Idea to impact: A framework for the strategic management of investment in road transport research

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Abstract

Research into transport quality and needs is fundamental to Australia's economic, social and environmental well-being. Transport has been identified by Australia's Chief Scientist's office as one of nine national research priority areas. This paper progresses the development of a model for strategic management of investment in transport research in Australia.

Recent research has suggested that it is very difficult to establish how much the public sector spends on road infrastructure research in Australia. Intuitively, the same problem would apply to transport research generally. This makes it difficult to determine precisely what the return on investment (RoI) is. Without that, prioritisation and management of this extremely important investment becomes difficult. There is therefore a need to develop a model for the strategic management of investment in transport research in Australia.

Some key desirable characteristics of the framework to be established for this purpose are derived. Many of these characteristics are not explicitly dealt with in current transport research management. This paper explores other fields of research and development (R&D) management and assesses their potential against expressed target characteristics.

An allocation matrix based on the analysis, and guidance to practitioners on using this matrix to allocate research, development and implementation (R,D&I) funding is also presented.

1   Introduction

The purpose of the paper is to explore the feasibility of managing the investment in research related activities in Australia in a strategic sense. It is intended as a means of starting discussion, rather than a finalised proposal for an accepted investment framework. As such it uses a selection of concepts that have been explored locally and internationally, while accepting that before a framework can be agreed, a more rigorous analysis is required.

Increasing emphasis is being placed on demonstrating that public spending on transport is delivering value for money. Expenditure on R&D is not and should not be exempt, but articulation of the full spectrum of the benefits of transport research is difficult because of the qualitative nature of some of these benefits (Shackleton 2013).

A framework for the management of the investment in R&D is needed, if the costs and benefits of this R&D are to be compared with other expenditure and benefits. This paper focuses primarily on the scope of activities addressed by such a framework, and the allocation of resources within the framework. It does not address the establishment of

programs to assess the actual realised benefits of the investment, other than to recognise that this activity is needed, and should be considered in any framework.

The paper commences by examining how benefit accrues from research, and the views of road agency executives on what is needed in order for the benefits to accrue. Using this information, some key characteristics of the management framework which current research funders believe are needed in order for it to be successful are identified.

The paper then evaluates R&D management approaches from both a high technology, public sector organisation and the commercially-focused private sector.

A framework is then proposed which meets the expressed requirement of funders and which forms the basis for progressing discussion on how best to manage the investment in research-related activities in a strategic manner.

2 The state of the art of public sector research management and evaluation

2.1 How research delivers value

A series of interviews with senior road agency personnel, described in detail by Shackleton and Young (2008, 2010), explored how road agencies value the research that they commission. The interviews were analysed against the simplified research process shown in Figure 1.

Figure 1: Generalised, simplified research activity model (Shackleton 2013)
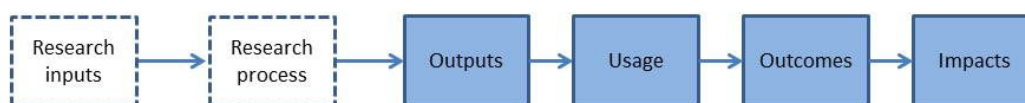
The first box represents the planning and inputs to the project, while the second represents the conduct of the project itself. Beyond that point there are artefacts and activities which can be valued or add value:

- research outputs 'are the primary means of communicating the results of academic enquiry' University of Queensland's library service (2012)
- research usage is what it says – the utilisation of outputs to some other end or purpose. In academia, this could be input to a further project or enquiry. In the private sector it would be the development of a product or service for commercial purposes. In common language 'usage' is interchangeable with 'development'.
- research outcomes are the product of research usage (CMGCR 2005)
- research impacts are the benefits of using research outcomes (Allen Consulting Group 2005) or the influence which the research exerts through the resulting outcomes (Davies, Nutley and Walter 2005; Molas-Gallart et al. 1999), or the 'payback' (Buxton and Hanney 1995).

The overriding finding (Shackleton 2013) from these interviews was that, unless the research ends up in an instrument i.e. a research outcome, most typically a guide to good practice, a standard or a policy statement) which can be implemented and lead to change (impact), then funders would find it difficult to attach much value to their investment. Therefore, the conclusion drawn from the study was that research, while necessary for change, is not sufficient for benefit, and funders and providers aiming to derive benefit from the investment

must adopt a mindset of 'research and development' (i.e. research and usage to create outcomes).

