



Innovation in the Australian Road Construction Industry – Making Better Use of Resources

Dr K. Manley and Ms A. Blayse

**School of Construction Management and Property, Queensland University of
Technology. Cooperative Research Centre for Construction Innovation.*

ABSTRACT

The Australian road construction industry, as with its New Zealand counterpart, is often judged by analysts to be relatively inefficient compared to productivity improvements seen in the manufacturing industry. This inefficiency wastes scarce resources and is seen as the result of poor innovation rates. A key obstacle to improved innovation rates in the industry, and hence improved productivity and client satisfaction, is the perception by small and medium-sized firms that innovation is unlikely to be successful.

This paper reports on the results of a case study program that sought to demonstrate the benefits of innovation in the industry and the nature of successful implementation processes. The program follows from the success of the Egan Demonstration Projects documented by Rethinking Construction (now Construction Excellence) in the UK, and the associated significant improvement in industry performance in that country.

The case study program profiled three innovative projects in the road construction industry. The projects were nominated by partners to the program, who were key public sector clients in the industry. To be selected as a demonstration project, measured benefits from innovation had to be available.

This paper reports on the results of the three demonstration case studies: Alliancing on the Port of Brisbane Motorway project; the use of ground penetrating radar to detect defects in bridge beams; and Australia's first fibre-reinforced polymer bridge deck on the road network.

The key findings from the studies are that: the benefits of innovation are significant; clients can play a key role in driving innovation; innovation involving adoption of existing advanced technologies and practices is just as beneficial as original innovation; the type of contract employed on a project can have a profound impact on the opportunities for innovation and the benefits derived; and small local businesses can be technology leaders.

Key Words: construction, innovation, drivers, obstacles, implementation processes, industry policy

1. INTRODUCTION

It is widely accepted in policy, business and academic circles that innovation is the main source of economic improvement for industries (OECD 2000). Experience in OECD countries also clearly shows that innovation has a positive impact on profitability at the firm level (Guellec and Pattinson 2001, 92). Further, innovation is the main factor supporting improved environmental outcomes arising from road infrastructure development (FHWA 2004, Slater 1994).

Innovations may arise from inventing highly novel, original and previously unseen technological products/services or managerial practices. More likely, however, especially for mature industries such as the road industry, innovations will be 'new' to the adopting organisation, but not necessarily new to the industry, country or world. Regardless of the degree of novelty associated with an innovation, substantial benefits can be expected.

This paper examines three case studies of innovation, with varying degrees of novelty, on Australian road and bridge projects. The purpose of the examination is to understand more about implementation processes and the way in which innovators overcome the obstacles they encounter. The study was driven by the poor performance of the construction industry. Productivity is still less than the all-industry average and client satisfaction levels are an on-going problem (Cole Royal Commission, 2003, 3). Innovation is seen as a key method of turning this performance around and improving sustainability outcomes. Indeed, innovation has been described as the key to the future competitiveness of all Australian industries (DITR, 2003, 33). The current paper responds to the lack of literature internationally on innovation implementation processes in the road industry context.

2. METHODOLOGY

A case study program was adopted in response to the research questions:

What processes are employed by innovators to successfully implement innovation on projects in the construction industry?

How are obstacles overcome?

The resources available to the case study program dictated that six case studies could be undertaken over nine months, between April and December 2003. The case studies were nominated by industry partners associated with the research project, and only examples which could demonstrate measured benefits arising from innovation were eligible for inclusion in the program. The innovation examples showing the greatest benefit to a construction project were selected for study. These best practice examples covered innovation arising from the contractor, consultant, client and supplier sub-sectors.

The case study program focused on construction innovation on projects in the Australian states of Queensland, New South Wales and Victoria. The focus on construction *projects* arose because most readily identifiable innovation takes place

in that context. The focus on the three states was driven by the fact that they account for 80% of Australia's construction activity (Cole Royal Commission, 2002, 16).

The case study program was limited to the road and commercial building sectors of the industry, reflecting the focus of the stakeholders (industry partners) in the research project. These sectors are also the most innovative when measured by R&D expenditure, compared to the residential building sector (McFallan, 2002, 19) and they are therefore likely to provide good examples of the benefits to be gained from innovation.

