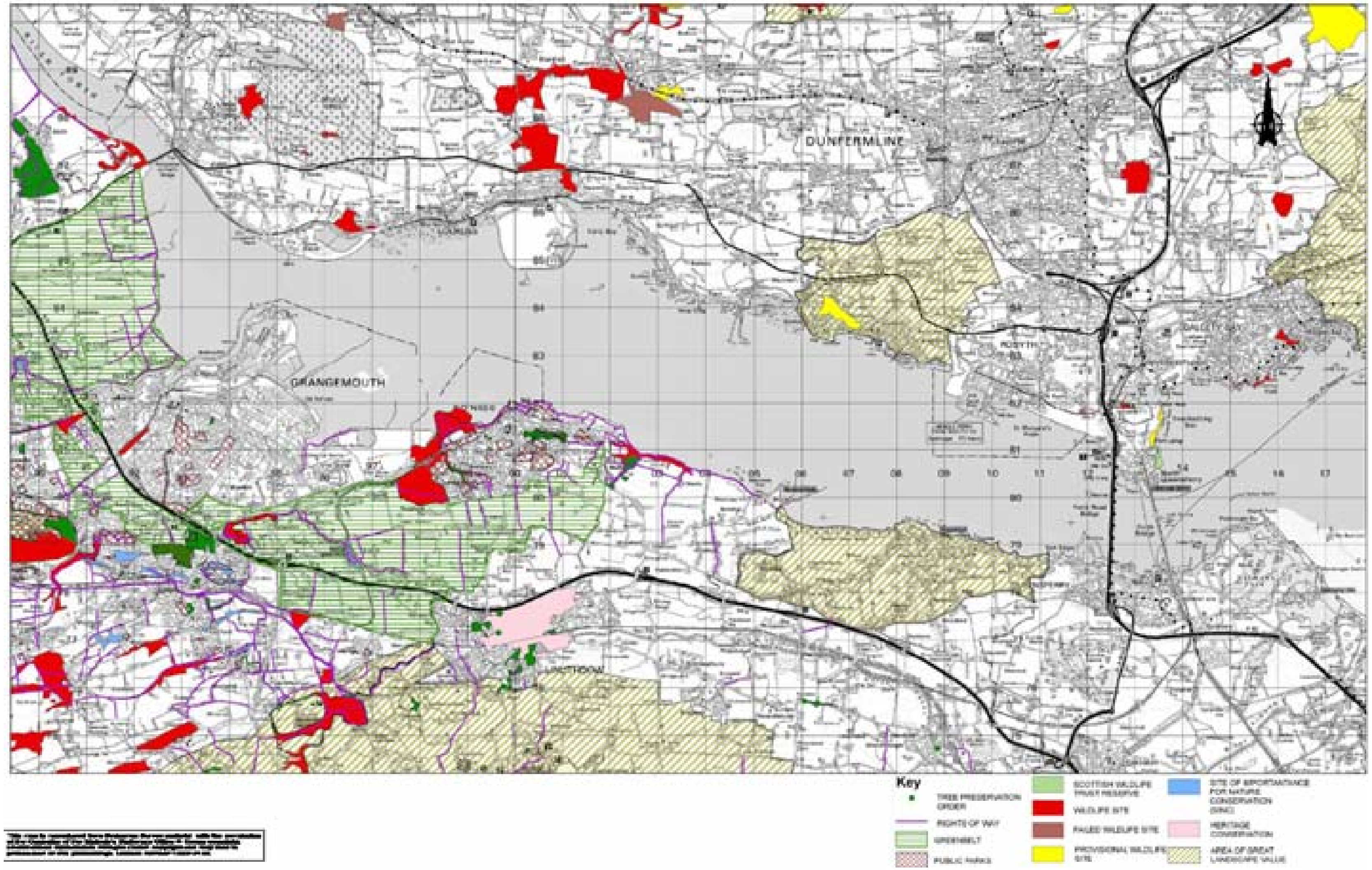


Figure 4.2: Environmental Baseline – Locally Protected Areas



In addition, the location of the Scheduled Ancient Monuments (SAM), listed buildings and landscaped gardens particularly on the south shore of the Firth pose localised environmental constraints.

The combination of the locally protected sites again affects significant lengths of the south shore of the Firth and the area on the north shore west of Rosyth.

It should also be noted that in addition to the designated intertidal habitat of the SPAs, other habitats outside the SPA are of integral importance to the Firth and its designations. Sea ducks, divers and grebes feed, loaf and roost outside the SPA in the open waters of the Firth, waterfowl use adjacent fields for roosting and/or feeding in high tides and salmon migrate upstream to spawn in the River Teith SAC.

There is, therefore, an important relationship between the designated areas and non designated areas of the Firth, where impacts outwith the immediate boundaries of the SPAs may still affect the integrity of the designated areas. At this stage, these relationships are difficult to quantify and the assessments that follow give more importance to direct impacts affecting the integrity of the SPAs. However, it should be borne in mind that direct impact does not equate, by default, to adverse impact on the integrity of the site. Equally, indirect impact could have an adverse impact on the integrity of the site, although it is less likely.

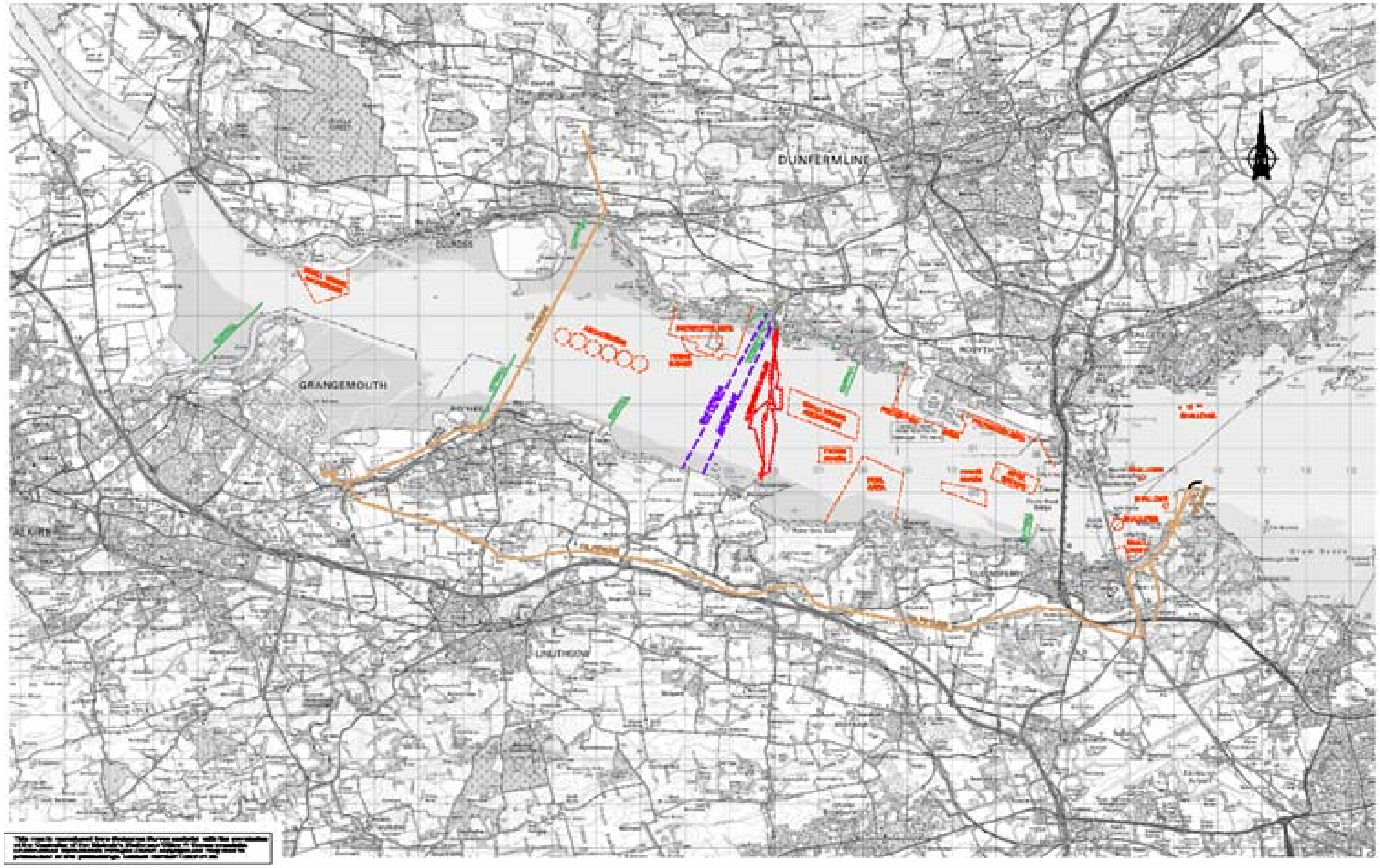
The physical constraints have been summarised on Figure 4.3 and can be summarised as follows:

- oil, gas, electricity lines crossing the Firth;
- firing range protected areas;
- vessel anchorages and berthing areas for H.M. Ships;
- various outfall pipes; and
- BP oil pipeline from Kinneil to Dalmeny and Hound Point.

Details of each can be found in Report 3.

One physical constraint which is worth elaborating upon at this stage is that imposed by the wide range of geological and geotechnical issues. The potential crossing types include both tunnel and bridge options, the feasibility of which is dominated by the constraints imposed by the geological setting. Specifically, these constraints relate to the rockhead contours in the Firth, the thickness and nature of the overlying alluvial deposits and the water depths in the main channels.

Figure 4.3: Physical Constraints around the Firth of Forth



Bridge structures require to span the main shipping channel and to have foundations in the bedrock, or highly competent non-cohesive strata at depths of not more than approximately 40 metres below Ordnance Datum. This depth is chosen as being consistent with the existing bridges. Deeper foundations may be possible in extreme cases but have not been considered at this juncture due to the significant additional costs that would be incurred. The existing FRB has caisson foundations on rock at about 30 metres depth for the southern pier. The northern pier stands on a submerged natural rock shelf (Mackintosh Rock) in about 10 metres of water. The Firth widens significantly on either side of the existing crossing points, which take advantage of the volcanic rock promontory of North Queensferry. The central support of the existing Forth (Rail) Bridge is founded on the island of Inch Garvie, a volcanic rock outcrop near the middle of the Firth.

Tunnels are technically feasible within the alluvial deposits in the Firth and in the rocks that define the banks of the Forth. Transitions to localised hard rocks such as volcanic sills and dykes may present significant obstacles to the progress of the large tunnel boring machines (TBM) required for a tunnel beneath the Forth. Hence, knowledge of hard rock intrusions within the drift materials is of specific interest when considering tunnel options.

The extent of coal bearing strata and mine workings, present in the west of the study area, are of interest for both bridge and tunnel options. The presence of mine workings in or beneath construction zones may necessitate pre-treatment such as grouting to avoid subsequent collapse. The costs associated with stabilising such mine workings may be significant.

There are a number of key constraints identified with respect to the future maintenance of the FRB. Many of these planned activities would significantly impact on traffic flow across the bridge as traffic management restrictions would be imposed for health and safety reasons. This would impose constraints on the ability of the FRB to operate normally for prolonged periods in the future and would need to be considered carefully.

4.3 GENERATION OF OPTIONS AND INITIAL SIFTING

A long list of 65 potential options was generated.

