Transport Engineering Technologies

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Abstract

This study is an attempt to marry some empirical observations on prospective technological developments in transportation and engineering with developments in economic theory. It draws on research undertaken by the Centre for Strategic Economic Studies on the aerospace industry (CSES 1995, 1999) and research on sustainable transport (Jolley 1996, 1999) as well as unpublished research on global developments in the defence industries. On the theoretical side, it makes use of the literature on evolutionary economics and innovation systems (note DISR 1998). In addition, it also draws attention to the relevance of technology foresight as a tool for influencing innovation systems (APEC Center for Technological Foresight 1998; AATSE 1999).

The first section of the paper emphasises the substantial stimulus to innovation that now exists in transportation and defence systems. This stimulus arises in large part because of the momentum associated with the push to develop sustainable transportation. The second section of the paper describes the new technologies being developed in different industries (materials technology, engines, industrial electronics, design and manufacturing technologies, new approaches to maintenance and repair and to safety). It indicates that these developments will give rise to potential technological synergies across a broad range of industries. The final section of the paper tackles the issue of how these potential technological synergies might best be exploited. It briefly reviews the economic analysis of innovation, gives some examples of Australian capacities for engineering innovation, and indicates how technology foresight as a tool can be applied to encouraging the development of a national innovation system in Australian engineering.

The Stimulus to Innovation in the Engineering Industries

One of the main contentions of this paper is that a very substantial stimulus to innovation exists in transportation and defence systems which, in turn, will have a significant impact on the technologies employed in the manufacture of transport equipment, industrial electronics and materials fabricators, and engineering companies supplying materials and components to these industries.

The Concept of Sustainable Transport

Sustainable transport is a new concept being given prominence by international institutions like the World Bank (1996). It combines the separate notions of economic efficiency, environmental sustainability and social sustainability.

Economically sustainable transport needs to be cost-effective and continuously responsive to changing demands. In large parts of the world, transport systems fail to meet the test of economic and financial efficiency, in part because of the way in which collective transport is run, in part because of the absence of road pricing and congestion pricing.

Environmental sustainability requires that the external effects of transport on the physical environment be taken into account when decisions are made on transport developments. The major environmental problems associated with transportation are air pollution, global warming, leaking tanks and oil spills.

Social sustainability requires that the benefits of improved transport reach all sections of the community. The accessibility of transport services to the community at large is an important aspect of social sustainability, as is an improvement in the safety of transportation.

In the absence of policy changes, an increased demand for urban transport services in a number of significant urban centres around the world could lead to a major deterioration in environmental conditions and increasing traffic safety problems. There will be increasing political pressures to achieve sustainable transport systems through the use of fiscal incentives and/or penalties, regulations and public investment. As a consequence, there will be significant encouragement to innovation in such industries as the manufacture of motor vehicles and other transport equipment as well as in the systems relating to traffic management.

The most significant influence on aircraft for the next century is expected to be the environment. Next-generation aircraft will be required to meet stringent requirements for engine emissions. Noise is a second important aspect of environmental regulation impacting on aircraft design. There is substantial pressure to develop cleaner, quieter engines that burn less fuel and produce more thrust (Scott 1999). In addition, environmental factors will increasingly become one of the key influences on innovation in other transport equipment, particularly motor vehicles.

The stimulus to innovation in transport equipment will also have important implications for regional industrial development. The pressures for developing more sustainable transportation, while significant in the advanced economies, are becoming quite acute in the developing economies of East Asia and Latin America. This, in turn, can be expected to dramatically shorten lags in the diffusion of new technologies from advanced to emerging economies. It could also encourage a greater participation in the innovation process itself by emerging economies.

Internal Costs and Benefits

The above comments focus on externalities that are increasingly coming into play as influences on transport technology. Internal costs and benefits have always been important considerations where competitive markets apply. Consumers are seeking a range of benefits for transportation while seeking to minimise costs. Improved customer amenity combined with affordability have long been major influences on the design of motor vehicles, which have also responded to external influences like the oil price shock, which was transmitted into higher petrol prices and then encouraged sales of more energy-efficient vehicles. The utilisation of e-commerce technologies is expected to increase the interaction between consumers and producers.

The demand for new civil aircraft is a derived demand, in contrast to a substantial proportion of the demand for motor vehicles. The airlines provide the service to consumers and business, and increased customer focus in aerospace manufacturing is taking place through the involvement of major airline customers in new aircraft projects at the design stage. The progressive deregulation of the world air transport industry has sharpened the focus of airlines on customer satisfaction. This has resulted in increased pressure on the aerospace manufacturing industry to cut prices while providing increased amenities. The result has been increased pressure for continuous product and process innovation (CSES 1996, 1999).

The defence industries have not been immune from this pressure for continuous product and process innovation. Technological innovation has long been a key factor in the strategic competition that underlays defence planning around the world. While the end of the Cold War had been expected to reduce the pressure for defence innovations, the period since the mid 1990s has seen a renewal of demand pressures on defence innovation. This renewal is based on the proliferation of local conflicts in different parts of the world, the political pressures in the US to reduce risks to military personnel while maintaining or enhancing strategic military capabilities, and pressures on many other countries to deal with the growing technological lead being developed by the US military. The US is not only the leader in developing new defence technologies. It is also the leader in developing more cost-effective means of supplying defence equipment. Pressures on the defence budget have led to a systemic exploration of means of improving the efficiency of defence procurement by taking a life-cycle approach to design, manufacture, operation and maintenance of defence equipment.