Logically, though, it follows that if the outcomes are not adopted and implemented, then there can be no impact (be it economic, level-of-service or some other form of qualitative gain). Risk aversion is believed to be a major barrier to the adoption of 'new' practices in the USA. To this end, the FHWA now makes available implementation support funding to early adopters of Strategic Highway Research Program 2 (SHRP 2) products, which allows some off-setting of the financial risks involved. Thus, while Shackleton (2013) found that R must be accompanied by D if funders are to value research, research can only deliver benefit if R & D is accompanied by I (Implementation). The existing ad-hoc process of transport research funding allocation and evaluation of its outcomes in Australia is unlikely to achieve this outcome.

2.2   Other findings

Two other findings from the study described above are relevant to a discussion on managing the investment:

- scope of research-related activities
- quantum and sources of funding

2.2.1   *Scope of research-related activities*

From the interviews with road agencies on how they valued research, it was apparent that they had an appreciation for a spectrum of research activities. The main categories discussed were applied research, basic research and blue-sky research (Shackleton 2013).

Whilst these were not defined, it was intimated that the certainty of a usable outcome rated highest with 'applied' research but lowest in 'blue-sky' research. However, it was clear that there was no desire to choose one over another in terms of funding, rather to find the right balance. The conclusion was, therefore, that a portfolio approach to investing in research was necessary.

A further important finding was that agency staff considered that 'success' in implementation and creating benefit also depended on not just taking research up into implementable outcomes, but also – in their terminology – embedding the outcomes within agencies and their agents. Effectively, they were indicating that knowledge transfer, or training, was an essential part of the research-related spectrum of activities.

2.2.2   *Quantum and sources of funding*

As part of the investigation, Shackleton (2013) also explored the quantum of funding made available for road infrastructure research. It was found that, apart from well-established and documented programs such as the Austroads program, Western Australia's WAPARC and Queensland's NACOE, funding was generally fragmented. Within agencies, the absence of a definition of 'research' as opposed to consulting services, advisory services and similar activities created a situation in which it became very difficult to understand and agree on how much was being invested in research activities.

Compounding this was the finding that, within the agencies, there was a considerable number of 'innovators' who tried new materials, methods, etc. at a localised project level, but did not place their findings in the hands of anyone outside of the project team or local office. Essentially, agencies were conducting highly relevant and applied research without identifying the activity as such.

Shackleton (2013) also analysed sources of funding outside of road and transport related government departments, and concluded that those departments were funding in excess of 95% of road infrastructure related research. Therefore, it is reasonable that a framework which manages road and transport agencies' investment is managing the majority of national investment, and that there is little need to consider additional requirements for the framework.

3   Requirements of a management framework

Presently, the state of the art in terms of the assessment of the return on investment (whether quantitative or qualitative) in Australia can be summarised as follows:

- research on its own is insufficient to create a return on investment, and it must be managed as part of a range of activities that includes the development of outcomes, and embedding those outcomes within the agencies and their agents
- a portfolio approach to the funding of research-related activities is needed, since the choice is not one type of research over another, but the balance between them
- funding of research-related activities is fragmented, which makes it hard to determine return on investment (RoI)
- lack of a common understanding of definitions of various research activities is compounding a lack of understanding of investment levels
- as agencies are providing the vast majority of funding, it is their prerogative to define the investment management process

Ideally, then, agencies would welcome assistance in the management of their investment, specifically, a process which:

- considers the full spectrum, from idea to impact, and better defines the different types of activities
- provides guidance on relative investment in the various types of activity
- acts as a means of defragmenting research resourcing, if not physically, then in a virtual sense, for management purposes.

Sections 4 and 5 explore the potential offered in other fields of R&D management to assist with the establishment of a framework which has these characteristics.

4   Describing the RD&I spectrum

Recognition that a spectrum of activities is needed (and by implication need funding) is a helpful start. From a management perspective however, the definitions of each phase vary and subjective in nature and therefore harder to apply (OECD 2002, Miller and Salkind 2002, Roussel, Saad and Erikson 1991, Jooste, Sadzik and Sampson 2005, Bell 2005, Grinnell and Unrau 1988).