The long list was subjected to an initial sifting process. This was undertaken with a view to reducing the list by eliminating options which did not satisfy the objectives of the study or were not technically feasible. 19 of the original 65 options were rejected for these reasons. Those rejected included the use of arch bridges and swing bridge options, which could not provide the required spans. Suggestions of bridges or tunnels crossing between Leith/Portobello to either Kirkcaldy or Burntisland were also rejected as these were uneconomic or beyond practical engineering limits.

Options involving ferries and hovercraft were also considered but rejected as they would not provide sufficient capacity on their own. However, such measures may have a complementary role to play as part of an overall strategy for enhancing public transport choice for cross Forth travel.

A number of options generated by the long list included heavy rail as part of a new bridge crossing or tunnel. Studies undertaken recently, notably the SEStran Integrated Transport Corridor Study (SITCoS), found that sufficient additional cross Forth rail capacity can be provided by enhancing the services using the Forth Bridge to cater for the expected growth in demand until around 2026. This can be done through the introduction of longer train sets (six cars) with accompanying platform extensions and two additional trains in the peak hour. Beyond 2026 Network Rail have indicated that still further capacity can be provided without recourse to a new rail crossing.

It was therefore concluded that future heavy rail capacity should be provided by enhancing the services across the Forth Bridge. This would provide a more cost-effective increase in heavy rail capacity rather than incorporating heavy rail provision into a new crossing. Previous studies had indicated that the technical requirements to incorporate heavy rail into a new crossing could possibly double its cost. The issue of cross Forth rail capacity and journey reliability should be considered by the main STPR Commission.

The Initial Sifting saw 46 options taken forward for further consideration. These options fell into seven broad categories:

- crossing location;
- bridge crossings;
- tunnel crossings;
- capacity/operational configuration;
- multi modal capability;
- operational options; and
- miscellaneous others.

A hierarchical approach to the appraisal was followed to ensure that the major issues were dealt with adequately before turning to the more detailed considerations.

The approach adopted was to consider the first three categories above; namely crossing location, bridge crossings and tunnel crossings. All other issues would be considered once a clear view on the primary issues was developed.

The remainder of this report therefore considers bridge and tunnel options in the following five corridors:

A – Grangemouth (West of Bo’ness);

B – East of Bo’ness;

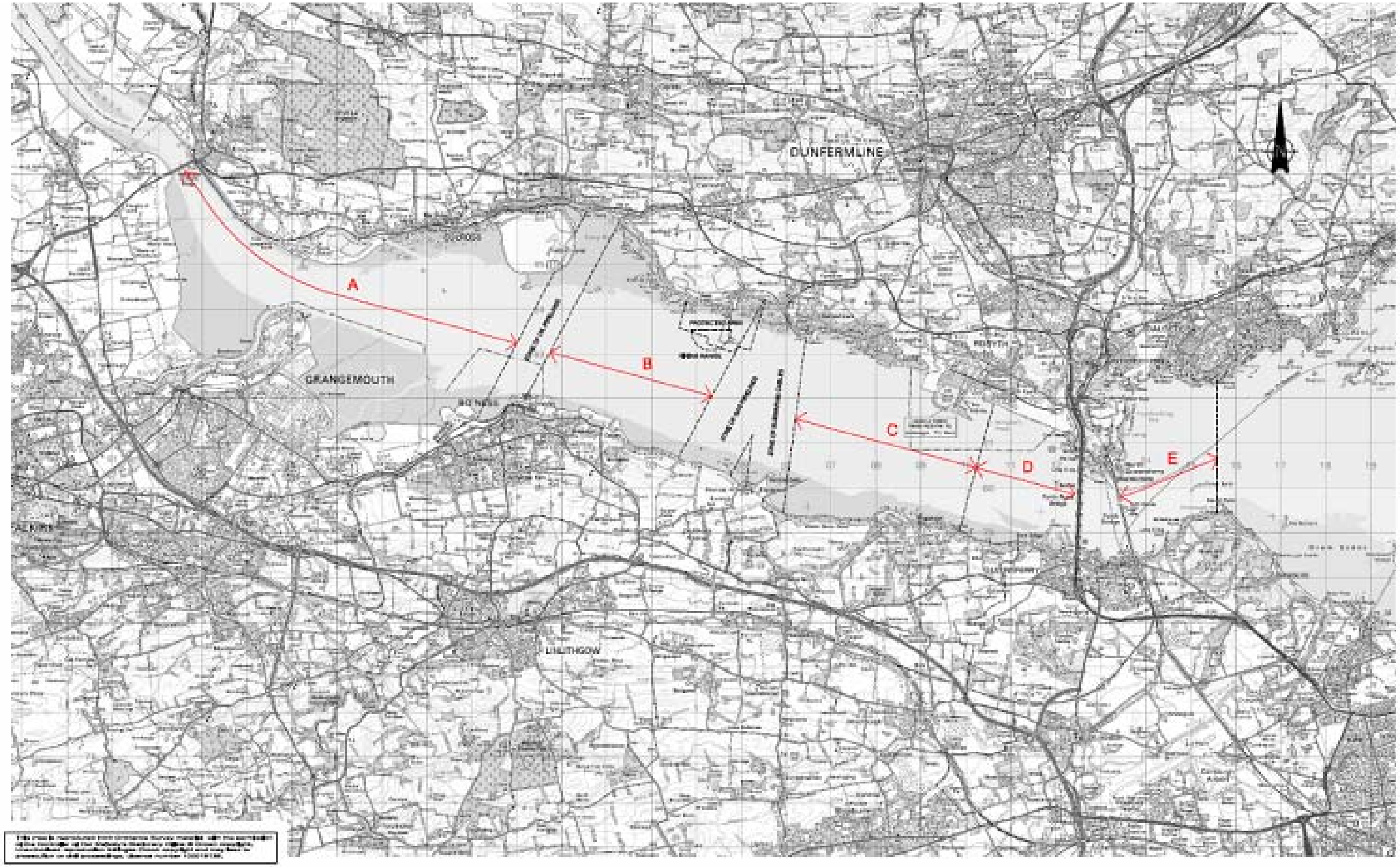
C – West of Rosyth;

D - East of Rosyth/West of South Queensferry; and

E – East of South Queensferry.

Each corridor has been determined by the constraints identified and is illustrated in Figure 4.4. In the STAG appraisal process each option is appraised against the study objectives (the planning objectives) and the Government's 5 key objectives of Environment, Economy, Safety, Accessibility/Social Inclusion and Integration. At this stage, however, the sifting aims to assess each corridor for its suitability in achieving the study objectives given the constraints identified. This is reported in Section 4.5.

Figure 4.4: Study Crossing Corridors



4.4 GENERAL DESIGN ISSUES

Before assessing each of the corridors, a number of key design issues associated with possible bridge and tunnel crossings were explored.

Bridge Crossings

By the very nature of the wide Firth and the need to span over the navigation channels, any bridge crossing would tend to have long spans. Any final bridge would, in all likelihood, combine a long span over the navigation channel combined with approach viaducts of shorter length.

The suitability and form of any bridge would depend on several design issues relating to constraints which include:

- navigation channel width and headroom clearance;
- underlying geology and its suitability for foundations;
- environmental constraints;
- archaeological and historical sites;
- pipelines and electricity transmission cables;
- urban developments; and
- proximity to existing bridges.

Both suspension bridges and cable stayed bridges would be able to accommodate these constraints and each are discussed briefly.

Suspension bridges are technically feasible across the Forth and have the advantage that they can provide large spans of up to 2000 metres. This has a clear benefit of providing adequate navigation clearance and minimises foundations for piers in the Firth of Forth. The FRB is a suspension bridge with a maximum span of 1006 metres and the preferred option for the crossing during the Setting Forth study was a suspension bridge with a maximum span of 1375 metres.

The maximum span suspension bridge achieved to date is the Akashi Kaikyo Bridge in Japan with a maximum span of 1991 metres. The main towers, which are 298 metres above water level, are 142 metres higher than those of the FRB. In the following sections it is demonstrated that bridges with spans of this magnitude may be necessary to cross the Firth of Forth within some of the corridors under consideration.

The advantages of suspension bridges compared to cable stayed bridges are set out below:

- the long spans provide maximum clearance for navigation channels;
- the design minimises the number of piers and foundations in the Firth;

- by reducing the number of piers a suspension bridge potentially reduces the environmental impact and blockage of the Firth that would be associated with foundation construction; and

- the longer span possible means that foundations of a suspension bridge can be founded in relatively shallow water, so reducing the construction and cost risks of working in deeper water.

Cable stayed bridges are also technically feasible across the Forth. However, due to the width of the Firth, and span limitations, it would inevitably require a tower foundation located in the deeper water close to the centre of the Firth unless use can be made of an island such as Beamer Rock. With current technology spans of approximately 1000 metres can be achieved. The maximum existing cable stayed bridge span is 890 metres on the Tatara Bridge in Japan. The towers are 224 metres high making them 66 metres higher than the FRB. Construction is currently underway on the Sutong cable stayed bridge in China with a maximum span of 1088 metres. Several cable stayed bridge options were developed in the Setting Forth project with maximum spans of 650 metres.

Rion-Antirion Bridge, Greece, pictured below was opened in 2004. It has maximum spans of 560 metres and its foundations are founded in water up to 65 metres deep. (See Figure 4.5 below)

Figure: 4.5 Rion-Antirion Bridge, Greece

The approach viaducts associated with cable stayed bridges would tend to be longer than those associated with suspension bridges as the main span of a cable stayed bridge is more limited in length than that of a suspension bridge. The Oresund Bridge between Sweden and Denmark has a maximum span of 490 metres and carries combined rail and road.

The advantages of cable stayed bridges compared to suspension bridges are:

- slightly shorter construction programme; and

- construction of the foundations at the landfalls is less complex than those for a suspension bridge as they do not need to provide tension anchorage. The foundations and substructure are relatively simple abutments. As a result of reduced excavation the potential problems associated with the presence of methane on the south landfall could be reduced.

Using experience and information gathered around the world it was concluded that a suspension bridge would probably take 5½ - 6 years to construct with a cable stayed bridge possibly taking around six months less.

Tunnel Crossings

Different forms of tunnel construction were examined. These included bored, immersed tube, cut and cover and mined tunnel. This review concluded that a bored tunnel utilising a TBM is the most desirable of the methods as it would avoid the main environmental problems associated with immersed tube tunnelling. Bored tunnelling would not impinge on the various SPAs and SSSIs that delineate the banks of the Forth. Mined and cut and cover tunnelling are considered as supplementary methods to the main bored tunnel crossing.

Construction of immersed tube tunnels across the Forth would have significant direct and indirect impacts on the SPA as a consequence of the need to dredge a channel in the sea bed. Methods of construction impacting in this way would only be selected if there were no other reasonable alternative methods available. In this case it is clear that a bored construction method for a tunnel is a valid and reasonable alternative and immersed tube crossings are not considered as the principal method of construction.

New European design standards, currently issued for consultation and to be introduced in 2007, dictate that the maximum gradient for new tunnels should be no more than 3 per cent. This would, in turn, dictate the length of any tunnel beneath the Firth of Forth. In the corridors examined the lengths of tunnels vary between 7-10 kilometres. Again, using experience and information gathered around the world it is estimated that the construction programme for a tunnelled crossing would be in excess of seven years.

4.5 CORRIDOR SIFTING

The sifting carried out within this study is undertaken in order to establish which options are unlikely to meet the study objectives. It is equivalent to the pre-appraisal phase of the STAG process. Any options passing this sifting exercise were then subjected to a Part 1 appraisal during the next work package.

The detail of the corridor sifting process can be found in Report 3. Each corridor was initially assessed against the eight planning objectives for the FRCS as stated previously in Section 3.4 of this report.

