Use of Innovative Pavement Solutions under Road Network Privatisation in the United Kingdom

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Synopsis

The procurement of new construction or major maintenance schemes on the motorway and trunk road network in the UK has dramatically changed in the last ten years following a Government Private Finance Initiative. Initially Design, Build, Finance and Operate (DBFO) was popular. This involves a consortium of contractor and consultant taking responsibility for an existing route length of typically 100kms, with only part of the length requiring new build, for a 30 year maintenance period. Capital is raised from the financial institutions, such as major banks, but the Highways Agency guarantees to pay “shadow tolls” based on the actual traffic carried.

In order to gain the benefits of construction know-how, without the long-term financial commitment of DBFO, the Highways Agency then tried Design and Build. However, the short tender periods discouraged innovation and so a scheme known as Early Contractor Involvement (ECI) has now been developed. In this approach, design and construction issues are confronted at conception, and dealt with in the planning approval process, several years before construction starts.

Across the rest of the motorway and trunk road network, maintenance is now organised into 20 geographical areas for which Managing Agent Contracts (MAC) are let to consultant/contractor consortia to maintain the highways to the required standard over a fixed number of years. From an engineering point of view, the introduction of private sector responsibility has been a catalyst to encourage change, with much more emphasis on achieving certain levels of performance, although some new ideas have not been without problems. The contractor/consultant consortia often carry more risk than in a traditional contract where designs and specifications are more prescriptive. However, some of these forms of contract have encouraged innovation, particularly by bringing in ideas from other countries and adapting them to the UK situation.

This paper briefly presents examples of highway privatisation schemes adopted in the UK. Some of the innovative solutions applied in DBFO projects, and for maintenance of major areas of the network, are described. In addition, an innovative network management scheme is outlined, which was developed for a Public Private Partnership, to maintain and operate the entire road network in a city..

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INTRODUCTION

In 1992, the UK Government announced its Private Finance Initiative (PFI) designed to facilitate closer co-operation between the public and private sectors. A driving force was the opportunity it would provide to introduce private sector finance, skills and disciplines into an area, which was previously the public sector's responsibility. The Public Private Partnerships (PPP) initiative is the framework within which much of this is being taken forward, and was introduced for the procurement of major highway works in 1994.

The main highway arteries in England are managed on behalf of the Government by the Highways Agency (HA), a body established in 1994. The Motorway and Trunk Road Network, for which it is responsible, comprises 10,000 km of road. It carries some 90% of heavy traffic and is largely dual carriageway but only embraces about 3% of the total road infrastructure. HA's strategic aim is "to contribute to sustainable development by maintaining, operating and improving the trunk road network in support of the Government's integrated transport and land use planning policies".

Amongst the HA's key objectives are the minimisation of whole life costs, carrying out of the Government's targeted programme of investment in highways, to improve safety and to work in partnership with users, operatives and the local highway authorities.

In redesigning its procurement policies to achieve improved value for money, the HA has initiated several new types of contract and these are still evolving through experience. The underlying principles are as follows:

- To reduce the traditional adversarial nature of conventional contracts through introduction of partnerships.
- To transfer risk to the private sector.
- To reduce the total number of contracts.
- To transfer responsibilities for long-term maintenance to private sector consortia.
- To provide a business framework, that encourages innovation, improved safety, sustainability and greater financial certainty.
- To reduce the time scale needed to go from concept to construction of major projects.

PROCUREMENT SCHEMES

Since 1994 a variety of new procurement schemes have been introduced, not only for major construction projects, defined as those costing over £5m, but also for maintenance, and combinations of both. The principles common to most of these schemes are those outlined above. The characteristics of each are outlined below, but some are very recent and the whole system is in a period of evolution.

Design, Build, Finance and Operate (DBFO)

This scheme has been active since 1996 when bids were invited for the first tranche of contracts. Currently, there are ten of these and they cover a variety of situations. The essential details are given in Table 1. In all cases, the successful company takes on the responsibility for some new construction, including the raising of finance for it. They also become responsible, over a 30-year period, for maintenance of that section of the network in which the new work is located. All the projects embrace responsibility for structures as well as the carriageway. HA are planning for about 25% of their current ten-year highway improvement programme to be procured by this mechanism.

A key feature of this new approach to highway construction and maintenance is the requirement that the contractors focus on whole life costs. This has encouraged an innovative approach, illustrations of which are given in a later section.