The New Technologies in Engineering Industries

The pressure for innovation in civil transportation and in defence equipment is expected to be very strong in the decades ahead. The new technologies that will arise from this process will impact on the production of various types of transport equipment, defence equipment and industrial electronics, as well as change the way in which transportation is managed. The second major contention of this paper is that this process will provide increasing opportunities for technological synergies across a broad range of industries. The industries mainly considered are motor vehicles, civil aerospace, defence equipment, shipbuilding, and industrial electronics. Both product and process technologies are examined – materials, engines, electronics, design and manufacturing, maintenance and repair, and safety.

Materials

Materials technology has become an important issue for the motor vehicle industry. The materials used in an average vehicle – glass, steel, aluminium and plastics – are highly energy-intensive in their manufacture. The quest to meet increased fuel efficiency guidelines while maintaining performance is leading to the consideration of new materials in vehicle manufacturing – lightweight alloys, plastics, composites and ceramics. The hope is that the greater use of lightweight materials will improve fuel efficiency while maintaining affordability, safety standards, performance and comfort. The key issues may well be affordability (there is a huge challenge in developing more automated manufacturing processes for new materials, particularly for composites), and safety (assessing the robustness of composites to accidental impacts is more difficult than for traditional metals) (Jolley 1999; Fries 1998).

With respect to materials technology, the motor vehicle industry is following a pathway travelled much earlier by the civil and military aerospace industries. These industries required durable light-weight materials, and found them in aluminium alloys. Over time, however, composite materials have taken on increased importance. While initially used in auxiliary fittings and doors, the Advanced Subsonic Technology Program (AST) being run by America’s National Aeronautical and Space Agency (NASA) is researching the use of advanced composite materials for wings and fuselage structures with a view to reducing weight further (Phillips 1999). The aerospace industry had to develop new manufacturing technologies for the new materials, and technologies for maintenance and repairs. While initially materials used in the aerospace industry were not subject to the same cost constraints faced by other manufacturing industries, these constraints are becoming more important and there has been increased emphasis given to developing appropriate manufacturing technologies.

Particularly noteworthy is the US Defence Department’s Manufacturing Technology program. A panel of this program is focused on promoting the production of composite structures that can compete with metal on a cost, as well as structural performance basis. A life-cycle cost analysis, incorporating both manufacturing and maintenance, should be utilised early in the design process. The panel is also focusing on a review of the consistency and quality of the sequence of manufacturing operations in order to identify processes that require the most improvement. Further research is necessary in developing tools to calculate design costs for composites, and the development of integrated databases to support design. Investment in composites repair facilities is also beginning, with research being conducted on improving maintenance procedures (McKenna and Sparaco 1998).

Materials technology developed for the aerospace industry has been utilised in shipbuilding. Aluminium alloys and new plastic-based composites can make ships both strong and very fast. There has been much borrowing from aviation design and construction. The development of cheaper manufacturing techniques for composites can also make possible their use for buildings and other structures. The synergies with developments in the motor vehicle industry are obvious. Not only are similar materials technologies being tapped, but materials safety and affordability are important issues. There are substantial opportunities for cross-fertilisation in research on appropriate manufacturing technologies and maintenance.

Engines

An important characteristic of the aerospace industry is that the Prime aerospace integrators (Boeing and Airbus) do not manufacture aero-engines. Indeed, most versions of Boeing and Airbus aircraft can be fitted with alternative engines. The global aero-engine industry is dominated by three major manufacturers – General Electric (US), Pratt & Whitney (US and Canada), and Rolls-Royce (UK). However, in order to reduce the huge costs of R&D necessary to meet competitive requirements for ongoing improvement in engines (improvements necessitated by ever more stringent environmental requirements in relation to noise and emissions), each of these companies is involved in intricate associations to spread costs and develop new engines. These associations involve smaller European engine manufacturers such as MTU DaimlerChrysler (Germany), Snecma (France), and BMW (Germany), as well as Japanese heavy engineering companies such as Mitsubishi and Ishikawajima-Harima. Military propulsion technology has a continuing influence on the technologies used for commercial aero-engines and, in some cases, military and commercial engines will be directly linked through a common predecessor (Kandebo 1999).

The aero-engine industry also employs a huge number of contractors and sub-contractors to provide components and sub-components. Investment castings are a prominent part of the industry. The Engine Supplier Base Initiative, involving the US Air Force, other US government agencies and the supplying and using industries, has stimulated technical progress in foundries and identified issues that have generated substantial improvements in quality, speed of design and supply, and costs (Velocci 1999). At the more general level, NASA is investigating aero-engine design with the twin goals of reducing flyover noise and lowering emissions by substantial amounts.

The development of more sustainable urban transport systems is expected to encourage the setting of ambitious new goals for automotive fuel economy and emissions. New innovations affecting the internal combustion engine, and significants developments with respect to hybrid-electric vehicles and vehicles powered by fuel cells are under way. Several of the more promising projects involve extensive international collaboration. While there is no direct interaction between aerospace and motor vehicle engine technologies, synergies may exist so far as program integration techniques and aspects of manufacturing are concerned (Jolley 1999). Engine technologies developed the automobile industry may have significant opportunities in relation to marine industries, heavy machinery and other capital equipment.

Electronics

Electronics has become an essential feature of motor vehicles and plays a key role in improving engine efficiency and overall performance. Most of the new engine technologies imply an enhanced role for electronics, as do innovations with respect to steering, braking and throttle control. Already, substantial technological change is occurring.