This initial sift was carried out prior to the STAG Part 1 and 2 Appraisal, which considered the sifted options against the planning objectives in more detail. It also considered the performance against the Government's five main objectives.

It was clear from the work summarised in Report 3 that Corridors A and B did not meet the objectives of the study and were, therefore, rejected from further study.

Overall the option which performed best against the objectives is a crossing within Corridor D. It is closest in distance to the existing FRB and would, therefore, be best placed to maintain Cross Forth transport links for all modes to at least the level of service offered in 2006. It is relatively straightforward to connect into the strategic transport network and again, its proximity to this network, would ensure that optimisation of the network operation would be achieved.

Corridor D is well placed in terms of the major settlements on either side of the Forth and this can provide public transport options within the crossing with minimum diversion. However, it should be noted that public transport priority could be provided on the FRB in all the corridor options.

It is considered that Corridor D (together with Corridor E) is the best performing option in terms of improving accessibility and social inclusion.

A crossing in Corridor D would allow the impacts of future maintenance of both crossings to be minimised due to their proximity to each other.

A bridge (or tunnel) in Corridor D (and E) would ensure that economic development and economic growth is supported.

The environmental impact on people, the natural and cultural heritage of a bridge in Corridor D is the least of all bridge corridors. It is not likely to have any direct impacts on the Firth of Forth or Forth Islands SPAs although there may be indirect impacts which may be significant. There is likely to be an impact on the St Margaret's Marsh SSSI and the Ferry Hills SSSI. Tunnel options perform better against this objective. They are likely to avoid direct impacts on the SPA and SSSIs, although there may be direct impacts on St Margaret's Marsh SSSI if cut and cover techniques are used in this area.

Finally, a bridge in Corridor D is the lowest cost option of all options considered. The next option in order of cost would be a bridge in Corridor E which is estimated to be some 50 per cent more expensive. The environmental assessment of a bridge in Corridor E is slightly worse than Corridor D. All other objectives are similar but no better than those of D. This additional cost of 50 per cent does not achieve any greater value when viewed against the objectives.

This section has summarised the performance of the options against the objectives. This sifting is undertaken in order to establish which options are unsuitable in making progress towards meeting the study objectives. It is equivalent to the pre-appraisal phase of the STAG process. Any options passing this sifting exercise are then subjected to a Part 1 and 2 appraisal during the next phase of the STAG process.

Corridors C, D and E however do perform well to varying degrees against the objectives and should therefore be taken forward.

5 STAG PART 1 APPRAISAL

5.1 INTRODUCTION

STAG is the official appraisal framework developed by Transport Scotland to aid transport planners and decision-makers in the development of transport policies, plans, programmes and projects in Scotland. It is a requirement that all transport projects, for which Transport Scotland support or approval is required, are appraised in accordance with STAG.

This chapter covers the Part 1 Appraisal of the options which emerged from the Pre-Appraisal, namely:

- Within Corridor C - West of Rosyth;

  - bridge crossing (suspension with a span of 1800 metres)

  - tunnel

- Within Corridor D - East of Rosyth/West of Queensferry; and

  - bridge crossing (suspension with a span of 1375 metres or cable stayed with spans of around 600 to 650 metres)

  - tunnel

- Within Corridor E - East of Queensferry.

  - bridge crossing (suspension with span of 1,650 metres or 1,850 metres)

  - tunnel

The corridors are shown in Figure 4.4.

5.2 ASSUMPTIONS

The issues with regard to the structural integrity of the existing FRB are well documented and it is recognised that a range of possibilities exist in relation to the future status and use of the existing FRB. As outlined in Chapter 1 the objective of this report is to appraise the options for a replacement crossing. It is therefore assumed that the existing FRB would no longer be available for any traffic.

The appraisal also took into account other operational assumptions which are detailed below.

Any replacement crossing would comprise, as a minimum, two lanes in each direction to ensure that the crossing would have the potential to offer at least the same level of service as offered by the existing crossing at present. Hard shoulders would also be provided on the bridge crossings. The requirement to have a tunnel bore in excess of 13 metres in diameter would mean using a TBM at the upper end of the range of boring machines currently available. This diameter would not be sufficient to accommodate two lanes and a hard shoulder. Standard edge strips would, therefore, be provided in any tunnel option.

The future of tolls on Scotland's crossings was discussed in the Scottish Parliament in late May 2007 and primary legislation is to be introduced later this year which would lead to the abolition of tolls at the FRB. However, during the course of the appraisal it has been assumed that tolls on the replacement crossing would be set at the same level as those in place at present on the existing FRB.

The STAG Part 1 appraisal was undertaken on the basis of the initial alignments developed for Report 3 – Option Generation and Sifting.

Corridor C Bridge

A probable bridge option for this alignment is a suspension bridge with a main span of approximately 1800 metres and side spans of 550 metres. The location of the bridge within Corridor C has been heavily influenced by the boundary of the SPA. In order to minimise any impact on the SPA, the southern landfall would be between the boundary of the SPA and Hopetoun House. At the northern landfall the preferred bridge alignment would pass over the SPA immediately west of Rosyth.

Corridor C Tunnel

The probable tunnel alignment would link the A823(M) Junction at St. Margaret's Stone to a point in the vicinity of Junction 2 of the M9. It would comprise a tunnel from a point close to Pattiesmuir and under Limekilns, reaching the south shore around Abercorn. The tunnel would then rise to a portal between Duntarvie and Carmelhill. This alignment would involve approximately eight kilometres of twin-bore tunnel.

Corridor D Bridge

A suspension bridge in this corridor would be approximately 2.2 kilometres long with a proposed main span of 1375 metres and two equal side spans of 416 metres. A cable stayed bridge would have two main spans, each in excess of 600 metres, with the central tower supported on Beamer Rock.

Corridor D Tunnel

The tunnel alignment in this corridor would connect the M90 near to Junction 1 to the M9 near to Junction 1a. The alignment would cross the south shore near Port Edgar and then rise to a portal between Dundas Mains and Junction 1a of the M9. A tunnel on this alignment would be approximately seven kilometres in length of which approximately two kilometres may be mined through dolerite whilst five kilometres would be of bored tunnel construction.

Corridor E Bridge

Two suspension bridge alignments are considered within this corridor.

Alignment 1

The area of relatively little urban development between Inverkeithing and Dalgety Bay forms a natural landfall. The south landfall would be located east of Long Craig Pier. In order to found bridge piers in relatively shallow water a suspension bridge with a main span of approximately 1850 metres, with side spans of approximately 550 metres, would be required.

Alignment 2

It is possible to bridge the potentially narrow crossing between Whitehouse Point and North Queensferry as part of a longer cross Forth route. In order to found the main towers of a bridge on this alignment in relatively shallow water, it would be necessary to provide a suspension bridge with a main span of 1650 metres, with side spans of 500 metres. Approach viaducts would be required to link the bridge to the north landfall. A further bridge would be required across Inner Bay between West Ness and East Ness.

The southern landfall for both bridge proposals in Corridor E have been determined to clear the Hound Point Marine Terminal. However, the presence of the pipelines between Hound Point and Dalmeny imposes complexity to the construction of the south anchorages and approach viaducts.

Corridor E Tunnel

Tunnelling could commence between Junction 2A of the M90 and Balgougie on the north shore. The tunnel would cross the northern shoreline in St. Davids Harbour area. It would then pass to the east of Inch Garvie, making landfall on the south shore at Lone Craig Gate. It would then rise to a portal between Dalmeny and the M9. The length of bored tunnel for this alignment would be approximately 7.5 kilometres. However, if a combined bored / immersed tube solution were used, the length may be reduced to approximately 7 kilometres.

5.3 PERFORMANCE AGAINST THE PLANNING OBJECTIVES

The majority of the planning objectives are met by each of the proposals, although it is evident that the degree to which they are met varies across corridors and crossing types.

For the majority of objectives, the tunnel proposals perform slightly less effectively than the corresponding bridge proposals. This is due to network connectivity issues and the limited ability for the possibility of additional lanes to be provided without the requirement for an additional tunnel bore.

Generally, there was a preference for Corridor D and E proposals, over Corridor C proposals, due to their proximity to the existing crossing and primary transport network which minimises diversionary routes, increases flexibility and allows them to better serve developed areas and trip generators.

The only objective not met by all proposals is to minimise the impact on people, the natural and cultural heritage of the Forth area. This is not met by the Corridor C bridge and Corridor E bridge proposals, due in part to a combination of their potential impacts on the Gardens and Designed Landscapes at Hopetoun House, Dundas Castle and Dalmeny and the cultural heritage interests within the corridors, but mainly as a result of the expected impact on the SPA.

5.4 IMPLEMENTABILITY

A review of the implementability of each of the options was undertaken during the STAG Part 1 appraisal process.

It is evident that the implementation and operation of a replacement crossing of the Firth of Forth would be a technically challenging project. A number of significant technical risks would require to be identified and addressed, and appropriate mitigation strategies developed.

In terms of financial implementability, a wide range of costs exist for the proposals. However, none of the proposals can be excluded due to the affordability implications.

In terms of public acceptance there has been media coverage which suggests that there is a preference for a tunnel option as opposed to a bridge. However, none of the proposals could be excluded on the basis of public acceptance at this stage.

It would appear that all of the proposals included in the STAG Part 1 Appraisal are “implementable” and therefore worthy of further consideration in the next stage of the appraisal process.

5.5 PERFORMANCE AGAINST THE GOVERNMENT OBJECTIVES

A qualitative appraisal of the overall performance of the various proposals against the Government transport appraisal criteria was undertaken for the STAG Part 1 appraisal. The most significant findings which emerged are detailed below.

When acting as a replacement crossing, all of the proposals would be expected to perform well against the Government objectives when compared against the Do Minimum situation. It is recognised that the ability to provide extra lanes for HOVs and public transport on a bridge crossing would enhance the performance of these proposals when compared to tunnel options. It is clear that the option of providing extra lanes within the tunnel options would not be possible without the construction of a further bore.

None of the proposals exhibit a beneficial or even neutral performance against the environmental objective, and this is particularly the case for the bridges on Corridors C and E. The northern and southern landfalls of the Corridors C and E bridge proposal cross, or come very close to the Forth SPA. Both C and E Bridge are likely to result in the direct loss of SPA habitat and as such are considered to have a major negative impact.

Development proposals which have a direct adverse impact on a European designated site, such as the SPA, are unlikely to be permitted where viable alternatives exist that have less or no adverse impact. This is the case with this study. The only reason for constructing within the SPA would be for over-riding reasons of public interest and if there were no other alternatives. Neither of these circumstances applies to the bridge options in Corridors C and E. The bridge in Corridor D should avoid direct loss of SPA habitat and is considered likely to have less of an impact on the site than bridges in Corridors C and E.

Furthermore, major negative impacts are anticipated for Corridor E Bridge due to the impact on the setting of the Forth (Rail) Bridge.

In terms of the economy objective, proposals for Corridor C were considered to provide less benefit than proposals for Corridors D and E.

5.6 OVERALL SUMMARY OF STAG PART 1 APPRAISAL

The purpose of the STAG Part 1 level of appraisal was not to highlight a preferred option, but to identify which of the proposals perform sufficiently well against the objectives to merit further study.

At this stage the critical issue which emerged relates to the Environment objective and the planning objective to "*minimise the impact on people, the natural and cultural heritage of the Forth area"*. It is clear that the bridge proposals in Corridors C and E perform particularly badly in this regard. STAG indicates that any proposal which fails to meet the Part 1 appraisal test should be rejected.

Furthermore the length of main spans in Corridors C and E (between 1650 and 1800 metres) are considerably longer than that in Corridor D (1375 metres). This would have an impact on construction timescales (and cost). The visual impact of a bridge in Corridor E on the setting of the Forth (Rail) Bridge is also clearly an issue.