Table 1 DBFO Contracts in England

Scheme	Length (km)	Cost of new construction (£m)	Type of Road
A1/M1	30	214	Dual, 3 Lanes
M40	122	65	Dual, 3 Lanes
A1(M)	21	128	Dual, 4 Lanes
A19	118	29	Dual, 2 Lanes
A30	102	76	33% Dual, 2 Lanes
A50	57	21	Dual, 2 Lanes
A69	84	9	40% Dual, 2 Lanes
A249	17	75	Dual, 2 Lanes
A419	52	49	Dual, 2 Lanes
A1	53	?	Dual, 2/3 Lanes

In deciding whether or not a particular scheme is suitable for the DBFO approach, the HA have to demonstrate that it offers better value for money than a conventional contract. A "public sector comparator" is used to assist in the process and this includes an allowance for the transfer of risk.

At tender stage, the bidders are encouraged to propose their own designs, including innovative ideas that deliver good value for money and identify any departures from HA's design and construction standards. They are expected to deal with traffic growth predictions and with any costs and risks associated with protestors interfering with construction of new works.

In the early schemes, statutory planning approval was already secured prior to tendering, so there were some limitations to design innovations but a short time scale for starting the project. A subsequent procurement method, involving contractors at a very early stage, allows innovation to be considered more widely prior to the public enquiry leading to planning approval.

The three main types of payment used in England for private highway projects are based on shadow tolls, congestion management, and availability of the highway to users. The payment mechanism for the first generation of DBFO projects was based on 'Shadow Tolls', where traffic counters and weigh-in-motion equipment were installed on different sections of the road, in order to count and classify vehicle types. Hence, payment is made out of taxation via the HA and is not collected as tolls on the road. The DBFO company is paid by the HA using their tendered unit rates for different vehicle types. Penalty charges are made for lane closures and poor safety performance.

A more detailed framework has been introduced in later projects based on an 'Active Management Payment Mechanism', which incorporates the following elements:

- Congestion management
- Safety performance
- Construction period payment (for project with major sections of new construction)

This type of payment is designed to provide an incentive to the DBFO Company to increase the network serviceability, the road safety and to allow for an efficient and cost-effective maintenance planning.

The congestion management payment is subjected to annual indexation and is based on average speed and flow (as a percentage of capacity) for vehicles. No payment is made if average speed is less than 67% of the target (eg. 60km/h for a target speed of 90km/h) and a vehicle flow less than 80% of capacity. Payments increase with speed and flow up to 100%, when the target values are met. A capped bonus payment is made if the capacity is above the target up to a maximum of 110%.

The safety performance payment is made at the end of each contract year, by comparing the actual safety performance of the project road with a safety benchmark. Additional payments or penalties are introduced if the actual performance exceeds or is below thresholds set either side of the target.

The construction period payment is based on construction milestones, up to the stage when the 'Permit to use' is issued for a particular section.

At the end of the contract period of typically 30 years, the road has to have a residual life of 10 years for the carriageways and at least 30 years for the structures. Detailed inspections are to be made by HA five years before the end of the contract and again 18 months before completion, to check that necessary remedial work has been carried out. There are financial incentives to ensure that the contractor complies. During the course of the contract, HA staff monitor progress to ensure compliance with the contract obligations. There is

a system of penalty points, which can be triggered if performance is poor. This can lead to termination of the contract in extreme cases.
The DBFO procurement method is intended for strategically important routes involving the largest investment.

‘Design and Build’ and ‘Early Contractor Involvement’

Design and Build (D and B) contracts have been a feature of HA procurement policy since the mid 1990's but contracts have generally not been let until after statutory planning approval has been granted, which can take a considerable time in England. By this stage, the design is significantly constrained, leaving little scope for innovation and buildability considerations.
The latest thinking is to involve the contractor with his designer and sub-contractors (the “supply chain”) at an earlier stage in the process in order to improve various aspects of the design and delivery mechanisms. Hence, Early Contractor Involvement (ECI) was developed, as part of the Government's ‘Speeding up Delivery’ initiative. The Contractor is selected by identifying a supplier that has all the right skills, and who is considered the most capable of working in partnership in order to identify the optimal solution and deliver it as efficiently and safely as possible.
Contracts are awarded on the basis of 30% for price and 70% for quality of the proposals. Note is taken of steps to avoid an adversarial approach.
The objectives are to improve risk management, increase innovation, secure long-term supplies, improve resource planning and staff retention, consider construction issues early in the process and reduce the overall time scale between conception and delivery of a scheme. Integration of the supply chain is regarded as a particularly important issue in terms of reliability, value for money and reduction in contractor disputes. This is part of the PPP ethos of establishing closer long-term working relationships. A fair and agreed allocation of risks needs to be defined at the outset through negotiation around a ‘risk register’. This is intended to improve the contractor’s cost estimates.
Improved value engineering and performance sustainability are two of the issues to be used in assessing progress on the contracts. Another novel feature is an element of ‘open book’ accounting, as part of the partnership with HA, to ensure actual costs are being met and a fair profit is achieved within the framework of ‘best value’. HA is aiming to create an incentivised team and involve it as early as possible in the project. The intention is to reduce the average time scale for delivery of projects from 12 to 7 years.
To run these new style contracts, HA utilises independent consultants as their agents. Communication between these and the project consortium are vital, particularly during the early brainstorming planning period.
For the contractor/consultant team, there are new challenges to be met relative to earlier procurement schemes. In traditional D and B, the team will have worked on an outline design prior to tendering, whereas with ECI they have no prior knowledge other than that set out in the tender documents. The concentrated time scale for all activities means that designers have to work with incomplete information in the early stages, while the various Statutory Bodies, who have to approve various aspects of the scheme, require full details and are not constrained by the time limits set for the D and B team. Many activities have to proceed in parallel rather than sequentially as in conventional procurement.
The advantages of ECI are that the combined skills of contractor and consultant result in a design for which buildability, costs and construction planning have been thoroughly considered in looking at alternative solutions.