The case studies were based on semi-structured interviews, and background documentation including award submissions, academic papers, magazine articles, internal reports and workshop presentations. Each case study involved multiple interviews covering representatives of at least two different organisations on the construction project being analysed. Each interviewee was a senior technical or management representative, and the range of interviewees covered all types of industry participants including clients, contractors, consultants and suppliers. Altogether, 20 interviews were undertaken; 17 under face-to-face conditions, and three by telephone.

The types of innovation studied involved both original innovation (that is, previously unseen developments) and adoptive innovation (that is, the use of advanced developments for the first time by a particular business). 'Adoption' of existing innovation by a business for the first time, is increasingly considered a valuable form of innovation (DITR, 2003, 15). Adoption activity can be seen as 'incremental' innovation, which diffuses the benefits of more 'radical' innovations. Further, both technical and non-technical innovations were researched.

The six studies undertaken were:

1. Whole of Life Costs - William McCormack Place, Queensland (Qld)
2. Concrete Planking - Suncorp Stadium, Qld
3. Project Alliancing - Port of Brisbane Motorway, Qld
4. Fire Engineering - Federation Square, Victoria
5. Fibre-Reinforced Polymers - Coutts Crossing Bridge, New South Wales
6. Ground Penetrating Radar - Cattle Creek Bridge, Qld

3. RESULTS AND DISCUSSION

This paper discusses selected results from the three road industry studies, covering innovation in project alliancing, fibre-reinforced polymers and ground penetrating radar. The objective is to outline and analyse successful innovation implementation processes, to provide industry guidance aimed at improving innovation rates, growth and environmental outcomes.

3.1 PORT OF BRISBANE MOTORWAY CASE STUDY

The Port of Brisbane Motorway (POBM) Alliance was formed to deliver five kilometres of four-lane motorway and 12 major new bridges, to carry an expected 8000 trucks per day by 2011, for a Total Cost Estimate (TCE) of \$112m. The project was completed early and under the TCE, after a one-year construction program. This stage of the motorway was opened in December 2002.

A project alliance is an agreement between a construction client and industry team, involving an undertaking to work cooperatively. An alliance is formed following an invitation to industry participants, normally from the Client, to submit a team proposal, often involving contractors, sub-contractors, consultants and suppliers. Selection of the team is based on value, not cost, and is often the result of a series of workshops. The successful alliance team (which includes the client) usually:

- shares project risk and reward in agreed proportions;
- adopts an open book approach to cost;
- develops a purpose-built contract, involving key performance indicators;
- agrees on a target cost estimate for the project; and
- forms a board to manage the contract, which represents all the businesses on the team (based on Rowlinson and Cheung 2003, 20).

The key innovation on the POBM project was the formation of an alliance to deliver the motorway; the first major road project alliance in the world. The alliance led to harmonious project relationships and hence the pursuit of opportunities for improved project performance and environmental outcomes which would not otherwise have been explored. Innovation on the POBM project centred around the alliance itself, but also involved a number of associated developments which were facilitated by the alliance structure. These innovations included:

- three-dimensional Global Positioning System (GPS) to control machinery – adopted for the first time on a construction project in the southern hemisphere;
- third party certification for safety, quality and environment – using integrated management systems to achieve triple-certification for the first time on an Australian road project;
- slip-formed, reinforced bridge barriers – adopted for the first time in Queensland;
- water quality design – winning an Australian award; and
- elevated tri-level motorway interchange – the first designed and constructed in Queensland.

3.1.1 The Implementation Process

Generally speaking, alliances are driven initially by clients. The Queensland Department of Main Roads (DMR) and Queensland Motorways Limited (QML) chose an alliance contract to deliver the POBM in view of the need for improved delivery performance on road projects, especially complex ones, to address concerns about poor cost/time outcomes, unsatisfactory quality, high rates of rework, poor stakeholder/community relations, and dissatisfied clients, designers and contractors.

Their choice was driven by their knowledge of potential benefits, given their first hand experiences on smaller alliance projects and their research into alliances in other industries. The initiative was in keeping with senior management commitment to innovative project delivery.

Further, there was recent advice from government auditors in the UK and Australia suggesting that public sector accountability concerns are not compromised by alliances as a form of project delivery. Indeed, it is likely that alliances will be employed with increasing frequency, as best practice public sector clients turn their attention away from hard dollar project delivery models toward more effective 'value-for-money' approaches. Implementation of alliances is also being facilitated in Australia by the lead taken by major contractors in championing the approach.