It was, therefore, clear that the bridge options in Corridor C and E did not offer any advantages over the bridge option in Corridor D but attracted impacts as identified above. It was considered that the bridge proposals in Corridors C and E should be set aside and not carried forward to the STAG Part 2 appraisal.

It was also clear from the work undertaken to date that, other than in relation to the Environment objective, the bridge proposals performed to a higher standard than the tunnel proposals.

At this stage of the STAG process, Corridor D bridge proposal appeared to generally perform to a higher standard against the majority of the planning objectives and Government objectives than the other proposals considered. The tunnel proposals within Corridors C, D and E all have sufficient merit to remain for further scrutiny.

The outcome of the STAG Part 1 Appraisal was that the following proposals were taken forward for further development:

- Corridor C – tunnel;
- Corridor D – bridge;
- Corridor D – tunnel; and
- Corridor E – tunnel.

6 CORRIDOR PROPOSALS

6.1 INTRODUCTION

This chapter outlines the four remaining crossing options taken forward from the STAG Part 1 Appraisal, detailing the type and nature of the proposed construction methodology.

It is recognised that the development of network linkages for the replacement crossing options would require significant detailed study, necessitating detailed traffic, economic and environmental appraisal to ensure the optimum solution is developed. This level of detail is outwith the scope of this study. However, to date an overview of options has been undertaken in order to confirm feasibility and explore key issues and likely costs.

In addition the operational characteristics of a replacement crossing would have an impact on the junction layouts and any associated network improvements which would be required.

Before considering each of the crossing options in detail a discussion on a number of issues relating to tunnel cross section is provided. The cross section of the tunnel is defined primarily by the type of tunnelling technique employed. The tunnel is designed to Dual 2 Motorway Standard with two 3.65 metre traffic lanes but does not include a hard shoulder. This reflects the limitations of the TBM diameter. The extremely high costs associated with the provision of hard shoulders means that there are very few examples of continuous emergency stopping lanes in bored tunnels. A one metre wide verge is required on each side of the carriageway and, when combined with a narrow hard strip, provides sufficient width to allow for traffic to pass a stranded vehicle (or provide access for emergency vehicles) should an incident occur.

Emergency walkways are required on both sides of the carriageway to enable users to move freely along the tunnel in order to reach a place of relative safety in the event of an incident. Unfenced walkways on the verges are raised 75 millimetres from the carriageway. Headroom standards require that an additional clearance of 0.25 metres is maintained above the vehicle envelope of 5.03 metres to provide protection to 'soft' equipment and services from high vehicles.

The cost of tunnelling generally increases with the cross sectional area. It is therefore important to optimise the use of the cross sectional area to include all necessary functional and safety provisions. There is a maximum diameter that current TBM technology would permit in given ground conditions

The cross section area of a sprayed concrete lined (SCL) tunnel is similar to that of a TBM tunnel, however the method of excavation means that there is significantly more flexibility in the actual shape that can be achieved to suit the traffic envelope and services. Guidelines indicate there would be a requirement for cross passages between the two tunnel bores to provide an emergency escape route for tunnel users in the event of an incident. Alternative emergency escape solutions could be provided utilising a void below the road deck. However for both TBM and SCL tunnels this would increase tunnel diameter. In an immersed tube tunnel, flexibility in shape is readily achieved as the shape of the unit can be fabricated to suit the requirements. The immersed tunnel unit is divided into different cells, to be used for traffic and services and for ballast purposes. It should be noted that the cross section of a cut and cover tunnel is similar to an immersed tube where the shape can be varied to suit requirements.

Figure 6.1 below shows a typical cross section for a bored TBM tunnel. A typical cross section of a mined SCL is shown in Figure 6.2 and Figure 6.3 shows a typical cross section of an immersed tube tunnel.

Figure 6.1 – Typical Cross Section for a Bored TBM tunnel

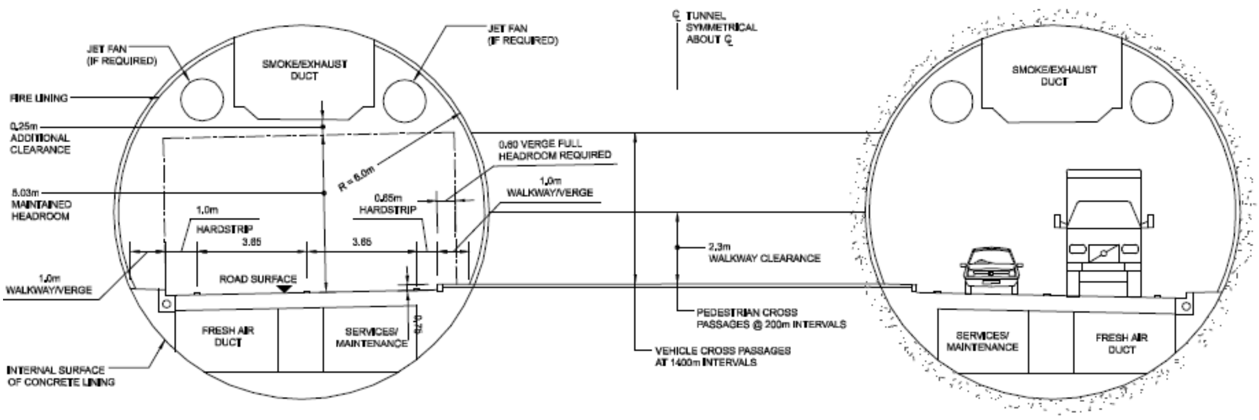


Figure 6.2 – Typical Cross Section for a Mined SCL Tunnel.

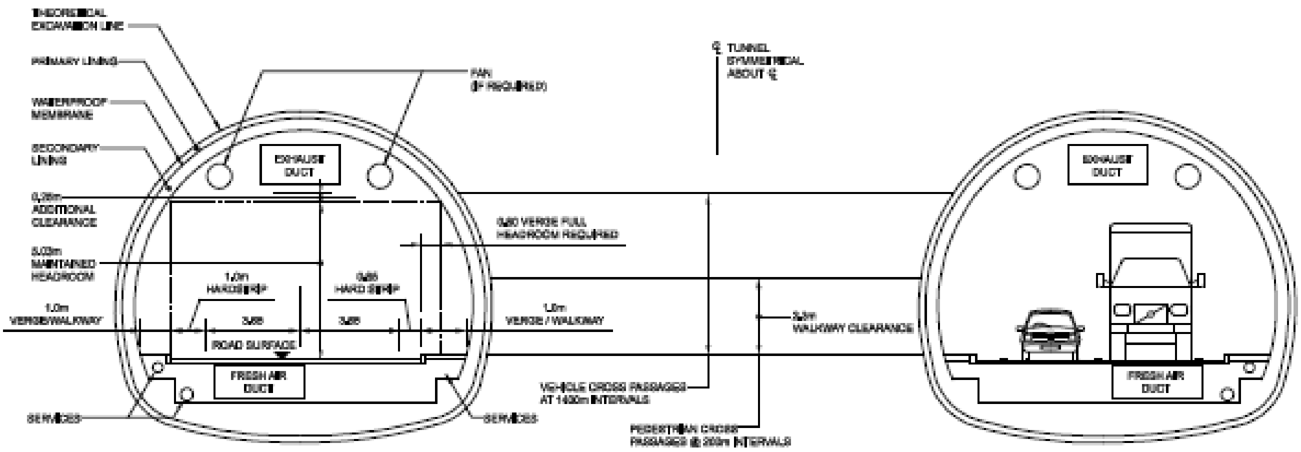
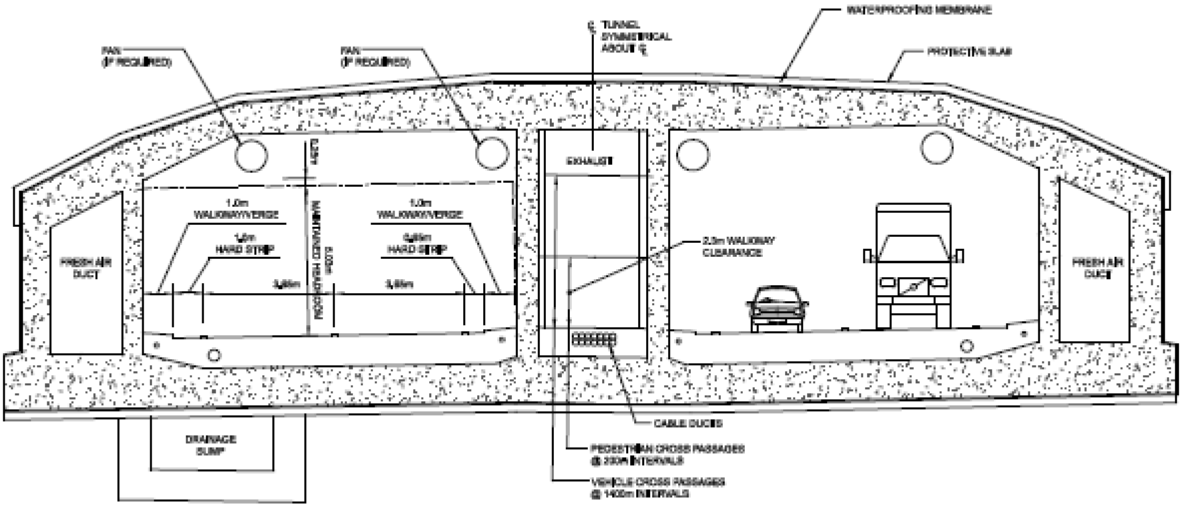


Figure 6.3 – Typical Cross Section for an Immersed Tube Tunnel



6.2 CORRIDOR C TUNNEL

The proposed tunnel in Corridor C is a twin bore tunnel (one tunnel in each direction) approximately 8.5 kilometres long with ventilation shafts located on both banks of the Firth of Forth. A mined SCL tunnel is proposed from the portals to the ventilation shafts. A bored tunnel using a TBM is proposed under the Firth of Forth between the ventilation shafts.

The northern portal is located north-west of Rosyth with an approach ramp linking the tunnel with junction 2 of the M90. The northern ventilation shaft is located near the remains of Rosyth Church.

It was concluded that the southern portal and toll plaza (if required) should face east to achieve better connections with the road network. The chosen location is directly to the south of the M9 adjacent to the disused Craigton Quarry. The ventilation shaft is located to the south of Wester Shore Wood.

The choice of the most appropriate tunnelling technique to be used is driven primarily by the predicted ground conditions and the suitability of each technique to meet the demands of those conditions. The limited geotechnical information available suggests that the bedrock is close to the ground surface on the shorelines but falls significantly when below the Firth of Forth. Considerable depths of soft alluvial river sediments and glacial deposits are expected directly under the crossing. The tunnel construction must negotiate a mixture of limestone, shale, sandstone and coal measures on the shore lines. Although there are no specific outcrops in the river on this alignment to indicate the presence of dolerite, the dolerite under Blackness Castle indicates that outcrops are in the general vicinity and its presence should not be ruled out. It is likely that high groundwater pressures would be encountered in the river sediments. In addition, there is a significant chance of encountering old mine workings in the area to the south of Wester Shore Wood where the ventilation stack and construction compound is proposed.

A mined SCL tunnel is proposed between the portals and the ventilation shafts at the river banks. This technique has been used extensively elsewhere for mining through similar materials as anticipated on the banks of the Forth.

A tunnel in Corridor C would take 7.5 years to construct and is estimated to cost £2.3 billion including network connections and Optimism Bias in Quarter 4 2006 prices.