HIGHWAY MAINTENANCE

Managing Agent Contractors

The proportion of HA's network which is maintained under the DBFO scheme is relatively small. For the largest part of the system, responsibility for maintenance has passed in recent years from the County Councils, acting as agents for Central Government, to the private sector. The latest framework involves appointment of Managing Agent Contractors (MAC's) with responsibility for a regional area of which there are 20 outside Greater London. As responsibility for some of the network is in the process of being transferred to local highway authorities, the number of HA areas is likely to decrease to 14 in the future.
MAC's are formed from consortia of contractors and consultants with a well-defined supply chain. Appointments are for four years, extendable to seven, and the first of these was made in 2001. The principles are similar to those in D and B in relation to value for money, innovation and reliable supply chains. New works up to a value of £0.5m can be undertaken, in addition to maintenance of a network which is typically some 500km in length. For new works between £0.5m and £5m, the MAC can design and supervise, but the construction work is tendered to an approved list of local contractors. MAC's are awarded on the basis of 80% quality and 20% price.

Maintaining performance quality, continuous improvement and general auditing of the contracts is handled by a group known as PRIDe (Performance Review Improvement Delivery), who are somewhat independent of the HA but act on their behalf.

Pavement Management System for a City

Portsmouth City Council (PCC) recognised the need to halt the deterioration of its highway asset and restore the network to a sustainable condition through a period of capital rehabilitation. In the absence of traditional funding, they submitted a business case through the Private Finance Initiative (PFI). In December 2000 PCC received notification that the project, a pioneering and innovative way of procuring better road maintenance, had been endorsed by Central Government. The project includes management and maintenance services for the complete highway network, bridges and other structures, street lighting, traffic signals and signing services, as well as street cleaning and landscape maintenance (1).

The contract requires the highways, which make up the road network, to be brought up to a specified condition in gradual steps during the first 5 years (The Core Investment Period). They are then to be maintained for a further 20 years to set Performance Standards and enable them to be handed back with the required residual life. The network is shown in Figure 1.

Figure 1 The Portsmouth Network (after Portsmouth City Council, 1)

A Pavement Management System (PMS) was developed for the network in order to optimise highway maintenance profiles and predict financial requirements during the contract period.

The project network includes 67 km of primary roads and 376 km of secondary roads. The primary network includes a section of motorway and 'A' class roads where three indices have been selected to describe pavement condition; residual life (structural), skidding resistance (serviceability) and visual surface condition in terms of defects (percentage of patching, major and minor defects). The secondary network comprises the 'B', 'C' and 'U' class roads, where only skidding resistance and visual surface condition in terms of defects are used to describe their condition. The Pavement Condition Index (PCI), Skidding Resistance Index (SRI) and Surface Condition Index (SCI) can be calculated and, hence, a Network Condition Index (NCI) determined, as shown below.