The above factors help explain the choice of an Alliance contract for the POBM. Within that structure, the team was keen to maximise outcomes, so DMR provided the opportunity to 'challenge' their Standard Specifications and established construction procedures and practice, through a detailed peer review process, value management workshops and joint problem-solving exercises. This resulted in key initiatives which underpinned project benefits, such as co-location of designers and geotechnical staff on site with construction personnel. Consultants were then easily accessible, enabling timely responses to constructability issues. Indeed, in order to deliver under the TCE, the Alliance '...recognised the need for a high level of design input, and more importantly, a significant integration of design, planning and construction activities.'

The Alliance also appointed an in-house Culture Manager to champion the alliance approach and assist in maintaining harmonious relationships and encouraging project integration, in part by providing coaching and support services. The emphasis on strong integration of project functions and building trust through effective relationships is reflected in the significant investment made in the design process and site management/facilities. The Alliance considers that this investment in integrated design, planning and construction was a major factor in achieving the project benefits outlined above.

3.1.2 Overcoming Difficulties

The Alliance encountered a number of significant difficulties during the project. Many of these involved relationships with the community, including community irritation with the 'start/stop' nature of the project in its planning and development stages; serious noise concerns from a local school; road closures resulting in loss of access; and construction across floodplains and wetlands, with associated environmental problems. The project's full-time Community Liaison Officer was a key resource in addressing these problems. The Officer promoted community ownership of the project, coordinating initiatives such as painted noise barriers, community events, site tours and a community hotline. These activities assisted in securing community support.

Nevertheless, the floodplain/wetland problem around the Bulimba Creek Oxbow was particularly difficult to solve. Rehabilitation of the area was an objective of the Alliance from the outset of the project (following ministerial commitments and advice contained in an earlier Impact Assessment Statement). The total cost estimate (TCE) included an allowance for a feasibility study. However, environmental groups were keen to see a fuller commitment to rehabilitation of the Oxbow area as part of the

POBM project. Indeed, the area was already significantly degraded and the motorway works could easily have exacerbated the problem. The Alliance took the lead in developing a Memorandum of Understanding between key stakeholders and securing a commitment of funds to carry out the rehabilitation. The Alliance framework accommodated the increase in scope that a full rehabilitation involved and facilitated the excellent results that have been recognised by several environment awards.

The 'virtual organisation' represented by the Alliance structure was able to draw on the collective skills of its team to find a best practice solution to the Oxbow problem. Initially, it appeared that \$11m in bridges and culverts would be required to meet the hydro-ecology objectives of environmental groups. However, through the adoption of advanced flood modelling software, the Alliance was able to demonstrate that \$250,000 in strategically placed earthworks and drainage structure would achieve similar environmental outcomes. The modelling software helped convince all stakeholders, through quantitative analysis, that the outcome being proposed was optimal. This solution was adopted thanks to a well structured team approach, which effectively integrated the often separate skills of design and construction.

There were other difficulties, which were internal rather than external. Firstly, there were challenges in adopting the Alliance 'best for project' culture. Although participants directly related with the project were well supported in making the required mind-shift from hard-dollar contracts, those at more junior levels and those further removed from the project adapted less well to the new delivery system. This caused some relationship problems between the Alliance and some DMR groups not directly involved with the project. However, during the course of the project, these problems became less frequent as the level of exposure of DMR officers to the Alliance culture improved.

Secondly, the preliminary design (horizontal and vertical geometry) of the Port Motorway presented some challenges and needed to be optimised in the detailed design stage. This included adjustments to the geometry to achieve the required design speeds in a very constrained site at the Gateway Motorway interchange. Leighton and Parsons Brinckerhoff came up with an innovative structural arrangement, involving a portal beam assembled in two parts, which spanned the Gateway Motorway. Adjustments to the design were also required to minimise the embankment heights on the soft foundation soils, while still maintaining flood protection. The optimum design was achieved with the designers (Parsons Brinckerhoff, Coffey Geosciences and DMR staff) working closely with the builder Leighton.

Thirdly, the design brief specified a 6.6 metre clearance height to bridge structures. However, Parsons Brinckerhoff challenged this and, in consultation with DMR, it was agreed to reduce clearances to 6.1 metres consistent with the adjoining motorway network, given that an alternative route for excess height vehicles was available. This adjustment delivered significant cost savings.