Cars have had on-board computers for years, but most have been limited to regulating engine performance or controlling braking and suspension. Now, however, the blending of car and computer technologies is being harnessed in new and promised innovations that will help drivers find their way in unfamiliar territory, pay road tolls without stopping, avoid traffic jams, and access the kind of information and entertainment features currently available only at home or in the office (Jolley 1999).

The potential blending of car and computer technology has strong support from the information sector. Netscape, Sun and IBM have formed a consortium to develop in-car computer systems. Microsoft has joined the competition with an automotive adaptation of its light-weight Windows CE operating system. While still pricey, in-car technology is getting cheaper. The motor vehicle industry recognises that it can push costs down further by standardising its technology. Ford, GM, Toyota, DaimlerChrysler and Renault recently joined together as partners in the Automotive Multimedia Interface Consortium, and most of the world's other car makers are expected to sign up shortly. Within the next few years, the consortium will issue standards for both hardware and software (Economist 1998).

Electronic road pricing is seen as playing a key role in traffic demand management in the future. Automated tolling equipment deducting charges from electronically tagged vehicles is being installed in more than 20 countries around the world. Over the longer term, this technology could be replaced by using global positioning satellites, combined with in-car receivers and digital maps. This would enable vehicles to be charged wherever they are within a specific geographic area and at rates that vary according to time of day and degree of congestion.

Intelligent vehicle-highway systems (IVHS) technologies include advanced traffic sensing and signal control technologies to improve traffic flow, (ATM or advanced traffic management) as well as on-board systems to help drivers interpret highway system data to reduce travel time (ATI or advanced traveller information) and improve safety (AVC or automated vehicle control). AVC technologies are in development which move beyond such facilities as adaptive cruise control, obstacle detection and infrared sensing to improve safety for night driving. The new technologies will intervene directly in driving. They include automatic braking and manoeuvring.

A further application of electronic technologies in urban transport relates specifically to air pollution minimisation strategies. The provision of on-board diagnostics indicating the effectiveness of emission control systems is one technology being pursued. Another method being trialed in California involves identifying polluting vehicles by means of an infrared beam across the tail pipes of passing cars (Jolley 1999).

Information technologies are also being utilised in public transport systems. Applications include automated people movers on light rail systems, transmission-based signalling, and advanced passenger information systems.

The electronic content of military and civil aircraft, already sizeable, will continue to grow over the next five years and beyond. The Electronics Industries Association of the United States (EIA) estimates that for military aircraft, the avionics share of total procurement cost is expected to increase from the current 39 per cent to 42 per cent by 2002. The share of research, development, test and evaluation expenditures made up by electronics is expected to increase even faster – from 39 per cent to 45 per cent. It is more difficult to quantify past and prospective shares with respect to commercial transports, but it is clear that the amount of electronics in civil aircraft is increasing. The EIA attributes the avionics share of the total factory sales of complete military and commercial aircraft to avionics as being nearly 25 per cent (Nordwall 1997).

An important component of the growth in expected demand for avionics is likely to be that of cockpit refits as older aircraft are upgraded to incorporate the benefits of integrated systems. New flight management systems, compatible with the future air navigation environment, are becoming available that are based on standardised parts and can therefore cover a very wide range of aircraft. The systems enable aircraft to fly closer to the most economic flight profile, and provide a capability for changing the software on board an aircraft so that upgrades are easily effected. A further area of development is totally integrated hazard avoidance systems.

Even more important as a source of future demand will be advances in global communication. These will necessitate upgrades in communications, navigation and air traffic management and surveillance utilising satellite communications and global positioning system (GPS) capabilities. The emphasis will switch from navigation aids on the ground to a comprehensive navigation, surveillance and air traffic management system in which decision-making is shared by pilots, controllers and airline operations centres. There will also be an improved capability to operate safely in difficult weather conditions.

The third significant, and arguably most important, component of future demand will be the passenger compartment. Entertainment and distribution systems have grown by periodically adding individual components. Honeywell, working with Airbus, is examining ways of integrating the ‘back of the bus’ to encompass control of aircraft systems, such as hydraulics, air-conditioning systems and toilets, with entertainment and communication systems. The passenger compartment is expected to change more often than the cockpit, implying regular passenger compartment upgrades. Avionics integrators are moving to develop closer relationships with inflight entertainment suppliers Rockwell Collins purchased Hughes-Aviocom International in December 1997, Honeywell formed a strategic alliance with Matsushita Avionics Systems in September 1998, and Sextant Avionique announced plans to purchase a majority interest in the B/E Aerospace inflight entertainment business in January 1999. Finally, the cycle of obsolescence in the world of electronics is forcing the continual redesign of avionics systems as individual components are continually being replaced (Velocci 1999).

Defence contractors have developed several new avionics technologies that could have significant civil applications. They include direct voice input (this enables a pilot to interact fully with an aircraft using a two-way voice activation system) and integrated helmet-mounted wide-angle head-up displays (Gardner 1999b).

Auxiliary Equipment

The increasing need to improve fuel efficiency is leading to a redesign of many of the auxiliary features of motor vehicles (Jolley 1999), including:

- the extensive use of aluminium and other light-weight materials in suspension and other components, including brake fittings, sway bars and wheels;
- major redesign of seats, bumpers and other components to reduce weight;
- high-pressure, low-rolling resistance tyres; and
- advanced transmissions (continuously variable automatic).

In some cases, earlier development in the aerospace sector may have relevance to emerging trends in auxiliary vehicle technology, particularly in terms of internal fittings.