NCI = PCI + SRI + SCI (For the Primary Road Network)

NCI = SRI + SCI (For the Secondary Road Network)

The current pavement structural life as determined via Deflectograph or Falling Weight Deflectometer surveys, skidding resistance, as measured by the SCRIM (Sideway-force Coefficient Routine Investigation Machine) or the Grip Tester, and visual surface condition, are input into the PMS to calculate the appropriate condition indices for various pavement sections. The proposed optimum treatments for the next 25 years are then predicted. The structural pavement deterioration models and maintenance strategies, as well as practical implications, can be incorporated into the PMS.
Strengthening treatments are considered based on the current indices, and the minimum condition requirement. Two main treatment options were used for the primary network, structural inlay with bituminous materials, to carry the future 20 years of traffic flow, and 30-40mm inlay (replacing the surface layer) to restore any poor skidding resistance or surface condition. Strengthening by overlay was not considered in this project due to the predominantly urban nature of the sites.
Replacing the surface course (30-40mm deep) is considered as the main type of treatment to restore skidding and visual condition for the secondary roads. However, this was replaced with surface treatment where only skidding resistance is poor and the surface is in an acceptable condition and/or for the unclassified 'U' roads with no commercial traffic.
The payment mechanism has two principal components; a Service Payment based on the network being available in an acceptable condition to all road users and meeting minimum performance criteria, together with a Usage Payment based on total number of commercial vehicle crossing three measurement points at the city entrance. Unlike other projects, where only the pavement condition at 'hand-back' is required, Portsmouth's pavement condition is to be monitored annually in order to achieve the minimum performance requirements during the contract.
Several factors might affect the payment deductions and failure to achieve the performance requirements such as:

- The reliability of testing devices in describing pavement condition during the contract
- The possibility of traffic growth variations and its effect on pavement deterioration mechanisms;
- Since the pavement condition indices will be collected annually, the possibility of pavements not achieving the required indices due to different deterioration modes is possible
- The effect of external factors on pavement condition indices, including service companies and poor drainage systems

A register has been prepared to identify the risks and the proposed mitigation actions.
Alternative variant bids were proposed in order to optimise services for this project, such as:

- Service contract terms longer and shorter than 25 years
- Longer and shorter core investment periods
- Alternative performance requirements
- Alternative highway network categories and hierarchy
- Changes to the scope of services set in the contract
- Changes to the proposed allocation of risk.

INNOVATIVE ENGINEERING SOLUTIONS

Alternative designs for DBFO projects:
The HA are usually prepared to accept alternative designs incorporating substantial departures from current standards for DBFO projects, since the Contractor/Operator will carry the risk of achieving the required highway performance over 30 years. This allows the use of innovative approaches, optimising materials and pavement design using local aggregates and implementing performance specifications, rather than those based on recipes. In order to ensure that the design assumptions are met during construction, appropriate field testing is required. Some examples of this approach have been described by Hakim et al (2).

New motorway construction: During the tender period for a new section of motorway, all design options were investigated for a section of new construction in order to assess the best design with respect to cost, construction timescale and operational and constructability considerations. The risk of delaying maintenance treatment and the consequent effects on pavement deterioration and higher cost of repair were compared with the original proposal using a Net Present Value approach. The initial construction cost, pavement life, deterioration models and maintenance profiles were also considered.
A detailed traffic analysis was carried out incorporating lane distribution, growth rates and damage factors for different vehicle categories, in order to optimise the design traffic for each lane. Pavement design periods of 20 and 40 years were considered, where a major structural strengthening would be expected during the contract for the former and minor surface treatments for the latter. Design for long life pavement structures was implemented. Staged design with early interventions in terms of structural overlay was also proposed before reaching the end of pavement life. The effects of these pavement design periods on initial

construction and whole life cost, including the maintenance profile, number of interventions, lane closures with the associated penalties and the Net Present Value were investigated. The 40-year pavement life option was found to be more economic, since a little increase in pavement thickness lead to a substantial increase in pavement life and reduced the major strengthening.
Current British standards require the pavement thickness to be designed to carry the traffic loading of the slow lane with a uniform construction across all lanes and the hard shoulder, which is used for emergencies and diversions during lane closures. However, lower traffic is likely to use the middle lane and commercial vehicles are not permitted on the fast lane. Hence, pavement thicknesses were calculated for each lane and a trapezoidal cross section was proposed to allow for the retention of a subsurface drainage path. The details are shown in Figure 4.