6.3 CORRIDOR D BRIDGE

The suitability and form of any bridge would depend on several design issues relating to constraints which were outlined in Report 3. Both suspension bridges and cable stayed bridges would be able to accommodate these constraints and each are now detailed below.

A cross section for a Dual 2 lane Motorway standard has been developed and is discussed below. An alternative cross section which includes a corridor for Light Rail has also been developed and this is discussed in Chapter 7 Complementary Measures.

For design purposes, it has been assumed that the crossing is designated as an urban motorway with a maximum speed of 50mph, similar to the existing FRB. In practice however, local traffic will be allowed to use the bridge and therefore it would not be classed as a motorway. Since the bridge is to act as a replacement crossing, provision is made for pedestrians and cyclists to cross the bridge.

The application of current standards for an urban 50 mile per hour road lead to the following minimum criteria.

- Lane widths to be 3.65 metres and each carriageway to be 7.3 metres wide.
- Hard shoulders to be 2.75 metres wide.
- Central Reserve to be 3 metres total width.

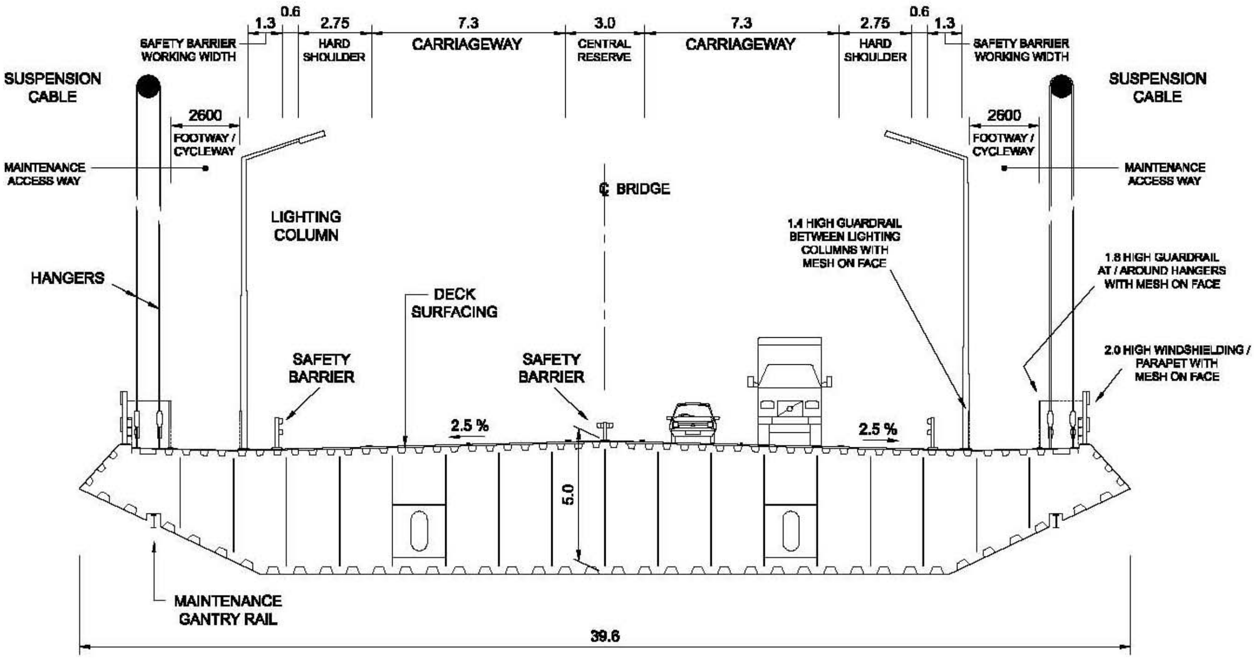
- Safety barriers at the edge of the carriageway with a working width allowance of 1.3m clearance to the nearest face of the lighting columns.

- An access way with a minimum width of 2.6 metres would be provided between the lighting columns and the structural hangers. This access way would also act as a combined footway/ cycleway. Guard rails would be provided each side of the access way. The rails around the hangers would be provided with anti-climb mesh to prevent vandalism to the hangers and be boxed around the hangers. The access way would allow routine inspection and maintenance work to be carried out without the need for carriageway restrictions or hard shoulder closures.

- Wind-shielding 2 metres in height would be provided with parapets at the edge of the bridge.

The resulting full width of bridge deck is approximately 40 metres and is illustrated in Figure 6.4.

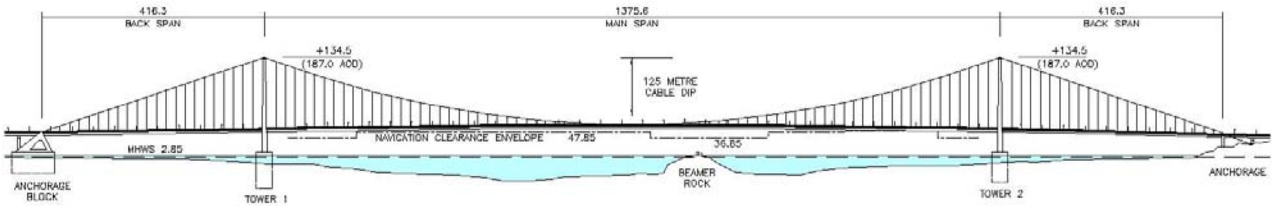
Figure 6.4: Deck Cross section for Dual 2 Motorway Standard



It should be noted that whilst a 2.75 metre wide hardshoulder is appropriate for this design standard it could not support the use of hardshoulder running by public transport modes or HOVs. If this was necessary (and this is described later in Chapters 8 and 9) then the hardshoulder would need to be 3.3 metres wide.

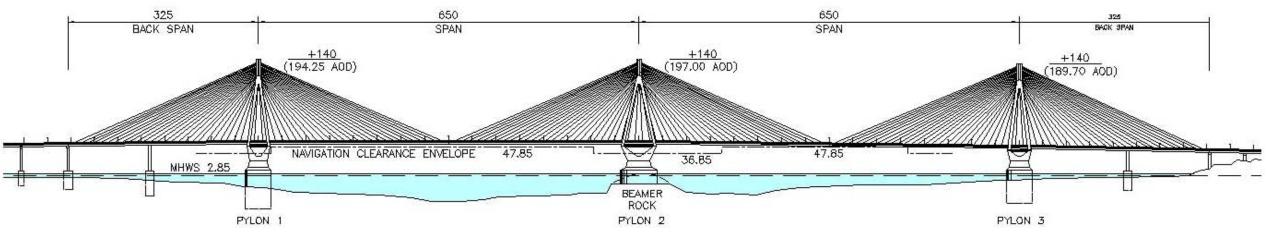
The 1375 metres main span suspension bridge (shown in Figure 6.5) would run from the northern end of a toll plaza (if required) between Linn Mill and South Queensferry, over Beamer Rock to Cult Ness headland between St Margaret's Hope House and the Queensferry Lodge Hotel. The overall length of the bridge would be approximately 2.2 kilometres. The vertical alignment of the bridge provides a minimum vertical clearance of 45 metres above mean high water spring tide level which is the same as that provided by the existing FRB. It is estimated that this would take 6 years to construct and its estimated cost is £1.7 billion including network connections and Optimism Bias in Quarter 4 2006 prices.

Figure 6.5: Suspension Bridge Option



The cable stayed bridge option would consist of two main spans of 650 metres with equal back spans of 325 metres. The central pylon would be founded on Beamer Rock. The alignment would be similar to the suspension bridge. The vertical alignment of the bridge provides a minimum vertical clearance of 45 metres above mean high water spring tide level with its crest over the pylon at Beamer Rock.

Figure 6.6: Cable Stayed Option



The second type of bridge considered in Corridor D is a cable stayed bridge with two main spans of 650 metres and 40 metre wide deck. This would take around 6 months less to construct than the suspension bridge and its estimated cost is £1.5 billion including network connections and Optimism Bias in Q4 2006 prices.

6.4 CORRIDOR D TUNNEL

The proposed tunnel on Alignment D is a twin bore tunnel (one tunnel in each direction) approximately 7.3 kilometres long with ventilation shafts located on both banks of the Firth of Forth. A mined SCL tunnel is proposed from the portals to the ventilation shafts. A bored tunnel using a TBM is proposed under the Forth between the ventilation shafts.

On the north, the site to the west of St. Margaret's Marsh has been safeguarded for construction and operation of a new Forth crossing as part of the Rosyth Dock Development Plan. The alignment goes through this site to enable a ventilation shaft and construction compound to be located there. The northern portal is located immediately to the south of Admiralty Road on the eastern side of the A90.

On the south side, the portal and toll plaza (if required) are located north of Humbie Reservoir. Disruption to this is minimised by completely avoiding the covered reservoir and providing a single crossing of the open reservoir at its narrowest point. A number of properties close to the tunnel portal area are also avoided. The ventilation shaft is located to the west of Queensferry.

The choice of the most appropriate tunnelling technique to be used is driven primarily by the predicted ground conditions and the suitability of each technique to meet the demands of those conditions. The limited geotechnical information available suggests that the bedrock is close to the ground surface on the shorelines but falls significantly when below the Firth of Forth. Considerable depths of soft alluvial river sediments and glacial deposits are expected directly under the tunnel. Outcrops in the river such as Beamer Rock demonstrate that there are dolerite intrusions in the area. It is likely that high groundwater pressures would be encountered in the river sediments. The tunnel must negotiate a mixture of sandstone, shale and coal measures on the southern bank and predominantly sandstone and dolerite on the northern bank.

A mined SCL tunnel is proposed between the portals and the ventilation shafts at the river banks. This technique has been used extensively elsewhere for mining through similar materials as are anticipated on the banks of the Forth. However it should be noted that the suitability of this technique is dependent on the competency of the rock which needs to be confirmed by a detailed site investigation at a later date. Notwithstanding this fact, the use of SCL offers cost savings over other forms of tunnelling. It also helps to speed up progress during construction, as other worksites can be set up at the ventilation shaft locations which can then be used as reception and launch chambers for the TBM drive under the crossing.

A large cutting is required on the southern side to accommodate the toll plaza should one be provided. The resulting environmental impact may be offset by the fact that the toll plaza (if required) would be hidden from view. Conventional approach ramps can be used to interface with the mined tunnel. A SCL tunnel generally requires a minimum of 5-10 metres of cover depending on the quality of the overlying material. Where excavation for the approach ramps and toll plaza (if required) is in rock, the sides can be cut steep or otherwise retaining walls can be constructed so that the land take is minimised.

A tunnel in Corridor D would take 7.5 years to construct and is estimated to cost £2.2 billion including network connections and Optimism Bias in Quarter 4 2006 prices.

6.5 CORRIDOR E TUNNEL

The proposed tunnel in Corridor E is a twin tube tunnel (one tunnel in each direction) approximately 7.3 kilometres long with ventilation shafts located on both banks of the Firth of Forth. A mined SCL tunnel is proposed from the portals to the ventilation shafts with a short section of cut and cover tunnel at the southern portal. An immersed tube tunnel is proposed for approximately 1.7 kilometres in the deep river channel with a bored TBM tunnel linking the immersed tube to the ventilation shafts.

The horizontal alignment of the tunnel is constrained by a number of factors including but not limited to the location of the portals (and any toll plaza on the south side), the need for ventilation shafts on both shorelines and the required connections to the road network and their performance against the objectives of the FRCS.

The northern portal is located immediately north of the A921. The site proposed for the ventilation shaft north of Inverkeithing Bay is steep and not an ideal location but due to environmental constraints, no alternative sites are practical.