4.1   NASA descriptors

The National Aeronautical and Space Administration (NASA 2015), developed nine Technology Readiness Levels (TRLs) to describe the endpoints of various activities needed to implement new technologies in their program, which are shown in Table 1. In the USA, a variation of these has been embraced by the Transportation Research Board (TRB) and Federal Highways Administration as a means of tracking the progress of various investments from idea through implementable outcome to actual implementation.

Table 1: NASA Technology readiness level descriptors and activity completion

TRL	Readiness level achieved when:	Meaning (authors' interpretation)	Categorisation of activity
1	Basic principles observed and reported	An observation of some behaviour/ relationship	Proof of concept
2	Technology concept/ and or application formulated	An idea is formed on how that might be used	
3	Analytical and experimental critical function and or characteristic proof of concept	The idea is tested as a concept	
4	Component and/or breadboard validation in laboratory environment	Exploitation of the concept tested in a laboratory	Prototyping
5	Component and/or breadboard validation in relevant environment (ground or space)	Exploitation of the concept tested under simulated/ real environment	
6	System/subsystem model or prototype demonstration in relevant environment	Testing interaction between new technology and existing ones	
7	System prototype demonstration in a space environment	Prototype tested under operational conditions	In service testing and adoption
8	Actual system completed and "flight qualified" through test and demonstration	Prototype refined, productised and used in a pilot mission	
9	Actual system "flight proven" through successful mission operations	Technology is deployed operationally; is standard practice	

From these descriptors it is clear that these milestones are applicable for 'single purpose, single environment' technologies – i.e. once it is proven to work (in space) it is deemed to be fit-for-purpose. However, in transport something that works in one environment may not work in another because of, for example:

- environmental conditions – a material that works well in arid conditions will not necessarily do so under tropical conditions
- legislative – a policy that suffices in one jurisdiction may contravene or conflict with laws in another
- natural resources – road standards suitable for 'farm to market' or commuter operations may not be suitable for the bulk haulage of mining, forestry or agricultural products.

4.2 Adaptation of NASA's descriptors to transport-related R&D

In order to adopt the NASA TRLs for transport-related R&D, the FHWA set out to redefine these levels. There appears to have been little formal progress in this regard, but the concept of using TRLs to describe the maturity of new concepts and technologies is becoming part of conversations at the Strategic Highways Research Program (SHRP2) in the USA and at the Forum of European Highway Research Laboratories (FEHRL).

Because of the relevance of the concept to the research work described in Section 2, the authors asked a small number of experts for their views on how best to adapt the NASA TRL descriptors to transport-related R&D activities.

The descriptors they arrived at are shown in Table 2.

Table 2: NASA's Technology readiness level descriptors adapted to transportation

Phase	Research question	TRL	Likely activity completed	Targeted achievement	NASA phase
Feasibility research	Can the potential practical and technical value of the idea be confirmed through review/ test?'	0	Scanning	Lists of potential solutions/ ideas	No equivalent
		1	Short literature review/desk-top study	Candidate option(s)	Proof of concept
		2	Empirical test	Single example of beneficial use	
Basic	What is the range of conditions for the applicability and benefits of the idea?	3	Review of feasibility/ extension of lit. review	Understanding of potential limitations and mechanisms that create benefit/value	
		4	Development of testing programs & protocols	Understanding of key performance characteristics and how to measure them	Prototyping
		5	Ad-hoc laboratory and/ or field trials	Additional instances of beneficial use	
Applied	What is the demonstrated range of applicability and benefit?	6	Comprehensive trial program/pilot implementation	Comprehensive understanding of likely successful outcomes	
		7	Implementation protocols	Understanding of how best to deploy/ implement to optimise benefit	In service testing and adoption
Codification, training & support	Do practitioners have the means to implement the innovation?	8	Guidelines, specifications, software tools	Transferrable, implementable knowledge	
		9	Training, KT and early adopter support	Trained practitioners, armed with best available knowledge	
Deployment assessment	Is practice following predicted service?	9+	Routine implementation	Benefits of innovation; validation of innovation, or need for modification	taken as read

Points of difference with the NASA approach are:

1. Emphasis on the need to train practitioners in using new ideas and technologies, and the inclusion of 'routine implementation' – being the ultimate objective – at the end of this innovation chain. This stemmed directly from the findings of the study cited above, and is recognition that in transportation the number of end users is very large. On the other hand, the NASA TRL would suggest that the use is confined within the agency itself and training has perhaps evolved as the new subsystem developed.