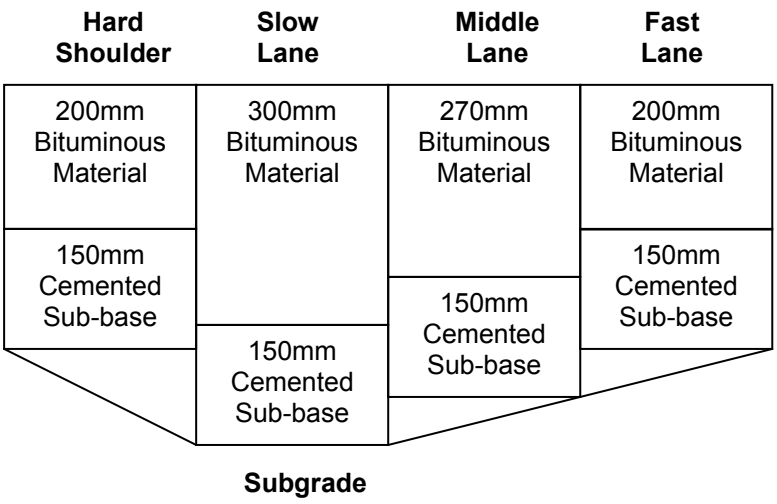

Figure 2 Trapezoidal Pavement Cross Section

Fully flexible, composite and rigid pavement alternatives were investigated in terms of construction cost, plant and material availability and speed of construction. The rigid option included jointed reinforced and un-reinforced and continuously reinforced options. The possibility of achieving higher compressive strengths than those recommended in the standards of 40MPa at 28 days was investigated. However, this pavement option was discarded due to the requirement for early pavement trafficking. Both flexible and composite pavements with cement bound lower base were considered.
The use of lime stabilised Pulverised Fuel Ash (PFA) for the earthworks and subgrade improvement offered an environmental benefit, due to local availability. Additionally, various types of available subgrade improvement materials were investigated in terms of performance, to predict their suitability for the pavement foundation. Trial sections were constructed using local aggregates for the implementation of end product performance testing, both at actual moisture content and when saturated. The tests consisted of in-situ stiffness, using the FWD and the Portable Dynamic Plate Bearing Tester both of which are shown in Figure 5, together with Dynamic Cone Penetrometer (DCP) tests, moisture content and rutting measurements and compaction trials.

Average FWD foundation stiffnesses of 47MPa and 37MPa before and after wetting were predicted respectively. Hence, the suitability of foundation materials and performance requirements were identified for use during construction.
Using cement bound sub-base with local aggregate was also considered, since importing well-graded granular material in accordance with the standard was not economic. This was extended to include various cement bound material strengths for use as lower base layers in flexible composite construction. Different mixture designs and cement contents were prepared in the laboratory using local aggregates. The results indicated that 5, 6.5 and 8% cement content by mass of dry aggregate could produce cement bound materials with 7 day compressive cube strength of 10, 15 and 20 MPa. Additionally, Indirect Tensile Stiffness Modulus (ITSM) tests (3) performed on specimens of the cemented material indicated an average stiffness of 10.5GPa.

Figure 3 FWD and Dynamic Plate Tests

Mechanistic design was used incorporating the actual material properties as measured during the trials. Performance testing was needed to ensure that the design assumptions were met during construction.

Whole life costing: This concept has been applied increasingly for projects where the contractor has long-term responsibility for maintenance. It has opened up strategic planning opportunities, which were not seriously considered under previous procurement arrangements that encouraged short-term thinking.
An example of the application of whole life costing is illustrated by the maintenance profile in Figure 6 for the new pavement shown in Figure 4, which was designed for a life of greater than 40.