Technological advances in new rail systems include improved tracks, ultra-fast trains, new suspension systems for trains, and pressurised carriages.

Design and Manufacturing Technologies

In the motor vehicle industry, computer-aided design and engineering is reducing the lag between new concepts and their introduction into production. Product reliability has been significantly increased as a result of improvements in manufacturing systems. The Japanese motor vehicle industry has been a leader in these areas, but an influential project called the International Motor Vehicle program, and run by the Massachusetts Institute of Technology (MIT) helped the

US industry to identify best practices and improve affordability and quality. Noteworthy also is the increasing importance of aerodynamic styling in motor vehicles. Key features are enhanced streamlining, using sophisticated body design and reduced frontal areas, aimed at reducing the vehicle's drag coefficient.

While the aerospace industry, by its very nature, has vast experience in aerodynamic design technologies, it has lagged considerably behind the motor vehicle industry in terms of manufacturing technologies. All this is now changing. At the design end, computer-aided design and manufacturing is to be taken further through the use of virtual prototyping in design, support, fabrication, production and assembly of new aircraft. Managers will be able to assess the operational effects and life-cost ramifications of the smallest changes in components. In manufacturing, newly designed machine tools are allowing greater automation in aerospace manufacturing processes and the better handling of composites. Boeing is developing a lean manufacturing system that closely follows the manufacturing techniques pioneered by Toyota in Japan. These include production 'pulled' by demand, quick correction of manufacturing problems and eliminating waste (Jolley 1999).

The shrinkage of defence budgets in the first half of the 1990s forced defence contractors to lower costs and improve service delivery. The greater attention paid to economic efficiency in defence procurement is encouraging increased outsourcing by primary suppliers. The Lean Aircraft Initiative (LAI) is a US Air Force-sponsored project charged with uncovering, quantifying and disseminating manufacturing and managerial practices that could dramatically improve the affordability of US military aircraft. LAI project members include 17 US airframe, engine and avionics manufacturers, the US Air Force, two labour unions, and MIT. MIT collects and collates all data, and presents it to the LAI's participants in such a way that it masks the origin of the information and disconnects it from a specific company. The LAI has its roots in MIT's International Motor Vehicle program (Kandebo 1996).

The Internet is now facilitating new and highly constructive relationships between manufacturers and their suppliers. Supply chain software programs are facilitating huge efficiencies in the overall manufacturing process. General Electric has developed a web-based link to its suppliers that enables them easily and quickly to make bids for GE components contracts. The system has cut procurement cycles in half, processing costs by a third and the cost of goods purchased by between 5 and 50 per cent. Chrysler has pooled more than 25,000 ideas for cost-cutting measures from its suppliers. It estimates savings of US$3.7 billion when all the schemes are fully implemented. Ford has deployed Internet applications to parts required by dealers and after-market parts distributors. It is also developing a series of web-based applications that it hopes will make the purchase of a car more personalised (Economist 1999).

Maintenance and Repair

The maintenance, repair and overhaul business (MRO) has always been an important part of the civil aerospace sector because of the importance of safety standards and the need to keep aircraft in near-to-perfect working order. A number of important new trends are emerging so far as MRO technologies are concerned. Product support systems covering the total life cycle are being developed by original equipment manufacturers of airframes, engines and avionics. Information technologies are beginning to be used in the MRO business, particularly with respect to diagnostics.

The civil aerospace industry has developed a set of procedures for dealing with ageing aircraft. Boeing’s current program covering ageing aircraft (Smith 1996) includes:

- a service bulletin modification program which mandates modifications be made to structure before the aircraft can be flown past a number of flights;
- corrosion prevention and control program required for inspections and some maintenance procedures;
- repair assessment program which requires airlines to monitor some old repairs made to structure to assess repair quality;
- review of supplemental inspection programs for special inspections of safety-critical structural parts even though there is no record of problems in that area;
- a widespread fatigue damage assessment program is under way at Boeing in an attempt to better understand that type of damage and, in particular, how it is influenced by corrosion; and
- an increase in purchases of old aircraft which are brought to the company facilities for testing and tear-down inspections.

In the defence sector, a key advance has been in the area of on-board diagnostics. New systems of on-board diagnostics have been developed that continually monitor a huge range of parameters relating to engines, airframe and auxiliary equipment. The system can search out abnormalities that might indicate impending failures or long-term fatigue and wear problems.

New technologies have an important role to play in enabling improvements in the maintenance of road vehicles. On-board diagnostic systems monitor all the emission controls on a vehicle and warn the driver, through instrument panel displays, of any faults that may occur. These systems have become mandatory for new passenger motor vehicles in the United States. Even greater opportunities for detecting malfunctioning vehicles is provided by the use of transponders to allow roadside units to monitor the condition of vehicles as they drive by. Within 20 years, these systems could be installed in sufficient numbers to render inspection and maintenance programs unnecessary (Jolley 1999).

While diesel exhaust emissions pose considerable health threats, programs to identify and rectify high polluting diesel-powered vehicles are still constrained by the lack of a simple, low cost test to identify these vehicles. There is intense interest in the United States, Australia and parts of Asia in developing appropriate testing technologies (AATSE 1997).

Safety

The largest external cost borne by individuals associated with transportation is the cost of injury and death caused by traffic accidents. Safety is becoming a key issue for both future vehicle design and innovation in transport infrastructure. Improvement in vehicle manufacturing systems is leading to increased product reliability. The prominence given to information on vehicle safety by motoring organisations is influencing consumer choice and providing a stimulus for an increased focus on vehicle safety in design processes.