Fourthly, exclusive use of DMR's standard (generally prescriptive) specifications for traditional delivery could have hampered the flexibility of the Alliance to pursue innovative solutions. Therefore, the Alliance and DMR adopted a 'fit-for-purpose' approach to the design and construction activities, enabling a more effective and efficient outcome.

Finally, the Alliance structure and the large scope of the project encouraged the team to put aside their risk aversion and trial a range of new technologies, including slip-formed, reinforced bridge barriers. Initially, DMR had some reservations about the bridge barrier technology being proposed by Leighton, concerned that it would not produce a fit-for-purpose result. Often, that would be the end of an innovation; however, in a collaborative alliance context and with many bridges to construct, Leighton and DMR had sufficient incentive to undertake some tests. The results justified the use of a concrete paving machine, instead of formworkers, providing project benefits in safety, labour costs and time.

3.1.3 Lessons Learned

The Alliance reviewed project performance and noted key learnings, including:

- building sound relationships with project stakeholders provides a solid platform for the resolution of issues which, under a traditional contract, could be insurmountable barriers to project completion;
- preparedness to trial and implement new technology results in excellent project outcomes in terms of cost, innovation and quality;
- involvement of designers in all phases of the project alliance is critical to producing infrastructure that is fit-for-purpose and meets quality and safety requirements;
- peer review of the design process is very effective in ensuring 'value-for-money' outcomes; and
- external review of quality assurance and key performance indicators is particularly necessary under alliances to ensure good project governance.

At a more detailed level, DMR and QML advise that, in relation to project alliances, clients should:

- develop a sound budget before entering into a project alliance, because budgets set expectations about TCEs;
- be informed buyers so they can make informed decisions – having designers and other technical experts as alliance members helps in this regard;
- show leadership to ensure that design changes intended to result in value improvements do not lead to reduced standards;
- conduct a financial audit of the Alliance proponent, rather than seeking financial information from all alliance project offerers in the initial stages of the selection process, in order to minimise the cost of tendering and improve value-for-money;
- conduct thorough workshops with offerers to help establish the effectiveness of relationships between various teams and the client;
- encourage the use of value management workshops and joint problem-solving exercises by the alliance team to help develop an appropriate scope of work to achieve needed functionality at acceptable cost;
- be involved in development of the TCE to avoid the perception that the TCE is a quasi-tender bid; and
- exercise care in the adoption of fit-for-purpose standards, and involve peer reviewers in the development of the TCE, to ensure that the drive to reduce cost is appropriately balanced against operational suitability, durability and whole-of-life costs.

3.2 COUTTS CROSSING BRIDGE CASE STUDY

The bridge at Coutts Crossing spans the Orara River, in northern New South Wales. The FRP bridge deck was installed in 2003 to replace a timber span constructed in the 1930s. The Coutts Crossing bridge is 90 metres long and 7 metres wide. The FRP deck replaced 12 metres of the bridge length

The innovation lay in the modular construction of the FRP bridge deck and the hybrid engineering of the material usage. The composite design employed has never before been used, and was developed specifically for bridge, to mimic a conventional concrete bridge deck, which is accepted best practice.

3.2.1 The Implementation Process

‘... innovation is a constant effort to stay outside your comfort zone’

The installation of the bridge deck at Coutts Crossing in February 2003 represented the culmination of more than five years of extensive collaborative research and development by a number of enthusiastic individuals and organisations, including state and federal government departments, private sector firms and the university sector. The Coutts Crossing project would not have been possible without this background research and development.

University of Southern Queensland's (USQ's) Fibre Composites Design and Development (FCDD) Group started research into fibre composite bridges in 1996. Shortly afterwards, Connell Wagner consulting engineers joined the research effort, with DMR becoming involved in 1998, contributing practical design information. The bridge design moved away from the initial lightweight ‘thin walled’ approach to a slightly heavier, but more robust, bridge structure. Through the development of an innovative casting technology, a far more economical and practical solution was obtained in mid-2001.

In 2000, the Cooperative Research Centre for Advanced Composite Structures, in conjunction with Roads and Traffic Authority (RTA), Victoria, and the Commonwealth Department of Industry, Science and Resources, instigated a feasibility study to evaluate the suitability of advanced composite materials for Australian civil infrastructure applications. A generic design exercise established which particular technologies should be encouraged. This involved the generation of a performance specification that met RTA requirements and the submission of two conforming preliminary design concepts.