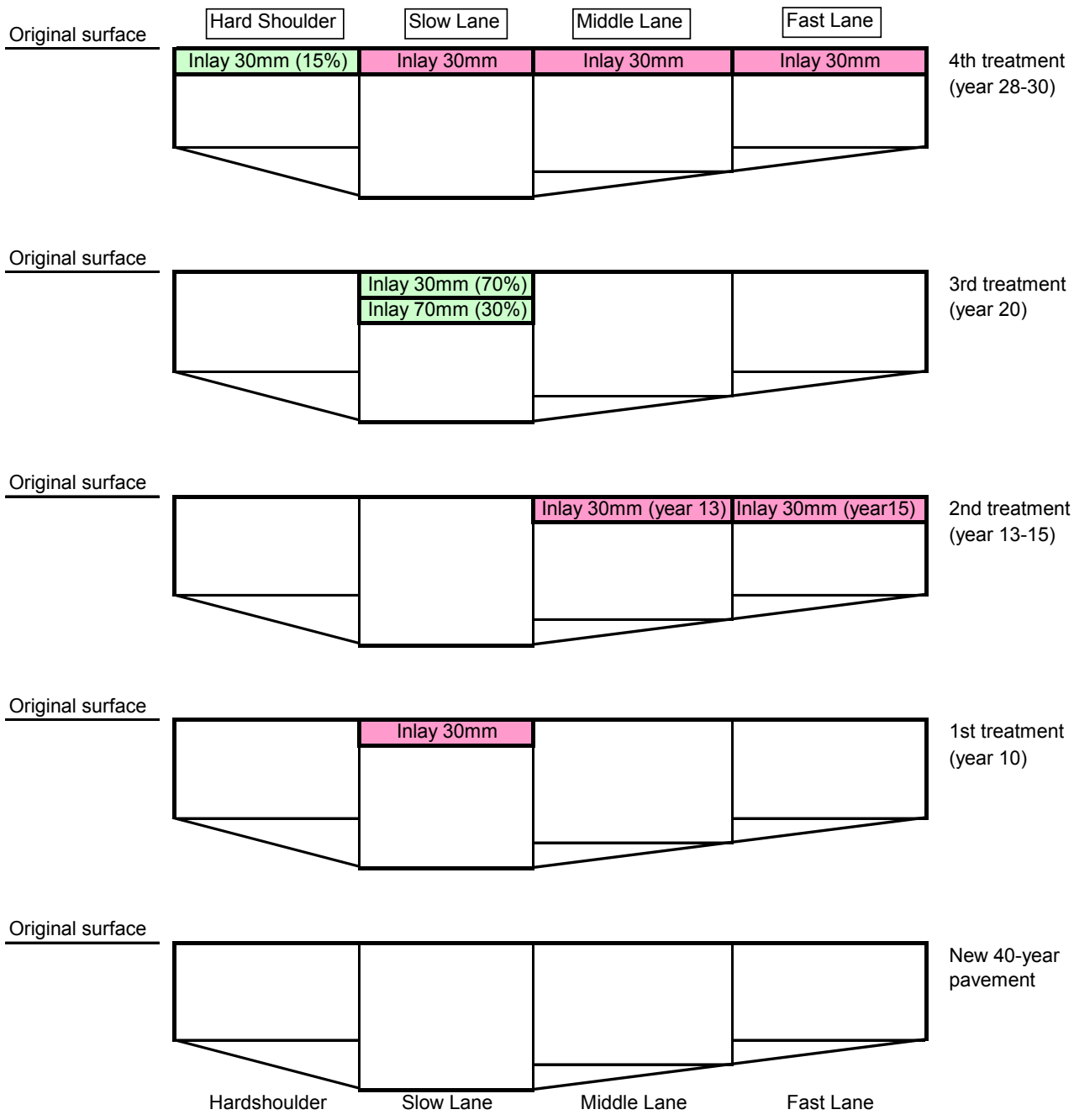

Figure 4 Maintenance Profile for Motorway over 30 year contract period

Even though no major strengthening was proposed during the 30-year contract period, replacement of the surface course would be needed to restore skidding resistance and to seal the surface in order to protect the pavement structure and achieve the requirement for long-life pavement. Based on previous experience, a surface layer life of 10, 13 and 15 years were suggested for the slow, middle and fast lanes respectively. Hence, replacement of the upper 30mm of surfacing was proposed at these intervals. This implies three interventions for the slow lane and two interventions for the middle and fast lanes. A 10-year residual life was predicted for the end of the contract. Additionally, deeper inlay with replacement of the surface and binder course (typically 70mm) was suggested for 30% of the slow lane pavement in year 20. Further allowance for minor maintenance and patching were also considered.

The maintenance profile of an alternative design concept was developed for a two-lane dual carriageway, where a pavement design life of 15 years was proposed, to reduce the initial construction cost and financial borrowing. A structural intervention comprising removal of the surface course (typically 30mm) and placing 90mm of the slow lane and 60mm of the fast lane and the hard shoulder was recommended in year 10. This treatment was suggested before reaching the end of the pavement life to increase structural integrity. Removal of the upper surface layer and replacing it with a new surface layer (keeping the same surface

level) for 50% of the slow lane and with 60mm (raising the pavement by 30mm) for the remaining 50% of the slow lane was proposed in year 20. Overlaying 50% of the fast lane and hard shoulder adjacent to the raised slow lane would be needed to keep the same surface level. The last intervention was planned for year 30 with 30mm inlay for both lanes and 15% for the hard shoulder.