But it is in the aerospace sector that the major developments have been made in harnessing technology to secure safety goals. Between 1965 and 1995 there was an eightfold increase in commercial flights, but accident rates per million departures dropped from close to 20 to around 2 for US operators, with a slightly less rapid decrease for non-US operators (Shifrin 1996). Major advances have occurred in aircraft design, aeromaintenance, air traffic control, the collection and utilisation of accident data to improve safety, and pilot training. Yet the industry remains focused on achieving further significant reductions in accident rates. The high growth rate predicted for future air travel makes this imperative.

The future agenda for air safety includes the following programs.

1. Research on the causes of flight crew fatigue, aimed at practical recommendations on workload reorganisation and fatigue-reducing methods before and after duty-time (Sparaco 1996).
2. The development of data exchanges on reported problems with flight management systems, covering aircraft and engines, equipment and airports (Ott 1996).
3. The use of new flight data and cockpit voice recorders, equipped with solid-state memory, which have a much greater chance of surviving trauma than tape systems (Hughes 1996).
4. The introduction of cockpit video recorders, expected to be of considerable use for accident investigation and safety training (Dornham 1996).
5. The shift in air traffic management from ground-based air traffic control to pilot/controller ongoing interaction in comprehensive air traffic management, which involves initially wide area augmentation systems and, perhaps, eventually continuous tracking (the so-called global automatic dependent surveillance systems), utilising yet-to-be launched GPS (Global Positioning System satellites) and satellite navigation (Ott 1998).
6. The crafting of new tools by weather researchers in collaboration with airlines for forecasting, detecting and avoiding turbulence (a growing use of routine airline flights to collect volumes of data on turbulence fields in real-time, improving on-board sensors and systems to detect turbulence, improved training of pilots and greater support for weather researchers) (McKenna 1998).
7. Studies being undertaken of a ‘smart alerting’ function which would coordinate and enhance cockpit safety system alerts, particularly in relation to impending collisions.
8. To address the problem of ‘controlled flight into terrain’ (CFIT), an advanced ground collision avoidance system has been developed by the US Air Force

which is applicable to both fighters and transports and is to be used in civil applications (it should improve upon existing ground proximity warning systems, which have had a dramatic effect in reducing CFIT over the past twenty years) (Gardner 1999a).

9. A NASA/FAA program looking at safety and efficiency including wind shear detection, aircraft ageing and aircraft icing.
10. The major new NASA research program, the Advanced General Aviation Transport Experiments (AGATE) aimed at improving safety in general aviation through safer design (including internal as well as exterior), avoidance of weather-induced accidents, developing low-cost multi-function displays, innovative teaching to reduce the cost of training, new systems to reduce pilot workload (Anselmo 1998).
11. Improving standards for the operation of older aircraft, including required modifications, corrosion prevention and control, and assessment of old repairs.
12. Research on improved technologies that can be utilised in the inspection of ageing aircraft (Smith 1996).

Technological Synergies

The nature of the technologies employed, and the intensive R&D that lies behind them, makes aerospace close to the most technology-intensive of all manufacturing industries. Of crucial importance are the spillover effects associated with the utilisation of these technologies. The synergies between civil and military aerospace are well-known, and are currently expected to increase (Scott 1999). The technological linkages between aerospace and shipbuilding, less well-known hitherto in Australia (although well-appreciated in countries like Japan and Russia), are becoming increasingly important with the developing similarities between airframe, hull design and construction, and the extensive use of electronics.

In the longer run, given the increasing importance of new materials technology, aerodynamic styling and on-board electronics, these linkages could extend across the whole transport equipment sector, including motor vehicles. These technological interdependencies rest on the delivery of key technologies which are capable of transforming production in a range of industries – advanced materials (which have significance for aerospace, motor vehicles, shipbuilding, other transport equipment, and building and construction), embedded information and communications technologies (aerospace, motor vehicles, shipbuilding, other transport equipment and transport system infrastructure), and aerodynamic design. Innovation in its broader sense also implies spillovers across the whole transport equipment and transport systems with respect to life-cycle design and manufacturing systems, maintenance and repair systems, and the development of a comprehensive approach to safety.

Defence contracts can provide a spur to technology in civil aerospace as well as other transport and engineering industries with respect to materials, electronics and on-board diagnostics. Civil aerospace, in turn, provides a lead to the defence sector with respect to computer-aided design and virtual prototyping, life-cycle planning, maintenance and repair, and developments in air safety. The motor vehicle industry is a leader in lean manufacturing, but the new technological challenges it faces could eventually put it in the position of influencing industries like aerospace in particular technologies.

Finally, primary defence contractors, civil aerospace suppliers and motor vehicle producers depend on sub-contractors and suppliers of cast and forged metal products, repetition engineers, heavy engineers, and electronic sub-components. There is a two-way relationship here. The depth of the supply chain underpins the flexibility and capabilities of the major manufacturers. On the other hand, the major manufacturers often provide an important conduit for technology and productive efficiency to their sub-contractors. Technologies can also move in the other direction. In civil aerospace manufacturing, the integrators of the finished aircraft are shifting many aspects of design and R&D towards primary risk-sharing contractors. In the manufacture of aero-engines, new developments are taking place through the agency of complex international consortia.