One of these was a concept developed by an Australian FCDD-led team. RTA selected this solution as the preferred alternative for demonstrating the appropriateness of the materials for Australian conditions. The economics of the design were potentially comparable with those associated with bridge construction using conventional materials. RTA also considered that the polymer composite design had other through-life advantages that increased its attractiveness.

In 2001, a project team consisting of Wagners Composite Fibre Technologies Pty Ltd (WCFT), FCDD, RTA and DMR completed the development of the concept and installed the first prototype on a quarry site at Wellcamp, near Toowoomba in Queensland, owned by Wagners Investments Pty Ltd (Wagners). WCFT played a key role in both the prototype bridge and the Coutts Crossing bridge. WCFT is a trading division of Wagners, a Toowoomba-based company with interests in concrete, quarries and transport. A relatively young company (formed in 1989), Wagners had a strong background in research and development, pouring millions of dollars a year into research activities. Wagners management sums up its approach to innovation as 'a constant effort to stay outside our comfort zone' and 'its belief that tomorrow's infrastructure will not be built using today's technology'.

Wagners first learned of fibre composites technology when USQ, which had placed a graduate engineer with the company, asked it to look at the feasibility of a lightweight semi-trailer as part of the graduate engineer's project. Wagners quickly saw the potential for other applications of fibre composite technology, including for rail sleepers, cross arms, power poles and bridges and beams. A research and development project on fibre composite bridges was launched and WCFT contributed significant up-front funding to develop the prototype bridge beam, which was matched dollar-for-dollar by an AusIndustry grant. WCFT (and Wagners) did not expect to make an immediate return on its investments in research, but could see a longer-term commercial return. Indeed, WCFT is planning to start operation of a production line in 2004, which is expected to deliver the first fibre composite profits for the company. To date, WCFT has put many millions of dollars into research on fibre composite bridges.

DMR was also an important contributor to the prototype development project, contributing the time of one of its bridge engineers, as well as testing equipment and a small cash payment to FCDD. The DMR engineer's role was two-fold. First, she contributed technical expertise to the project. Second, and very importantly, she ensured that the prototype was one that could later be transformed into a product commercially available to DMR for use on Queensland's road networks. The engineer ensured that the prototype met DMR's design, safety and environmental criteria and that it was constructed in a way that delivered a suitable cost structure for later use.

The prototype was completed in early 2002, and an extensive series of field tests followed, revealing that the concept exceeded expectations of its technical performance. The prototype bridge is still in use at Wagner's quarry, with an estimated 150 quarry trucks passing over it every day. 'Health' monitoring is ongoing. The prototype bridge project was awarded a 'Highly Commended' by the Institution of Engineers in September 2002.

The success of the prototype led to the proposal to place an FRP bridge on the road network. After initial project development by RTA, WCFT, and FCDD, a site was selected and it was decided to replace an existing timber span bridge at Coutts Crossing. Connell Wagner was engaged by WCFT to review and modify FCDD's fibre composite bridge concept to suit the site-specific requirements (essentially, however, the design was the same as the prototype). The new Coutts Crossing bridge is an innovative combination of fibre composite and conventional materials constructed and installed by WCFT. FCDD assisted RTA in its superintending

responsibilities. Initial site testing shows that the bridge is performing well, and this will be periodically monitored by RTA over coming years.

WCFT treated the installation of the bridge at Coutts Crossing as a research and development project, largely because the RTA budget would only allow for the cost of an equivalent bridge constructed from traditional materials. WCFT has, however, been able to apply the experiences learned during the project, and expects that mass production will lead to profitable sales to road and traffic authorities in the near future. WCFT has a patent over the design cross-section of the individual beams as well as the manufacturing process used for construction of the bridge deck. WCFT believes that the collaborative history of the project involving DMR, RTA, FCDD and others has been invaluable in the commercial development of the technology. These partners steered WCFT in directions it might not have otherwise gone, and also provided essential technical and moral support.

The partners continue to conduct individual research projects on fibre composites, as exploring the full potential of the technology remains an on-going priority for them.

3.2.2 Overcoming Difficulties

Manufacture of the fibre composite bridge prototype proved to be a challenging task. The fibre composite industry is not new – it sells to the aerospace, marine and other industries – however the construction industry is a new market for fibre composites. Accordingly, material uniformity and product stability were still being developed during the prototype process. There are thousands of resins and fibres, all with different structural properties, that could have been employed.