Alternative design for a maintenance project: A major maintenance operation on a 4.5km section of dual carriageway, consisting of un-reinforced concrete slabs in 5m bays, was needed due to cracked concrete slabs, poor joint performance and weak foundations. Full depth reconstruction for the majority of the slow lane and part of the fast lane, was originally proposed by the Managing Agent Contractor (MAC). This included removal of existing concrete slabs and part of the contaminated weak sub-base, and replacing with 320-350mm of Heavy Duty Macadam (HDM) asphalt road base and base course overlaid with a thin surfacing, over 150mm granular sub-base. For the remaining sections, rehabilitation included full depth joint and crack repairs with 200mm asphaltic overlay. The estimated cost of the project was £6m.
The MAC designer proposed an alternative design, using crack and seat technology for the existing concrete slabs, followed by new asphalt surfacing for both carriageways. Crack and seat has both financial and environmental advantages, such as eliminating expensive and time-consuming joint and crack repairs, reducing traffic disruption and re-using the existing concrete. Both the HA and MAC saw the potential of the crack and seat alternative and went into a partnering agreement with the Contractor/Designer.
In order to design the asphalt overlay, the partners agreed to carry out a more robust regime of field testing to assess the existing pavement condition. The pavement investigation included structural evaluation using a FWD, coring, Dynamic Cone Penetrometer (DCP) tests and a Ground Penetrating Radar (GPR) survey together with a materials testing programme. The mechanistic design approach addressed two modes of pavement failure; overstressing of the subgrade and traffic and thermally induced reflection cracking within the asphalt layers. A programme of construction monitoring was proposed which included visual inspection of the crack pattern and surface condition, FWD testing on each cracked and seated slab, to ensure the specified residual stiffnesses had been achieved and coring through the cracks to ensure that a full depth vertical crack had been created. Full details are described by Hakim et al (4) and Thom (5).
Figures 7 and 8 show the Cracking and the Seating operations.

Figure 5 Cracking of concrete slabs

Figure 6 Seating of the cracked concrete slabs

The strengthening operation was completed ahead of time, at a reduced cost and to the satisfaction of the Client. The partnering arrangements worked extremely well in providing a better "value engineered" product. The savings to the HA compared with the original design were in the order of £0.8m or 13%.

Assessment of bond between pavement layers: Good bond between pavement layers is a desirable condition to provide a coherent composite structure with good resistance to repeated wheel loading. However, lack of bond between pavement layers is a phenomenon frequently encountered during pavement investigations. Binder ageing is the main cause for pavement layers debonding, although poor quality control during construction, lack of tack coat, contamination of the lower layers or lying of stiff material with cold weather, may result in poor bond. Recent studies carried out by Hakim et al(6) based on in-situ testing suggested that even though a combination of traffic and higher temperature improves bond between layers, age alone does not seem to be enough to get the same effect.

Pavement coring is the simplest method for visually identifying the state of bond between pavement layers; however, more sophisticated test methods, such as FWD and other portable impact test devices have also been used to assess the layer interface bonding conditions in situ.

Deflection testing is carried out on new pavement as a quality control measure to ensure that the pavement can carry the future traffic loading. This is particularly important for Design and Build contracts where the contractor has to hand the project back to the client at the end of 3 years warrantee period.

The case selected to illustrate the issue of debonding is that of a long-life flexible pavement which had been in service for three years, with 310mm of bituminous material constructed over a good quality foundation. An FWD survey indicated low residual life, a function of low back-calculated stiffness found for the bituminous materials. A detailed investigation including coring and bituminous material laboratory testing was then carried out and the results indicated intact bituminous materials with high stiffness but with poor bond between the layers at a depth of 140mm, based on separation under coring as shown in Figure 4. The average laboratory-determined bituminous base stiffness, measured in ITSM tests, was in excess of 6,000MPa at 20oC, in line with expected values for the materials used.

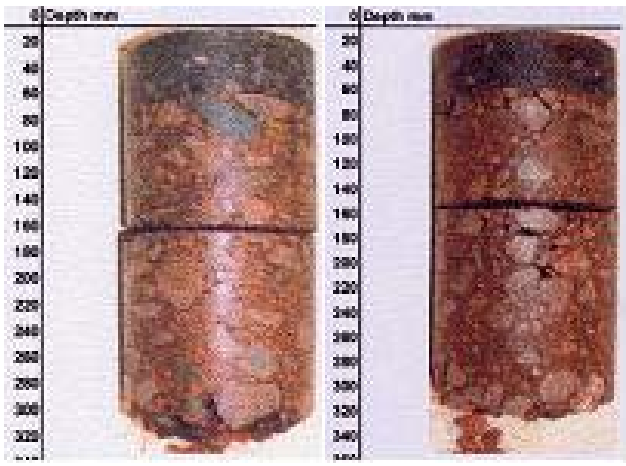

Figure 7: Separation between Asphaltic Layers after Coring

Lack of bond between pavement layers produces higher deflections under surface loading, since the layers act independently in the absence of shear continuity at the interfaces. This gives the same effect as a pavement with low material stiffness. In this case, the FWD data were re-analysed using the method developed by Hakim et al (6) to predict both the pavement layer stiffnesses and the bonding condition between bituminous layers. The results were consistent with the coring survey showing low bond stiffnesses, often less than 100MN/m^3. In comparison, a bond stiffness value greater than 10,000 MN/m^3 is normally associated with good bond (6). The re-worked FWD back-analysis also confirmed the level of stiffness found in the ITSM tests.