There are economies of scope across a range of technologically advanced heavy engineering industries. The key aspect is systems integration, which requires state-of-the-art project management skills. In Japan, heavy engineering conglomerates have exploited these economies across aerospace, shipbuilding and civil engineering projects. In the United States the economies are exploited across civil and military aerospace and other defence projects. The motor vehicle industry has traditionally been more self-contained. US automobile producers have tended to shed peripheral interests over the past decade, although European companies such as DaimlerChrysler, BMW and Fiat still cover a wide range of interests. However, the new technologies being developed in the industry are leading to new associations between vehicle producers and innovative engineering companies.

The Pattern of Innovation

Studies by Pavitt (1994) indicate that five broad groups of industries appear to have qualitatively different patterns of innovation. Two of these groups are relevant to the present study.

The first is termed ‘scale-intensive industries’. Firms are involved in both product and process innovation. They are generally large and are usually involved in high volume production –often involving complex products that require efficient organisation of a complex production system. Firms are sometimes vertically integrated so that they manufacture their own processing equipment, they may also control their own distribution networks. Research and development and other innovation may be highly formalised in large laboratories. Industries in this category may include, among others, the automotive industry.

A second category is that of the ‘science-based industries’. These industries are generally based on radical innovation linked to scientific advances. Research and development expenditures are considerable and undertaken within substantial laboratories. The innovative products are usually capital or intermediate inputs to other industries. Firms in these industries are normally large, but the science-based group also includes a number of small high technology ‘start-up’ firms. The electronics industry is part of this group of industries.

Some industries appear to share the characteristics of more than one group. Dosi (1988) suggests that aerospace and some other defence-related industries have many of the characteristics of science-based industries, but also have much in common with scale-intensive industries. The previous analysis suggests that the automotive industry is now shifting towards a hybrid science-based and scale-intensive innovation pattern.

Towards a National Engineering Innovation System

The impetus to innovation across a wide range of engineering-related industries is coming as a result of pressures for more sustainable transportation and from the strategic needs of the defence sector. A wide range of new technologies and systems innovations are being developed. The potential for technological synergies exists across a wide range of industries. In order to deepen our understanding of this situation, it is worthwhile considering recent developments in the economic analysis of innovation.

The Economic Analysis of Innovation

The development of economic analysis of innovation and evolutionary innovation systems – the so-called systemic economics – has highlighted the pervasiveness of market imperfections in the current global economy. Imperfect knowledge, ‘bounded’ rationality,[1] transaction costs, substantial variations in power, and competence among economic agents are among the characteristics of economic systems that are at odds with the assumptions of the neoclassical paradigm (Bryant and Wells 1998).

Innovation stems from an ability to produce, incorporate and apply a wide range of knowledge. This knowledge can be gained from fundamental research, but is also acquired from engineering know-how, employees’ experience and ‘institutional’ knowledge. Unlike the results of universal scientific research, many of these knowledge bases are not public goods – they represent ‘tacit knowledge’. This tacit knowledge is not codified, is barely transferable and is embedded in people, organisations and structures. It is a vital component of the innovation process because it determines the level of individual acquisition options from the overall knowledge base (Hofer and Polt 1998).[2]

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[1] Fransman makes the following comment:

> … the field of vision of for-profit corporations is determined largely by their existing activities in factor and product markets, in production and in R&D and by their need in the short and medium term to generate satisfactory profits. The resulting bounded vision implies that new technologies emerging from neighbouring areas where the corporation does not have current activities are likely to take some time to penetrate the corporation’s field of vision … The need to generate satisfactory profits in the short to medium term therefore bounds the vision of the corporation, contributing in some cases to a degree of “short-sightedness”. One example is the creation of technologies for “the day after tomorrow” where the degree of commercial uncertainty is frequently great. In view of their bounded vision, corporations often tend to under-invest in the creation of such technology. (1990, p. 3)

[2] Tacit knowledge is embodied in people – the skills of engineers, R&D staff, workers and managers. Any firm-level strategy for the development of knowledge will, in a sense, be part of an employment strategy. Kline and Rosenberg (1986) emphasise the bounded and relatively limited character of firm-based knowledge means that firms seek to innovate on the basis of cumulatively-developed knowledge which they already possess: they seek to learn on the trajectory they are familiar with.

Within a firm, successful innovation results from multi-directional feedbacks between the various forms of competence and skill on which a business is based – marketing, finance and product and process development. Innovation is a process of interactive knowledge creation in which marketing skills are used to channel information about user needs into the development processes which shape the technical and performance attributes of products (Smith 1998).

Systemic economics suggests that there are substantially more types of spillover benefits than are readily identified in neoclassical theory. Lipsey and Carlaw (1998) identify four kinds of spillovers that create opportunities for useful policy interventions, and pitfalls for policies that ignore them. These four categories comprise:

- improvements to the efficiency of one technology that may be usefully applied to many other technologies in ways that cannot be appropriated by the initiators;
- the impact of changes to technology on surrounding structures (for example, the value of existing technologies, locations, skills and firms);
- changes in one element of the productive structure occasioned by changing technology, for example physical capital, may require changes in elements like human capital, location, organisation; and
- experience in the use of new and imperfect technologies generates non-appropriable new knowledge, which benefits producers and future users by assisting in product improvement.

Most economic analyses of macroeconomic change agree that long-run economic growth depends on innovation. It is a characteristic of evolutionary economics that it stresses the institutional bases of innovation. It argues that:

- the activities of firms are of much more importance than of individuals in determining innovation;
- the commercial competitiveness of firms is dependent in large part on both technological and organisational inventiveness; and
- a reduction in transactions costs through effective linkages between firms and also with other organisations is of critical importance in developing efficient innovation systems (Bryant and Wells 1998).