The first batch of pultrusions supplied to make the prototype bridge was rejected, as the product did not meet DMR and WCFT standards for bridge components. Another problem was encountered with the adhesive to connect the pultrusions. The heat distortion temperature was intended to be 100 degrees Celsius, but a chemical manufacturer up the supply chain had changed the chemical properties of the adhesive, so that the heat distortion temperature was only 60 degrees Celsius. The design team was, however, able to out-engineer this concern and accommodate the difference.

The DMR engineer involved in development of the FRP bridge describes the challenges in her USQ Masters thesis, which observes that the design of the fibre composite deck units evolved through several phases during the prototype development process. The use of combined modular sections to make bridge beams was a constant theme, however the type of modules, materials and design philosophy changed dramatically, as difficulties were encountered and overcome. In all, five designs were trialled.

Another difficulty – or perhaps more a challenge than a difficulty – was that so many parties were involved in the development and construction of the prototype bridge. These parties were from different backgrounds – academia, the private sector and government. At times, differences in objectives became apparent, particularly when the costs or quality of materials to be used were at issue. It appears that tensions were overcome by overwhelming goodwill and trust established between the parties during the development stage. Another element in the successful resolution of conflicts was the interest that the parties had in successful completion of the project –

for example, WCFT in future commercial sales of its product, DMR in the future application of the technology to Queensland's bridges, and materials suppliers in supplying to manufacturers like WCFT in the future. Individuals interviewed for the case study indicated that the involvement of all the collaborators was essential to the success of the project.

3.2.3 Lessons Learned

- Innovations are fostered by collaborations between industry, academia and government.
- Companies believe that investing money in research and development can reap significant commercial benefits.
- Involvement of clients in the early stages of innovation development can improve outcomes.
- Linkages with university research bodies can yield commercial benefits for far-sighted companies.
- Goodwill and trust are essential in collaborative innovations.
- Public sector research and development grant schemes can yield tangible commercial benefits.
- Successful innovation often requires commitment, perseverance and a willingness to sacrifice short-term gain.

3.3 CATTLE CREEK BRIDGE CASE STUDY

The original timber bridge over Cattle Creek was constructed in 1941. It was replaced in 1999 by a concrete bridge, which was constructed by a private sector contractor under a Schedule of Rates agreement. The bridge opened in May 2000, following the cooperative and innovative resolution of problems with defective concrete bridge beams, using Ground Penetrating Radar (GPR).

The innovation on the Cattle Creek Bridge project was in using high-frequency GPR to investigate the interior of potentially defective prestressed concrete beams in a precisely calibrated way. This latest generation of GPR technology is only just beginning to be used globally for structural applications, and the Cattle Creek Bridge application was a very early, and successful, test of the technology in this field.

3.3.1 The Implementation Process

The decision to use GPR to identify the location and number of defects in the beams of the Cattle Creek Bridge involved a commitment to trial the technology for this type of application. Georadar was willing to spend research and development funds to demonstrate the benefits of the technology before project stakeholders committed to a more comprehensive testing of the beams.

Since its establishment, Georadar has internationally pioneered many surface and underground applications of GPR. As noted above, an 'innovation champion' at DMR's Central Queensland Regional Office persuaded his colleagues to consider using GPR and Georadar to identify the defects in the Cattle Creek Bridge project. This champion had become interested in radar technology after his involvement in addressing the problem of collapsed trenches at Rockhampton Airport in 1975. The solution was to drill at 750 millimetre intervals along the length of the runway to

identify the location of the sub-surface collapse zones. The inefficiencies of the approach encouraged his interest in non-invasive, non-destructive methods of identifying hidden defects. He began to read widely across scientific literature and later encountered Georadar, commissioning them to perform several survey projects using low-frequency GPR to investigate deep geological targets.

Georadar had been working to develop the more challenging high-frequency GPR technology for over nine years before the Cattle Creek Bridge project. They consider the Cattle Creek Bridge a fortuitous opportunity for real-world application and testing of new technology, noting however, that 'luck favours the well-prepared mind'. They first used pre-cursors of the high-frequency GPR technology to test the concrete shell structures of the Opera House in 1992. They realised then the need for significantly improved resolution to increase the accuracy of defect identification. Over subsequent years, several individuals and organisations, including international scientists and antennae manufacturers, worked with Georadar to develop the technology.