The life of the above pavement was considered to be low in relation to the expected future traffic. The ideal long-term strengthening treatment was to replace the upper de-bonded 140mm with new materials, ensuring that an appropriate tack coat was applied. However, this was clearly not yet required since the upper layers still had high laboratory stiffness values and a good pavement surface was still present with no sign of deterioration. There is also little or no proven validation of pavement lives in such cases, predicted purely on the basis of an increased asphalt tensile strain, following traditional mechanistic principles. It was, therefore, decided not to carry out any immediate treatment but to recommend surface deterioration monitoring and future testing. This issue, the realistic assessment of the effects of layer debonding, is seen as one of the key remaining unknowns in pavement performance prediction.

Reflective Cracking: One of the major maintenance problems for composite pavements is reflective cracking treatment, for MAC and DBFO consortia, in terms of lane closure, traffic delay and associated penalties. Composite pavements, where cement bound lower bases are used below the bituminous surfacings, often develop reflective cracking during the pavement life. Reflection cracks start developing in the cemented layers due to the early life shrinkage typical of these materials and reflect through the upper layers as a result of traffic loading and the difference in thermal movements between the bituminous and the cemented materials. Although reflective cracks are not considered as structural failure mode, they may indirectly induce fast deterioration of the pavement structure allowing water passing to the lower layers. The typical maintenance treatment used to prevent this deterioration is sealing the cracks. However, a relatively recent recommendation in the UK to induce transverse cracks in a controlled manner during the construction of the cemented base (at 3m spacing), has resulted in improved control and this has allowed cement treated bases to continue in widespread use.

Standard FWD pavement surveys carried out on such type of pavements may indicate a stiff and long-life pavement structure. However, the presence of reflective cracks may be detected by localized FWD deflection peaks. Specific programs, such as THERMCR (8), may be used to evaluate the pavement life to prevent thermally induced reflective cracking. The results obtained using this program with typical UK climatic conditions were very close to reality. Moreover, it has also been shown that the use of either Stress Absorbing Membrane Interlayer (SAMI) systems or a reinforcing grid had the potential to extend the overlay's life. The effectiveness of such treatments depends critically on the degree to which traffic influences the reflective cracking observed. Where cracks are in poor conditions, with poor load transfer, it is likely that traffic load will be the primary cause of reflective cracking. An alternative program, developed by Thom (8), OLCRACK, has been developed for this purpose.

A case study was selected to represent the application of new tools for the treatment of reflective cracking. Reflective cracking was found to be a major issue for a rigid composite pavement of a motorway in the UK. Twenty-five to thirty-five meter long concrete slabs were strengthened by 80mm asphaltic overlay. As a result of the thin overlay, reflective cracking appeared in the early life of the surfacing. Due to level restrictions (bridges, safety barriers, etc.), it was difficult to increase the overlay thickness without reducing

the thickness of the underlying concrete slabs, which would have resulted in a structurally weaker pavement. A joint system, comprising a combination of SAMI, placed at the interface between the concrete and the asphalt layers, and a reinforcing grid, placed at the mid-thickness of the asphaltic overlay, to be applied over a width of 1m across the joint, was the result of a study carried out using OLCRACK. This system was studied to provide the overlay a higher resistance to reflective cracking without changing its thickness.

CONCLUSION

An outline of the various procurement arrangements, which have recently been introduced for highway construction and maintenance in England, has been presented. They have all stemmed from a government initiative to encourage partnerships between the public and private sectors. Some of the schemes are in their infancy and time will be required to form a judgement as to their success. However, it is clear that engineering innovation has been encouraged by the opportunities that have been created. Partnerships between contractors and consultants, working over longer time scales than hitherto within a less confrontational environment should improve value for money. It also has the objective of providing a better way of doing business, which generates longer-term security and the encouragement of improved staff training as well as improvements to safety and delivery of sustainability targets.

The levels of congestion on UK highways have reached serious proportions in recent years. The HA is committed to a 10 year programme of highway improvements and the new procurement methods have been designed to achieve their objectives more effectively than would have been the case under the old contractual framework.

Innovative pavement engineering solutions have been encouraged by the new procurement arrangements. The improvement in the materials technology, new pavement structure design solutions and more specialized pavement survey technology and analysis have been adopted.

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