2. In the middle levels (prototyping), NASA focuses on making sure the technology works under the single set of circumstances under which it will need to operate – integration with other parts of the system. With the adapted model for transport, levels 3 to 5 in Table 2 are about understanding under which sets of circumstances the innovation will deliver benefit. Thus, NASA has a single clear objective (system compatibility and functionality) under a single set of circumstances (space), while

transport has a single objective (deliver benefit, albeit qualitative, hard to measure, etc.) under a wide range of potential circumstances.

4.3   Correlation with road agency views

The first need for a framework for managing research investment derived in Section 3, was to consider the full range of activities in the innovation chain as identified by road agencies, and to better define the various sub-types of research activity. The original NASA approach did the latter, but treated some of the latter stage activities implicitly. The modified NASA approach shown in Table 2, does meet the brief, as shown in Table 3.

Table 3: Activities and definitions to meet the stated needs of road agency executives

Phase		Research question/ objective	Targeted achievement
Research activities	Feasibility research	Can the potential practical and technical value of the idea be confirmed through review/ test?'	Single example of beneficial use
	Basic research	What is the range of conditions for the applicability and benefits of the idea?	Additional instances of beneficial use
	Applied research	What is the demonstrated range of applicability and benefit?	Understanding of how best to deploy/implement to optimise benefit
Development/ codification,		Do practitioners have the means to implement the innovation?	Guidelines, standards, packaged information to support implementation
Training & implementation support		Is the innovation implementable?	Trained practitioners, armed with best available knowledge
Deployment assessment		Is the innovation delivering predicted benefits?	Benefits of innovation; validation of innovation, or need for modification

5   Guidance on allocating resources

5.1   Relevance of the private sector to resource allocation

In the private sector, 'research' is overwhelmingly coupled to 'development', i.e. 'research and development (R&D)' in the literature, which gives an indication of the importance of exploitation of the research outputs to the private sector (Roussel, Saad and Erickson 1991). Thus, despite apocryphal claims that public good and private sector R&D are different, because one is for commercial profit, they are in fact very similar terms of the need to see research as necessary, but not sufficient, for innovation.

It is also telling that the same body of literature is nearly silent on why private sector companies conduct R&D. Shackleton (2013) speculates that this is because it is 'taken as read' that R&D is needed to keep developing a product portfolio. Harmantzis and Tanguturi (2005) suggest the following reasons:

- Competition: to gain and sustain a competitive advantage in the product category in which they compete and have competence, and to increase market share
- Innovation and product diversification: to foster innovation and add new products into the existing product portfolios
- Financial: the ultimate goal is to materialise the R&D gains by increasing sales and profits, i.e. satisfy investors.

On the face of it, this looks different to reasons usually proposed for 'public good' R&D. However, on reflection, only the 'competition' motivation is at odds with 'public good'

research. Innovation is needed to allow road agencies to do more with less. Financially, there is a growing realisation that funders need to experience some direct savings from their R&D to make their willingness and ability to invest in R&D sustainable. Research that brings great public benefit (e.g. fuel savings through innovative road surfacings) whilst likely to increase agency costs, may not provide the means of recovering those costs to the agency itself.

The bulk of the literature on private sector R&D analysis is also silent on evaluating the research activity, its outputs and usage. Link (1993) put it succinctly:

> 'Surprisingly, the literature related to evaluation of R&D is sparse….in comparison to….literature on project selection and termination'

As Link points out, most emphasis is on project selection (what to fund and what not) and when to terminate investment, the latter usually happening when what Cooper and Kleinschmidt (1995) term 'technical success' is lacking, i.e. when technical objectives – product performance, etc. – are most forthcoming.

Therefore, R&D management in the private sector is focused on project selection and termination, or portfolio management and extracting maximum benefit from the R&D investment by avoiding development activities that appear to offer lower potential impacts. (Chao and Kavadias 2008; Cooper and Edgett 1997, Cooper, Edgett and Kleinschmidt 1997, 1998 and 2001; Roussel et al. 1991; Sanwal 2007). This portfolio management comprises two phases, resource allocation and portfolio balance checking.

Rust (2010) showed how the situation in 'public good' road infrastructure research was also best served by an investment portfolio approach. Therefore, any framework for the management of transport-related R&D in Australia would benefit from the adoption of private sector practice.