The southern portal and toll plaza (if required) are located to the south of the A90, to the west of Dalmeny oil storage depot. The ventilation shaft is located south of the B924 near Dalmeny Park.

Due to the depth of the Firth of Forth in this corridor and the cover required above a TBM, the gradient of a fully bored TBM tunnel in this corridor would have been too steep to effectively connect with the road network in the south. An immersed tube tunnel requires only approximately five metres of cover at the river bed. Locating the portal and toll plaza (if required) on the northern side of the A90 was investigated but the gradient was prohibitive. A 3.3 per cent gradient has been achieved on the southern approach to the immersed tube, while the recommended maximum of three per cent has been maintained on the northern side.

The increase in tunnel gradient above three per cent may require additional safety measures in accordance with the EU Road Tunnel Safety Regulations 2007 Consultation Draft. Further refinement of the alignment at detailed design stage should ensure that the gradient stays close to three per cent.

Construction of the immersed tube section of the tunnel provides a number of challenges. A suitable casting basin must be found for construction of the units. A possible site has been identified near the Rosyth Dockyard. However, extensive modifications would be required to transform it into a suitable dry dock.

Construction of the immersed tube requires significant dredging and disturbance of the sediments along and adjacent to the alignment. As the Firth of Forth has a long history of industrial and commercial operations upstream of the crossing there may be trapped pollutants within the existing sediments. The dredging operation may release pollutants in a relatively short period and, therefore, in a concentrated form which would have a negative environmental impact.

Outcrops in the area such as Inch Garvie demonstrate that there are doleritic intrusions in the vicinity of this tunnel alignment. Where it is not possible for the alignment to avoid these areas, the rock would need to be dredged by drill and blast techniques to create the required bed profile for the immersed tube.

The interface between the immersed tube and TBM tunnels is likely to require the construction of a large caisson or cofferdam to provide a dry working area for construction of the connection. A “soft eye” is required in the wall of the cofferdam so that the TBM can breakthrough it into the connection area. A significant amount of dredging would be required to obtain the required depth to meet the bored tunnel. Removal of rock at this location would require drilling and blasting. An insitu connection unit is required to be constructed within the cofferdam to transition from the circular shape of the TBM to the rectangular cross section of the immersed tube.

On the south side, there have been significant mine workings around the location of the tunnel portal and the proposed toll plaza (if required). The area has recently been grouted to a depth of approximately 60 metres prior to the construction of the M9 spur extension. The BP Kinneil to Dalmeny oil pipeline runs directly adjacent to the proposed portal and would almost certainly need to be diverted prior to construction.

A mined SCL tunnel is proposed between the portals and the ventilation shafts at the river banks. The use of this technique would need to be confirmed by a detailed site investigation, however, it offers cost savings if used. It also offers the opportunity of simultaneous construction of all sections of the tunnel if other worksites are set up at the ventilation shafts and used as reception and launch chambers for TBMs, while fabrication, dredging and placement of the immersed tube tunnel can occur independently.

A tunnel in Corridor E would take approximately 7.5 years to construct and its estimated cost is £2.4 billion including network connections and Optimism Bias in Quarter 4 2006 prices.

7 STAG PART 2 APPRAISAL

7.1 INTRODUCTION

The STAG Part 2 Appraisal provides detailed quantified appraisal against the government's transport appraisal objectives. This chapter provides only a brief outline of those elements of the STAG appraisal which help to differentiate between the options. Further details can be found in Report 4[7].

7.2 ASSUMPTIONS

Within the STAG Part 2 appraisal, the performance of the crossing options has been tested using the TMfS.

At that stage of the exercise the objective was to find the most suitable option for a Replacement Crossing. As explained in earlier chapters this would take the form of a like for like replacement with the existing dual two lane facility – the FRB. A new bridge crossing would likely have hard shoulders provided and a new tunnel would include edge strips. However, these additional features are not represented in the modelled representation within TMfS and, therefore, the bridge and tunnel options are treated similarly. Any distinctions in operational performance arising from this difference are commented upon in a qualitative manner.

The modelling of the Do Minimum situation assumes that the FRB would be closed to all traffic from 2019. The Do Something situation assumes that a replacement crossing would be in place. No complementary measures have been assumed to be present at this stage.

7.3 TECHNICAL IMPLEMENTABILITY

The focus of the option development work undertaken since the STAG Part 1 appraisal has been to confirm the most efficient and technically robust options for each alignment and crossing type.

Corridor C Tunnel

A construction programme for Corridor C has been carried out which indicates that tunnel construction would take approximately 7.5 years.

The proposed programme depends on a number of key factors. The rate of construction is principally governed by the number of TBMs used. For the purposes of this study it is assumed that two TBMs would be used. Furthermore, the rate of tunnelling would be affected by the ground conditions encountered. It is difficult to analyse the likely rate of progress at this stage, as there is limited ground information available. Should unexpected ground conditions be encountered, such as dolerite intrusions, then an impact to the programme could be significant.

[7] Forth Replacement Crossing Study – Report 4 – Appraisal , Transport Scotland/Jacobs/Faber Maunsell – June 2007

In addition to key project risks, there are a range of issues that may benefit from refinement at a later stage. In particular, the interface between the two tunnelling drives at the ventilation shafts. Considerable time savings may be achieved as part of construction optimisation at a later stage.

Corridor D Bridge

Outline construction programmes for the suspension and cable stayed bridges have been developed. Initially, it was assumed that environmental impacts would not lead to any changes to the programme. On this basis it was estimated that the suspension bridge programme would be approximately 6 years and the cable stayed bridge programme approximately 5.5 years.

The construction of a suspension bridge follows a generally linear programme, with little opportunity for concurrent working. The exception to this is that more than one tower or foundation can be constructed at the same time if the resources, particularly specialist plant are available. For the construction of a cable stayed bridge, after the main pylons have been constructed there is scope to erect the cable stays and deck from the three main pylons concurrently. This offers a reduction in the programme as noted above.

These programmes were reviewed against the specific environmental constraints arising from summer breeding birds located on Long Craig Island and wintering birds located on the SPAs at Port Edgar and the north intertidal zone. It was assumed that work up to the bridge deck level in the vicinity of Long Craig Island would be interrupted for 2 summer months each applicable year. In addition, for the SPAs, two scenarios were investigated: one in which construction work up to the underside of the bridge deck in the vicinity of the SPA would be interrupted for 2 winter months every second year and one in which the construction work would be interrupted for 5 months every third year. As a consequence the construction programme for the suspension bridge would be increased by a maximum of eight months and the cable stayed bridge a maximum of ten months.

Preliminary ground investigation has been carried out in the vicinity of the bridge at Corridor D for both suspension and cable stayed bridge options. Therefore, preliminary information regarding depths to rock level has been available for this study. Further site investigation would be required for the detailed design.

For long span bridge construction one of the biggest risks to the programme is the weather. This particularly affects the main cable erection. The effects of delay have been allowed for in the derivation of the costs as a major risk element. Other delay elements include amongst others, extra time for excavation of more material to reach rock level, bad weather affecting main cable, deck erection and main tower erection and problems associated with drilling and tunnelling for the suspension bridge anchorages.

The construction of both forms of bridge would entail the prefabrication of large deck panels off site. These sections would be towed on barges to the bridge site and lifted into place.

Whilst being technically challenging, this option has fewer technical uncertainties associated with it than any of the tunnel options.

Corridor D Tunnel

The construction sequence for Corridor D is largely consistent with that for Corridor C. Both tunnel proposals involve the implementation of different tunnelling techniques, for the crossing and the approach sections.

At 7.3 kilometres, the overall length of Corridor D is approximately 1.2 kilometres shorter than Corridor C, this suggests that there could be time savings associated with this option. However, because of the likelihood of encountering doleritic intrusions around Beamer rock and the need to potentially intervene from the surface, this is likely to extend the programme. It is assumed that the net effect would be an overall construction programme similar to that of Corridor C, i.e. approximately 7.5 years.

Corridor E Tunnel

The construction of this tunnel varies significantly from the other two proposals because of its use of an immersed tube tunnel for the deepest section within the Firth of the Forth.

Unlike the other tunnelling techniques this approach requires the prefabrication of sections at a nearby casting yard, followed by the floating of the sections into line before lowering them into place.

Whilst the use of this method of construction has many advantages, such as the avoidance of technically challenging cross passages, these advantages are offset by the additional environmental constraints that may be placed upon this method. In addition, the construction of the immersed tube option requires large cofferdams to be constructed in situ, and the need for more complex transition units. Collectively it has been assumed that the net effect of all of these factors would result in an overall construction programme similar to that of the other two corridors, i.e. approximately 7.5 years.

7.4 PERFORMANCE AGAINST THE PLANNING OBJECTIVES

Chapter 5 of this report provided an analysis of performance against planning objectives, in line with STAG Part 1. STAG Part 2 appraisal requires a refresh of performance against planning objectives in the light of option development, and outcomes of the modelling process.

The modelling process does not currently fully capture the anticipated operational characteristics of the long term strategy for the crossing(s) with respect to public transport priority, and the amount of road space available to single occupancy vehicles. However, this would be undertaken once the outcome of the long term use of the FRB is better understood.

7.5 PERFORMANCE AGAINST THE GOVERNMENT OBJECTIVES

Environment

The Environmental Appraisal findings show that environmental impacts for most options would generally be similar, typically minor to moderate adverse. However, the main exception to this are impacts on biodiversity where Tunnel E and Bridge D options may have Major to Moderate adverse impacts.

For Corridor E Tunnel this is due to the proposed immersed tube that would disturb sediments and may impact on the Firth of Forth SPA and Forth Islands SPA, which are protected at the European level, as well as other European protected species such as cetaceans. In addition, approach roads at the southern end of Corridor E Tunnel pass through the Dundas Castle GDL, which is a national designation.

For Corridor D Bridge there is a significant risk of indirect disturbance to protected species, particularly within the Forth Islands SPA, but also relating to the Firth of Forth SPA. This may impose significant seasonal constraints during construction, as the Forth Islands SPA protects breeding birds (i.e. spring and summer) whilst the Firth of Forth SPA protects over-wintering birds. In addition, the northern landfall of Corridor D Bridge passes through the St Margaret's Marsh SSSI, protected at national level, and would involve the loss of some areas of ancient woodland.

Safety

Typically, the proposals result in marginal reductions in all accident types in all options. Corridor D Tunnel, Corridor E Tunnel and Corridor D Bridge perform similarly, with accident savings valued at around £220 million. Corridor C Tunnel produces benefits at a slightly lower level of approximately £180 million.

No specific security issues have been identified which would differentiate between the options. The majority of issues can be managed through best practice in relation to bridge and tunnel operations.

Transport Economic Efficiency

In all scenarios analysed above the monetised benefits are greater than the costs. Corridor D Bridge produces the most favourable results, with the lower cost of the cable-stayed variant giving the highest NPV and BCR. Corridor E is the most favourable of the tunnel options in economic terms. This option produces the highest level of monetised benefits, but at a significantly higher level of cost than Corridor D Bridge. This results in an inferior NPV and BCR. The higher level of benefits is as a consequence of the proximity of the southern connections with routes into the city of Edinburgh. This would be contrary to current regional and local policies.

A summary of the results is given in Table 7.1 below.