From the perspective of evolutionary economics, innovation policy should be based on four principles:

- policy should be process-oriented, aiming to encourage linkages that lower transactions costs and facilitate access to skills and knowledge bases so as to enhance diffusion;
- policies should seek to influence expectations, as this can assist in building social consensus and in disseminating new technologies;
- policy should particularly support and encourage experimental behaviour, focusing attention on innovation and knowledge as the bases of competition and encouraging the development of 'learning' organisations; and
- both variety and competition should be maintained, the first to provide novelty and allow for uncertainties, the second as the incentive to innovate (Bryant and Wells 1998; Hofer and Polt 1998).

Encouragement to the Development of a National Engineering Innovation System

Contemporary developments in the theory of innovation point to the potential interconnectedness between enterprises that can form the basis of substantial economic change. They also emphasise the scope for policy intervention to realise gains from technology spillovers. Innovation systems can be the key driver for future economic development.

The empirical analysis of new technologies in engineering industries presented in the early part of this paper emphasises the substantial innovations in both product and process technologies occurring internationally across industries such as motor vehicles, civil aerospace, defence equipment, shipbuilding and industrial electronics embedded in transport equipment, defence equipment and transport systems. The potential for very substantial technological spillovers across all of these industries exists. Yet the firm-based knowledge vital to driving such innovation is bounded, and this paper stresses that substantial improvements in the efficiency of the innovation process could be created by forging new networks across the whole range of these industries.

Australian Capacities for Innovation

The analysis of future technological possibilities in the engineering industries essentially referred to international developments. Substantial possibilities exist for Australian industries to contribute to this process. This is exemplified by developments in such industries as motor vehicles, aerospace, defence equipment and shipbuilding. These developments are being encouraged by the strong level of demand associated with upgrading Australia's defence technology, the need for reforms in our transportation systems, and strategic international linkages between Australian companies and leading international companies. Some specific examples of the role played by enterprises in Australia in developing new technologies are outlined below.

The motor vehicle components industry and the hybrid car

The Australian-developed concept car, aXcess australia, a collaborative venture of 130 Australian component manufacturers and designers along with the CSIRO, to show off the work of the Australian car components industry, has been on a world tour of motoring shows. While the car will not go into commercial production, its componentry is on sale. The first buyer is Hyundai, which has awarded a Victorian company, VDO, a five-year contract to build the dash instrumentation for its next Lantra (McKay 1999).

The next generation aXcess car, being designed at present, aims to demonstrate that the Australian industry has some novel ideas to solve the problems of pollution and greenhouse gas emissions. It will be a series hybrid vehicle, in which an internal combustion engine drives a generator which powers an electric motor which, in turn, powers the wheels. The petrol engine, a radical Australian innovation known as a scotch yoke or SYTech engine, is designed to run at a relatively constant speed, reducing fuel consumption and emissions. CSIRO inventions will provide the generator and a ware-cooled electric motor as well as a supercapacitor and lightweight gel battery (Strong 1999).

Innovation in the aerospace industry

ASTA Components, located in Fisherman's Bend, Melbourne, has been producing the largest single skin sheet composite structure ever subcontracted for Boeing's 777 aircraft since 1993. ASTA was involved in the design of the component through the secondment of engineers to Boeing's Seattle design office, which was a critical component in the success of the program. The rudder is 12m in length and 4m wide (including the separate tab structure). A new feature of the design is the integration of the leading edge with the skin. Several innovative manufacturing processes were developed by ASTA including computer theodolite alignment of the assembly jigs (eliminating the need for master tooling), and special lifting and moving techniques to move the large skin sheets from bond shop to assembly shop. ASTA are the sole source for the 777 rudder, and have delivered 200 shipsets since the beginning of the program.

Hawker de Havilland performs design, manufacture, testing and certification support work on civil and military aircraft. An example is the design, testing and manufacture of the composite wing flaps for the new model Lockheed C-130J Hercules transport. The outboard flap is 8.4m by 1.2m, and the centre flap is 3.6m by 1.4m. The requirements of Lockheed were that the flap be resistant to high cycle fatigue, (operating life of 30,000 cycles or 30 years), be interchangeable with a metallic flap (same bending and torsional stiffness), be weight neutral and meet a February 1996 flight test date. The materials used in the construction of the flaps are carbon fibre laminate inlaid with copper mesh for lightning protection.

British Aerospace Australia is to spend 35 million to establish a new military aircraft systems design facility in Melbourne. The new Military Aircraft Systems facility, which will support activities of the UK parent, British Aerospace, will generate $50 million in exports for Victoria as well as address aircraft system design opportunities in Australia and the region. The investment decision took into account the support received for the venture by the Victorian Government and the opportunities to work with the Aeronautical and Maritime Research Laboratory (Defence Science and Technology Organisation – DSTO) and the Sir Lawrence Wackett Centre (Royal Melbourne Institute of Technology), which specialises in aeronautical design. It is expected that BAe Australia will recruit some 250 new engineers over the next two to three years across the fields of aeronautical. structural, electronic and software engineering. The initial work package for the Military Aircraft Systems Group is to develop a new weapon pylon for the UK's Nimrod Maritime Reconnaissance Aircraft. Other work packages for military aircraft including the Hawk, Eurofighter Typhoon and Tornado are currently being identified.