5.2   Private sector methods for allocation of resources within a portfolio

There are a number of methods used by industry when allocating resources to projects or products. These are, in decreasing order of frequency of use (Cooper et al. 2001):

- financial methods, where decisions are made on the envisaged financial returns of an investment in a product
- strategic methods, where the business strategy is used as the basis for allocating resources to areas or programs
- bubble diagrams, which have evolved from the Stars, Cash Cows, Dogs, portfolio analysis model proposed by Day (1977), although these are also very commonly used for balance checking, too.
- scoring models, where products or programs are rated on a numeric scale according to a number of predetermined factors and ranked in terms of total score
- checklists, where a list of success factors or 'deal breakers' is used to determine whether or not a project or program should proceed or should be terminated.

Cooper et al. (2001) analysed the efficacy of these strategies by correlating the use (or otherwise) of these methods to the apparent success of portfolios.

Importantly, they found that the use of financial models did not guarantee that allocation and spending reflected the business's strategies and priorities. However, using business strategies and priorities as the basis for allocating of funding did not impair the financial returns on the portfolio.

In a road infrastructure, 'public good' R&D environment, Rust (2010) found that the strategic drivers of the broader context of road infrastructure – such as national policy, economic climate, and specific transport objectives – must drive R&D investment decision-making for programs to be relevant and of value.

Under this approach, allocation most often takes the form of allocations to 'strategic buckets' (Cooper et al. 1998). The key decision is defining the strategic buckets (Cooper and Edgett 1997). Common means of defining these buckets are:

- strategic goals - management is required to split resources across specified strategic goals
- product lines - resources are split across product lines
- project type - deciding what percentage of resources should be directed to new product developments, maintenance projects, etc.
- familiarity matrix - using the extent to which industry is familiar with a technology (or product) and the extent to which it is known generally, Roberts and Berry (1985) describe this approach in more detail.
- geography - essentially the allocation of resources on the basis of location.

None of these address the expressed need for investment in the different types of research discussed in Section 3. Without the Technology Readiness level (TRL) model described in section 4, this would appear to be a different means of allocating resources. However, with the TRL model acting simply as a road map from idea to impact, it is apparent that investment in, say, a particular product type would encompass investment in every TRL over time (or as many as deemed warranted by the potential benefits of further investment). TRLs, or associated activities, are therefore a secondary basis for allocation, and not the primary basis.

5.3   Methods for checking portfolio balance

Essentially, checking portfolio balance is an oversight mechanism to ensure that decisions made in allocating resources to individual projects have not resulted in an overall imbalance. Having decided on allocations to strategic buckets, successful portfolio managers also check the appropriateness of these allocations with other tools (Cooper et al. 1997). This usually takes place at the project level or, in the case of large R&D investments, at the program and project level.

The basis of this checking is usually associated with risk versus reward assessment. Cooper et al. (1997) indicated that the most commonly used dimensions used are those shown in Table 4. The first of these – risk and reward – is used four times as often as any of the others (Cooper et al. 1997). These results are most often plotted on a graph to display the two dimensions simultaneously.

A key decision – in the private sector – in terms of portfolio balance is the split of resources between developing new products and simply updating existing ones (with new features, for example). An analogy with transport-related research would be deciding whether to invest in developing a new network traffic management platform (through exploiting a new idea or thinking) or to simply 'tweak' the existing one to overcome some identified shortcomings. In TRL terminology, the new platform would be a low TRL (0 or 1), while the 'tweak' would be a 7 or 8 (Development).

Table 4: Commonly used dimensions of bubble diagrams for checking portfolio balance

Dimension	Commentary
Risk v. reward	The objective is to evaluate whether high-risk projects have an associated reward potential (however, the enterprise chooses to define those terms).
Newness v. technical newness	This is a refinement of the above, where the risk is cast in terms of newness and the reward is cast in terms of newness to a particular market
Technical feasibility v. attractiveness	In this case, technical feasibility of a product or technology is used as an indicator of risk.
Strength v. attractiveness	Similar to technical feasibility v. attractiveness, except that the enterprises current are taken as an indicator of risk; a strong position being taken as a lower risk.
Cost v. timing	In this model, the cost of implementing a new technology t is compared to the ability to start generating revenue sooner.