The Cattle Creek Bridge problem presented a timely opportunity for testing and refining Georadar's latest advances. All parties committed to a cooperative approach to the problem. Georadar deployed their technology under an Intellectual Property (IP) agreement with DMR. In turn, DMR's willingness to commit funds to trial the technology facilitated their access to the benefits of GPR for the Cattle Creek Bridge, and to subsequent testing work, subject to an IP agreement. Significant funds were also committed by the supplier of the bridge beams, which was keen to arrive at a cooperative and efficient solution to the defect problem. Additionally, the experience led quickly to improvements in the supplier's manufacturing processes.

3.3.2 Overcoming Difficulties

The most important difficulty associated with the use of GPR to audit the Cattle Creek Bridge beams was the risk of failure, because the technology had not previously been used that way. All key stakeholders – the client, consultant, contractor and supplier – agreed to trials of the new technology because they accepted the need for judicious risk taking. They championed the innovation: DMR Head Office was very keen to find an efficient solution to the beams problem and created the organisational conditions for innovation to succeed; DMR Central Queensland Regional Office had networks in place that pointed to the potential value of GPR; and Georadar was the technical expert, with an international reputation for championing developments in GPR.

Having decided to test GPR, the parties needed to cooperate during the trial and investigation period. This was assisted by a history of good relationships, which were maintained throughout the project's uncertainties. The networking of key individuals had previously built the inter-business relationships upon which an efficient solution to the Cattle Creek Bridge problem depended. DMR believes that without these good relationships, a more costly solution would have been necessary. In particular, DMR and Georadar have independently noted that the positive attitude of the supplier was crucial in ensuring the positive outcome.

3.3.3 Lessons Learned

- Problems are strong innovation drivers.

- Problems can create opportunities for learning and future benefit.
- Investment in problem-solving on a particular project/application often reaps flow-on/spill-over benefits across a number of projects/applications.
- Fine-tuning of new technology to suit specific applications depends on opportunities for testing in real-world situations.
- The presence of 'innovation champions' is often crucial to the adoption and development of innovative technologies.
- Organisations willing to invest in research and development can reap significant benefits over time.
- A culture of cooperation is often necessary for identification of innovative solutions to problems.
- Innovation is not a short-term endeavour – persistence is required.
- Involvement in knowledge networks is a good insurance policy against uncertainties of the future.

4. CONCLUSIONS

Overall, the experiences of innovators in the case studies highlight the highly interactive nature of successful innovation processes and the importance of robust business networking. Although R&D activities are shown to be important, the success of each innovation has been ensured by high level organisational expertise. Innovation then relies on technical advances and people skills.

The case studies also show that:

- the benefits of innovation are significant;
- clients can play a key role in driving innovation;
- innovation involving adoption of advanced technologies and practices developed elsewhere is just as beneficial as original innovation;
- the type of contract employed on a project can have a profound impact on the opportunities for innovation and the benefits derived ;
- small local businesses can be technology leaders.

The case study findings, supported by an associated literature survey, indicate that innovation in the building and construction industry can be usefully leveraged through:

4.1 Building Relationships with Key Players

- active use of innovation brokers to facilitate efficient access to technical support providers and other external players with complementary knowledge bases
- building robust relationships with manufacturers supplying the industry, in view of their involvement in R&D programs
- building long-term relationships with clients in view of the shift towards more cooperative approaches to project delivery

4.2 Streamlining Activities

- mobilising integrated approaches to construction projects, in response to industry fragmentation arising from the 'one-off' nature of most projects and the proliferation of small players

- improving knowledge flows by developing more intensive industry relationships, offsetting the disadvantages of production based on temporary coalitions of firms
- integration of project experiences into continuous business processes to limit the loss of tacit knowledge between projects

4.3 Growing an Appropriate Internal Business Environment

- building a culture supportive of innovation, including encouraging staff to share ideas, enhancing in-house technical competence, supporting innovation champions, appreciating the opportunities presented by problems; encouraging prudent risk-taking; and establishing recognition programs.

4.4 Effective Client Leadership

- maintaining high levels of technical competence, advanced demand patterns, and a positive approach to prudent risk-taking
- promoting innovative procurement systems, including partnering or alliancing, to enhance cooperative problem solving, the adoption of non-standard solutions, and equitable allocation of risk
- strengthening performance-based standards through the enhancement of technical knowledge and the formulation of simple enforcement strategies.

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