Table 7.1 Monetised Summary of Costs and Benefits (£millions, 2002 values and prices)

Corridor	C	D	D	D	E
Crossing Type	Tunnel	Tunnel	Cable-Stayed Bridge	Suspension Bridge	Tunnel
Present Value of Benefits (PVB)	4,655.6	5,303.1	6,026.1	6,026.1	6,317.1
Present Value of Costs (PVC)	-2087.4	-1967.7	-1,397.3	-1,574.9	-2,172.2
Net Present Value (NPV)	2568.2	3,335.3	4,628.8	4,451.1	4,144.9
Benefit to Cost Ratio (BCR)*	2.23	2.70	4.31	3.83	2.91

*ratio, not monetary value

Economic Activity and Location Impacts

At the national level, the main positive impacts are to be felt on existing businesses. At the regional level, existing businesses and new businesses are forecast to experience positive impacts. At the local level, all the corridors are anticipated to have positive economic development effects with Corridors C and D tending to favour West Lothian while Corridor E tends to favour north and central Edinburgh.

Integration, Accessibility and Social Inclusion

All options perform similarly in relation to Integration. This also applies to the Accessibility and Social Inclusion criteria. This is particularly the case given that a replacement crossing is being compared with a scenario where the FRB does not operate as it does at present.

8 TWIN CROSSING STRATEGY

This assessment provides an overview of the possible operational arrangements for the proposed crossing(s) of the Firth of Forth if a twin crossing strategy were to be introduced after the existing FRB was refurbished and brought back into use.

The key objective is to develop an operational arrangement, which complies with the requirements of the study brief, current Transport Scotland policies, complements the proposed alignments and allows flexibility during abnormal conditions.

Based on the assessment of 160 different operational arrangements the following options have been recommended:

- **Option OP1:**
  New crossing: Two lanes for any vehicles;
  Existing Crossing: One bus lane and one HOV lane.

- **Option OP3:**
  New Crossing: One lane for any vehicle and one lane for Bus and HOV;
  Existing Crossing: One lane for any vehicles and one lane for Bus and HOV

The final recommendation on operational arrangement can be confirmed after more detailed assessment of all of the above options. This assessment would include Variable Message Sign requirements, possible locations of park and choose/ride sites and details of network connections.

9 COMPLEMENTARY MEASURES

Complementary measures are those schemes which, whilst considered alone would be unlikely to satisfy the objectives of the study, might be introduced to complement the overall cross Forth strategy. These include public transport enhancements and other sustainable forms of transport. In addition to forming a key supporting element of the overall strategy they could be introduced as early, quick win, stand alone packages in advance of a replacement crossing.

These measures can therefore be considered as having a role to play at three different times in the future:

- In advance of the construction of a replacement crossing;
- As part of the replacement crossing strategy; and
- As part of a twin crossing strategy if the existing FRB was to be refurbished and brought back into use.

An assessment of the complementary measures has been undertaken to assess the effectiveness of the proposed measures against the study objectives and these have been included in Table 9.1 below. Each measure has been assessed based on it is likely performance and for ease of implementation.

The results produced have been based on careful assessment of the each proposed schemes, using the available information. However, it is clear from the results that the constraints imposed on motorists may have an impact on the number of people making journeys between Fife and Edinburgh/Lothians.

Table 9.1: Complementary Measures - Summary of Assessment

Objective / Complementary Measure	HOV Lane	Bus Priority	Park & Choose	Maximise use of Cross Forth Rail	Kirkcaldy – Leith Ferry	Active Traffic Management	Variable Tolls	Personalised Travel Planning	Light Rapid Transit
Maintain cross-Forth transport links for all modes to at least the level of service offered in 2006	✓✓	✓✓	✓✓	✓✓	✓	✓	✓✓	✓	✓✓
Connect to the strategic transport network to aid optimisation of the network as a whole	✓✓	✓✓	✓✓✓	✓✓	o	✓✓	o	✓✓	✓✓
Improve the reliability of journey times for all modes	✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
Increase travel choices and improve integration across modes to encourage modal shift of people and goods	o	✓✓	✓✓	✓✓	✓	✓	✓✓✓	✓✓✓	✓✓✓
Improve accessibility and social inclusion	✓	✓✓	✓✓	✓✓	✓	o	✓	✓✓✓	✓✓✓
Minimise the impacts of maintenance on the effective operation of the transport network	✓✓	o	✓	o	×	✓✓	o	o	o
Minimise the impact on people, the natural and cultural heritage of the Forth area	o	✓	✓	✓✓	o	✓	o	✓✓	✓✓
Support sustainable development and economic growth	o	✓✓	✓✓	✓✓	o	✓	✓	✓✓✓	✓✓
Overall Performance	✓	✓✓	✓✓	✓✓	o	✓	✓	✓✓	✓✓
Ease of Implementation	✓✓	✓✓	✓✓	✓✓	✓	✓	×××	✓✓✓	××

Key	
✓✓✓	Very Positive Support
✓✓	Moderate Positive Support
✓	Positive Support
o	Neutral
×	Negative Support
××	Moderate Negative Support
×××	Very Negative Support

The easiest and potentially most beneficial measure to introduce at an early stage in any overall Forth Crossing strategy is the use of a specific and targeted personal travel planning scheme. The cost/impact of such a campaign could provide significant dividends to peak period traffic flows. This scheme also accords well with the recently published SEStran RTS which places a (High/Medium) priority on the implementation of a region-wide scheme[8].

All of the other possible complementary measures would require the construction of new infrastructure in some shape or form and would require longer lead in times for implementation. However, their successful implementation would significantly improve public transport service reliability and hopefully reduce single occupancy car journeys across the Forth.

Finally, Table 9.2 below outlines the current best estimate of the cost of each proposed measure.

Table 9.2: Complementary Measures - Summary of Costs

Complementary Measure	Proposed Total Costs (£Millions)
HOV Lane – A90/M90[9]	13
Bus Priority	
- A90 northbound bus priority[10]	4
- "Bus Right of Way" Network Fife[10]	6
Park & Choose	
- New sites at Halbeath & Rosyth[10]	7
- Expanded Inverkeithing & Dalgety Bay[10]	5
- Ferry Toll[10]	9
Maximise use of Cross Forth Rail	
- Further Capacity Enhancements[10]	10
- Upgrade of track between Thornton to Inverkeithing[10]	10
Kirkcaldy to Edinburgh Ferry Service[11]	16
Active Traffic Management (Halbeath Jnc.3 to Jnc. 1)[12]	40
Personalised Travel Planning	1

Based on the assessment and implementability of the proposed complementary measures it recommended that the following measures are implemented:

- Personalised Travel Planning Scheme;
- Maximise use of Cross Forth Rail;
- Bus Priority Extension;

[8] SEStran - Regional Transport Strategy 2008 -2023, March 2007
[9] Fife Council – Presentation on HOV Proposals – December 2006
[10] SITCoS Report, June 2005
[11] Options for a Cross Forth Passenger Service, Halcrow, May 2004
[12] http://www.highways.gov.uk/knowledge/1334.aspx

- Park and Choose Sites;
- HOV lanes; and
- Active Traffic Management.

These initiatives would provide quick win benefits and would help to reduce traffic demand on the existing FRB. In addition they would have a clear role to play in any future replacement crossing strategy.

10 PROCUREMENT, FINANCE AND LEGISLATIVE ISSUES

10.1 PROCUREMENT AND FINANCE

An initial assessment of the options to procure, fund and deliver a Forth Replacement Crossing has been undertaken. There are a range of alternatives available for both the procurement and the funding. At this stage it is not possible to determine the optimal procurement and funding route for the new crossing.

It is still too early in the overall project development to be definitive on procurement and finance options. As the project develops factors may emerge that may require a change or refinement of the procurement and funding strategy. However, from the initial assessment of the crossing options it is clear that there is nothing being identified which would preclude or materially impact on the procurement and funding options identified at this stage. In summary the main findings to date are as follows:

- the project clearly demonstrates the attributes for consideration to be implemented as a Public Private Partnership (PPP);
- the risk differentials between the technical options identified at this stage are not material in terms of the ability to develop the procurement options identified;
- the eventual form of the PPP will be dependant on the ownership of key risks such as demand, programme and existing bridge condition; and
- tolling policy and PPP concession length will have a significant impact on the overall affordability of the project.

At the next stage of project development the extent to which private or public funding is applied will be determined in the context of Transport Scotland's preferred overall risk profile.

10.2 LEGISLATIVE ISSUES

A variety of statutory mechanisms have been reviewed by which, alone or in combination, the Scottish Ministers would be able to secure the necessary legal authority to construct a Forth Replacement Crossing. In a similar manner to the procurement and finance issues, it is not possible to be definitive about the best way forward until the following have been resolved:

- the identity of the promoter of the project;
- the type of crossing involved;
- the other parties who may be involved in the construction and operation of the crossing;
- the timing of the project; and

- the extent of the project (for example whether it involves the existing bridge and/or link roads to the new crossing).

As the project progresses and these issues become resolved then a clear picture of an appropriate legislative route should appear.

11 SUMMARY AND CONCLUSIONS

11.1 STUDY OBJECTIVES

The study has assessed proposals for a replacement crossing for the existing FRB if one is required. The possible need for a replacement is due to the lack of certainty that the existing bridge is going to be available in the future. Also, recent reports from FETA would suggest that the refurbishment of the existing crossing will have severe impacts on traffic flows across the bridge for a period of between 3 and 4 years.

The level of repair/refurbishment carried out on the FRB will be determined by the role that is ultimately intended for that crossing and the level of investment required to support that role. For example, if the FRB is intended only for use by light vehicles in the future then there may be no requirement to replace the main suspension cables. A decision can also be taken on whether the deck should be replaced thereby removing the need for expensive painting and strengthening of the existing deck structure.

The key point is that once the replacement crossing is open there is flexibility and time to decide how best to refurbish and operate the FRB.

The FRCS is, therefore, primarily concerned with determining the form, function and location for the replacement crossing. Further development of the emerging options for a replacement crossing will be required to determine the role that the existing FRB should play once refurbished. However, this is dependent upon the level of investment that is required to achieve a number of different possible outcomes. A final decision may, therefore, have to be left until further information is forthcoming from, amongst others, the FETA Cable Replacement Study.

However, if the FRB was to be refurbished and re-opened then consideration would have to be given to how it could be used in combination with the replacement crossing. This study has considered how an operational strategy could be developed. The guiding principle of the operation of this combination would be that there should be no more than two lanes available for general traffic in each direction. Additional capacity would be reserved for sustainable modes such as public transport or HOVs.

The report also considers how an operational strategy could be developed in relation to using any new crossing alongside the FRB. An assessment of the complementary measures has been made. These could be implemented prior to a replacement crossing being constructed and as part of a new crossing. These measures are also considered in the context of a twin crossing strategy in the event that the refurbished FRB is brought back into commission.

11.2 EXISTING AND POTENTIAL PROBLEMS

There will be an increased requirement for significant maintenance on the FRB in the future regardless of the problems associated with cable corrosion. This maintenance cannot be undertaken without temporary traffic management measures being put in place which will restrict the capacity of the crossing. Evidence from recent occasions when maintenance on the bridge has taken place at weekends indicates that serious congestion is experienced. Delays of between 60 and 90 minutes have been recorded even when traffic flows are some 30 per cent lower than the corresponding weekend in 2006.

The forecast increases in daily traffic crossing the Forth will exacerbate the high levels of congestion experienced during restrictions or closures on the FRB. It is also envisaged that due to the type of maintenance works expected to be undertaken on the bridge in future, that it will not be possible to limit these traffic management restrictions to weekends as is currently the case.

It is envisaged that in the future road users will be faced with an increased number of occasions when restrictions are placed on vehicles using the bridge on both week days and weekends. Due to the growth in traffic the delays and queues experienced are likely to be greater than those encountered during maintenance periods.