Adacel Technologies Limited undertakes large-scale contracts for Government and corporate clients, including some of the world's leading defence and telecommunications suppliers. It also develops and markets proprietary software, simulation and computer training products. In February 1998 Adacel Technologies completed an $8.5 million capital raising and public listing. Adacel has developed OSPREY – an integrated air traffic management system for oceanic and remote areas that uses highly-reliable VHF and satellite data linking to optimise airspace management and safety. OSPREY accurately depicts the air traffic pattern beyond radar coverage. The system also supports direct datalink communications between controller and pilot. In October 1998 Adacel announced that it had acquired the right to use a complementary Air Traffic Management system developed by Canada's CAE Electronics Ltd. Adacel intends to combine the use of the intellectual property developed by CAE with their own Osprey product to produce the world's leading CNS/ATM system. Adacel expects to leverage its defence technology base into commercial markets over the next three years as part of its growth strategy, and is also seeking a presence in Europe, Asia and the US (CSES 1999).

Avionics and defence

Australia has developed significant capabilities in the defence arena with respect to avionics. These capabilities include program management, electronic and software systems integration, adaptation and modification, repair and maintenance, and design. The size of the defence market that underpins these capabilities is considerable.

Tenix was formed when the original Transfield empire was split in December 1996. Tenix has two main subsidiaries in Hawker de Havilland (aerospace) and Tenix Defence Systems, which undertakes naval projects (the ANZAC frigates in Victoria), land systems (including military vehicle assembly in South Australia), and aircraft avionics. The government-owned ADI, a defence business covering everything from battleships to bullets, is to be privatised, and the Australian Government has received final bids for it.

Shipbuilding

In addition to the substantial level of activity in defence shipbuilding, Australia has developed an export-oriented civil shipbuilding industry. It specialises in large aluminium-hulled ferries (particularly catamarans), and small luxury cruisers.

Technology Foresight

Economic theory suggests government policy can play an important role in developing innovation networks. On a global basis, the engineering industries have significant potential for a broad range of interrelated product and process innovations. Australian companies in the engineering sector have some significant capabilities which could be utilised in new product and process innovations. In developing a broader framework for innovations across the Australian engineering sector, there is considerable scope for the technique of technology foresight to play an important role.

The APEC Center for Technology Foresight offers the following definition of technology foresight:

> Foresight involves systematic attempts to look into the future of science, technology, the economy and society, with a view to identifying emerging generic technologies and the underpinning areas of strategic research likely to yield the greatest economic, social and environmental benefit. (1998, p. 4)

Technology foresight is a process, not a technique. It provides opportunities for large numbers of people and organisations to assess the significance of technological possibilities in a range of future scenarios. It can focus on the prompt identification of emerging generic technologies that are still at the pre-competitive stage and encourage their more rapid development. It is a tool for establishing priorities in public R&D, a means of developing a social contract between science and technology on the one hand and government and the people on the other, and it facilitates the development of national systems of innovation. It is also a means of establishing links and exchanges, and creating networks vital to improving both public and private knowledge development and sharing and hence a capacity for innovation.

Technology Foresight and Innovation in Australian Engineering

An indication of how a technology foresight exercise might be applied to the task of developing a national innovation system in Australian engineering is briefly outlined below.

1. The goals of the exercise would be to:
   - focus attention on long-term strategic needs which industries must meet;
   - break down existing boundaries on firms' technological knowledge and encourage broader technological linkages;
   - encourage the development of learning organisations in industry; and
   - sharpen the focus and increase the efficiency of public policies as they impact on industry development.

2. Who should be involved?
   - Industries – motor vehicles and components, civil aerospace, defence equipment, civil shipbuilding, equipment for traffic and transport management, suppliers to these industries (repetition engineering, fabricated metal products, suppliers of advanced materials) and perhaps, other users of advanced materials (consumer durables, construction materials).
   - Government – transport planning and research (sustainable transportation, advanced traffic management techniques, transportation safety), defence procurement needs, industry policy, public R&D planning and resourcing, education and training planning.
   - Relevant researchers from the CSIRO, other public agencies, and the universities.

3. An important task of the exercise would be to develop a vision, shared between the public and private sectors, of future strategic needs that will influence industry and what technology might achieve to further these needs. The

importance of influencing expectations, building consensus, and providing a framework encouraging companies to structure technological search and choice.

4. Exchanges through the foresight process could facilitate the establishment of cross-industry technological linkages, creating the opportunity for new networks and increasing the boundaries of firm-centred technological know-how.

5. The exercise could result in the development of a framework for public policies towards these industries and activities. In particular, it could lead to a:
   - re-evaluation of public R&D priorities and consider new frameworks for public/private cooperation (beyond the existing CRC's);
   - plan of how existing industry programs (R&D Start, Technology Access, Major Investment Project Facilitation, Investment Promotion, the Innovation Investment Fund) can be fine-tuned;
   - assessment of the implications for tertiary education planning and for vocational training and education; and
   - consideration of the implications of defence procurement programs for civil applications, industry exports, and international alliances centering on defence requirements.

6. Over the longer haul, such an exercise might clear the way for developing opportunities for international strategic alliances in the supply of equipment by:
   - leveraging Australian niche advantages in product and process technologies with Asian manufacturers with respect to new technologies for motor vehicles, traffic management and other sustainable transport technologies and defence equipment;
   - encouraging the development of Australian consortia for international tendering based on exploiting new technologies;
   - taking advantage of new opportunities for international sourcing in defence procurement with respect to the US and the UK; and
   - examining the possibility of, and likely benefits from, technological agreements with Russian science and technology in aerospace and other sectors.

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