11.3 PLANNING OBJECTIVES

Current and emerging policies that are relevant to STPR and in particular the FRCS have been considered in detail. The recently published NTS and associated documents have been particularly important in guiding the development of the study objectives. These have also drawn extensively on previous work undertaken by both SEStran and FETA. Consideration has also been given to the consultation that has already taken place in the development of current policy and undertaken directly as part of this study.

Following careful consideration of these two aspects (current/emerging policy and consultation) a number of study specific “SMART” objectives have been developed and tested within the relevant reference groups. This has led to the setting of a final set of study objectives which has guided future work in the latter phases of this project. Specific performance indicators used to identify any gaps and shortfalls between the future performance and the expectations of the transport network in the vicinity of the Forth bridges have been identified.

11.4 OPTION GENERATION AND INITIAL SIFTING

A long list of 65 potential options was generated and this was subjected to an initial sifting process. This was undertaken with a view to reducing the list by eliminating options which did not satisfy the objectives of the study or were not technically feasible. Following this process, the approach adopted was to consider the crossing location and whether bridges and/or tunnels would be feasible solutions in following the five corridors:

A – Grangemouth (West of Bo’ness);

B – East of Bo'ness;

C – West of Rosyth;

D - East of Rosyth/West of Queensferry; and

E – East of Queensferry.

Each corridor was assessed for its suitability for a tunnel or bridge crossing. The work undertaken confirmed that Corridors A and B did not meet the objectives of the study and were therefore rejected. It was concluded that these corridors would not be considered further within the study. However, Corridors C, D and E did perform well to varying degrees against the objectives and these were taken forward to the STAG Part 1 Appraisal, with bridge and tunnel options considered for all three corridors

11.5 STAG PART 1 APPRAISAL

The STAG Part 1 appraisal was undertaken on the basis of the initial alignments developed for Report 3 – Option Generation and Sifting.

The majority of the planning objectives were met by each of the proposals, although it is evident that the degree to which they were met varied across corridors and crossing types.

At that stage of the appraisal, the critical issue which emerged related to the Environment objective and the planning objective to minimise the impact on people, the natural and cultural heritage of the Forth area. The bridge proposals in Corridors C and E performed particularly badly in this regard as both the northern and southern landfalls cross, or come very close to, the Forth SPA which may lead to loss of SPA habitat. Both were considered to have major adverse impacts on a European designated site and are unlikely to be permitted when viable alternatives exist that have less or no adverse impact. The bridge in Corridor D was considered to avoid this impact.

STAG indicates that any proposal which fails to meet the Part 1 appraisal test should be rejected. In this case, given the importance of the SPA and the likely impact which these bridge proposals would have on it, it was considered that the bridge proposals in Corridors C and E should be set aside and not carried forward to the STAG Part 2 appraisal.

The outcome of the STAG Part 1 Appraisal was that the following proposals were taken forward for further development:

Corridor C – tunnel;

Corridor D – bridge;

Corridor D – tunnel; and

Corridor E – tunnel.

11.6 CORRIDOR PROPOSALS

The design detail and construction methodology of each of the four remaining proposed crossings has been examined. Also, included for each option is a summary of the network connections required to connect the new crossing to the existing road network. Attention has been placed on developing technically and operationally robust and efficient solutions for each option.

The tunnel in Corridor C is 8.5 kilometres in length and would be constructed through a combination of TBM and SCL tunnelling techniques. It is expected to take 7.5 years to construct with the capital cost of construction estimated to be £2.3 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

There are two types of bridge options suggested for Corridor D. The first is a suspension bridge with 1375 metre main span and a 40 metre wide deck. It is estimated that this would take 6 years to construct. Its cost is estimated to be £1.7 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

The second type of bridge considered in Corridor D is a cable stayed bridge with two main spans of 650 metres and 40 metre wide deck. This would take around 6 months less to construct than the suspension bridge and is estimated to cost £1.5 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

The tunnel is Corridor D is 7.3 kilometres in length and would also be constructed using a combination of TBM and SCL techniques. It would take 7.5 years to construct and is estimated to cost £2.2 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

Finally the tunnel is Corridor E is also 7.3 kilometres in length and would be constructed using a combination of TBM, SCL and immersed tube techniques. It would take 7.5 years to construct and is estimated to cost £2.4 billion, including network connections and Optimism Bias in Quarter 4 2006 prices.

11.7 STAG PART 2 APPRAISAL

Implementability

There are currently a greater number of technical risks for the three tunnel options. This is due to uncertainties in relation to ground conditions. Corridor E Tunnel also has issues associated with the construction of an immersed tube tunnel. There are fewer technical risks with the Bridge in Corridor D.

Environment

The Environmental Appraisal findings show that environmental impacts for most options would generally be similar, typically minor to moderate adverse. However, the main exception to this are impacts on biodiversity where Tunnel E and Bridge D options may have Major to Moderate adverse impacts.

For Corridor E Tunnel this is due to the proposed immersed tube that would disturb sediments and may impact on the Firth of Forth SPA and Forth Islands SPA, which are protected at the European level, as well as other European protected species such as cetaceans. In addition, approach roads at the southern end of Corridor E Tunnel pass through the Dundas Castle GDL, which is a national designation.

For Corridor D Bridge there is a significant risk of indirect disturbance to protected species particularly within the Forth Islands SPA but also relating to the Firth of Forth SPA, which may impose significant seasonal constraints during construction, as the Forth Islands SPA protects breeding birds (i.e. spring and summer) whilst the Firth of Forth SPA protects over-wintering birds. In addition, the northern landfall of Corridor D Bridge passes through the St Margaret's Marsh SSSI, protected at national level, and would involve the loss of some areas of ancient woodland.

Safety

Typically the proposals result in marginal reductions for all accident types in all options. Corridor D Tunnel, Corridor E Tunnel and Corridor D Bridge perform similarly, with accident savings valued at around £220 million. Corridor C Tunnel produces benefits at a slightly lower level of approximately £180 million.

No specific security issues have been identified which would differentiate between the options. The majority of issues can be managed through best practice in relation to bridge and tunnel operations.

Transport Economic Efficiency

In all scenarios analysed in the Part 2 Appraisal the monetised benefits are greater than the costs. Corridor D Bridge produces the most favourable results, with the lower cost of the cable-stayed variant giving the highest NPV and BCR. The most favourable tunnel option is that of Corridor E. This option produces the highest level of monetised benefits, but at a significantly higher level of cost than Corridor D Bridge. This results in an inferior NPV and BCR. The higher level of benefits arises as a consequence of the proximity of the southern connections with routes into the city of Edinburgh. This is clearly contrary to current regional and local policies.

A summary of the results is given in Table 11.1 below.

Table 11.1: Monetised Summary of Costs and Benefits (£millions, 2002 values and prices)

Corridor	C	D	D	D	E
Crossing Type	Tunnel	Tunnel	Cable-Stayed Bridge	Suspension Bridge	Tunnel
Present Value of Benefits (PVB)	4,655.6	5,303.1	6,026.1	6,026.1	6,317.1
Present Value of Costs (PVC)	-2087.4	-1967.7	-1,397.3	-1,574.9	-2,172.2
Net Present Value (NPV)	2568.2	3,335.3	4,628.8	4,451.1	4,144.9
Benefit to Cost Ratio (BCR)*	2.23	2.70	4.31	3.83	2.91

*ratio, not monetary value

Economic Activity and Location Impact

At the national level, the main positive impacts are to be felt on existing businesses. At the regional level, existing businesses and new businesses are forecast to experience positive impacts. At the local level, all the corridors are anticipated to have positive economic development effects with Corridors C and D tending to favour West Lothian while Corridor E tends to favour north and central Edinburgh.

Integration, Accessibility and Social Inclusion

All options perform similarly in relation to Integration. This also applies to the Accessibility and Social Inclusion criteria. This is particularly the case given that a replacement crossing is being compared against a scenario where the FRB does not operate as it does at present.

11.8 TWIN CROSSING STRATEGY

This assessment provides an overview of the possible operational arrangements for the proposed new crossing of the Firth of Forth if a twin crossing strategy were to be introduced after the existing FRB was refurbished and brought back into use.

The key objective was to develop an operational arrangement, which complied with the requirements of the study brief, current national policies, complements the proposed alignments and allows flexibility during abnormal conditions.

Based on the assessment of 160 different operational arrangements the following options are recommended:

- **Option OP1:**
  New crossing: Two lanes for any vehicles;
  Existing Crossing: One bus lane and one HOV lane.

- **Option OP3:**
  New Crossing: One lane for any vehicle and one lane for Bus and HOV;
  Existing Crossing: One lane for any vehicles and one lane for Bus and HOV

The final recommendation for the operational arrangement can be confirmed after more detailed assessment of all of the above options. This assessment would include Variable Message Sign requirements, possible locations of park and choose/ride sites and details of network connections.

11.9 COMPLEMENTARY MEASURES

Possible Complementary Measures have been identified that would be used to improve the performance of the network on, and in the vicinity of, the Forth bridges and on any replacement crossing. These measures might be considered interim measures prior to the construction of any Forth crossing but should also be considered in terms of how they might be maintained as part of the final strategy. Measures considered for further assessment include HOV lanes, bus priority measures, park and choose sites, further bus services, additional rail capacity, ferry services, ATM and variable tolls. The last option may no longer be available given the likelihood that tolls will be removed in the near future.

11.10 RECOMMENDATIONS

The principal factors for differentiating between the options are Implementabilty, Environmental Impact, and Economic Efficiency. Other factors are principally altered by the method of operation, or the suite of Complementary Measures.

It is recommended that Corridor E Tunnel should not be considered further for the following reasons:

- the environmental impacts;
- the implementability risks associated with tunnels;
- the impact of drill and blast construction techniques on Hound Point;
- the mine workings on the south side; and
- the high cost of this option.

Of the remaining tunnel options (C and D), there is little to choose between them. Both are estimated to take 7.5 years to construct and have similar costs (£2.2 - £2.3 billion). The monetised benefits of D are marginally better than C due to its proximity to the existing cross Forth corridor. The environmental benefits of both are similar and do not impact on the SPA. When considered as a replacement crossing the tunnel options would not be able to provide the same facilities as a bridge crossing as pedestrians and cyclists would not be permitted into the tunnel.

However, it is recommended that the bridge in Corridor D be taken forward as the best overall performing option from this study. This is for the following reasons:

- it is significantly cheaper than the tunnel options;
- it can be delivered quicker;
- it has fewer risks associated with its construction; and
- It has the best performing BCR.

Environmentally, however the bridge options do not perform as well as the tunnel options in Corridors C and D. There are likely to be direct impacts on the St Margaret's Marsh SSSI in the north side of the corridor. There may also be indirect disturbance to protected species within both the Forth Islands and the Firth of Forth SPAs. These may impose seasonal constraints during construction. The full scale of these impacts would not be known until such time that an Environmental Impact Assessment has been carried out.

Of the two types of bridge structure the cable stayed bridge has advantages over the suspension bridge in that it is the cheaper option and can be delivered around 6 months earlier. The use of cable stayed techniques would avoid the need for complex foundations on the landfalls therefore avoiding the methane risk on the southern side. Cable stayed bridges are modern forms of long span crossings and there is therefore the opportunity to create a vista across the Forth of three different types of bridge construction comprised of the old (Forth Bridge), recent (FRB) and the new (the replacement). The visual impact of this vista is clearly something to be discussed with Architecture and Design Scotland.

Given all of the above factors, it is recommended that the replacement crossing be a cable stayed bridge in Corridor D. This should incorporate two lanes with hardshoulders plus pedestrian walkways/cycleways in each direction. Network connections should be provided principally to join the A90/M90 to the north of the Forth and to the M9 in the south.