Source: (Cooper et al. 1997)

The risks of getting the balance wrong in the private sector are relevant to transport R&D as well. The balance between exploitation and exploration is driven by the exiting capability of the organisation (Griffin 1997, Nonaka and Takeuchi 1995). Overinvestment in exploitation reduces the organisation's ability to discover opportunities and respond to environmental changes. Over-reliance on exploration results in excessive costs in failed experiments, and in insufficient rewards from successful ones (Greve 2007).

Guidance on deciding on balance is in short supply. However, Chao and Kavadias (2008) have identified two parameters which influence this balance:

- environmental complexity − the extent to which the enterprise's external environment (or market) is complex
- environmental stability − the extent to which the enterprise's environment is stable, or not under any pressure to change.

They point out that, in a complex environment, the performance landscape would have numerous peaks and troughs. As a result, at least some of the portfolio needs to be used to explore the landscape for more fruitful performance peaks.

In an environment which is unstable, but simple, the investment should be directed towards extracting the maximum performance out of existing practice with the reasonable certainty that the investment is unlikely to be sub-optimal.

5.4   Correlation with funder requirements

5.4.1   General observations

As already discussed, the collective agency requirement is for a strategic management framework that provides some guidance on the relative allocation of resources between different types of research and research-related activities Information from the private sector approach to allocation indicates that:

- allocations on the basis of strategic objectives (so-called strategic buckets) offer the best return on investment
- some guidance on the relative balance between buckets and activities is needed
- a portfolio balance check is needed after resource allocations have taken place, with most tools using risk and reward as a basis of assessment.

5.4.2 Defining the strategic investment buckets

What has not emerged from the discussion and assessment is the definition of the 'strategic buckets' into which allocations can be made. Whilst the four phases (feasibility to development) could be regarded as buckets, in classic portfolio management, the individual stages of the R & D process are not the first order of allocation; they are a secondary means of allocation (Shackleton 2013).

Rust (2010) argued that the strategic buckets should be based on strategic needs, and this is reflected in private sector R&D resource allocation. Developing this, Shackleton (2013) argued that the mission statements of Australasian road agencies (as they existed in 2009) revealed three key technical objectives common to all:

- decreasing the structural cost to the infrastructure by making materials and/or pavement structures more resistant to permanent structural change under load
- decreasing the contribution to road crash trauma using improved geometric or spatial design processes
- increasing the ability of the network to overcome its spatial (as opposed to structural) limits to increase productivity.

Since 2009, several agencies have been reorganised or restructured and their mission statements updated. Today, the three common objectives of agencies responsible for road transport are:

- stewardship of a cost-effective infrastructure network
- provision of infrastructure that is safe
- stewardship of a network of infrastructure that optimises the journey experience – in terms of accessibility and reliability – for people and freight.

This suggests that an initial framework for managing the investment in transport research R,D & I would take the form shown in Table 5.

Table 5: High level allocation matrix for an investment framework

Goals	Feasibility	Basic	Applied	Development	Implement-ation support	Assessments
Cost effective infrastructure						
Safe Infrastructure						
Journey accessibility and reliability						

5.4.3 Items relating to balance

Balance between goals
Deciding on the balance between agency goals is subjective and difficult, particularly in terms of the basis for deciding. Even using 'size of problem' commuted to dollars – e.g. $18b for capex and maintenance of the road infrastructure, $27b for the cost of road crashes, $20b for the cost of congestion – ignores the interdependence between objectives. Journeys and safety depend on infrastructure, considering infrastructure without considering safety is poor practice. Austroads has recognised this and gone out of its way to ensure that projects it commissions are not restricted in technical terms to the focus of the Task Force administering the project.

Balance between activities

Balancing funding between the five or six activities is equally fraught. As mentioned earlier, Chao and Kavadias (2008) offered some guidance between the relative balance between the research spectrum and the development activity. Because there is no 'implementation support' in private sector R&D (this is simply routine sales and marketing and warranties) they are silent on two of the activities identified.

However, work in the USA (Transportation Research Board 2009) has indicated that it is prudent to budget approximately twice as much for implementation support and post deployment assessments compared to budgets for R&D alone. This leads to a refinement of the matrix as shown in Table 6.

Table 6: High level investment framework with R&D/post R&D balance

Goals	Feasibility	Basic	Applied	Development	implementation support	Assessments
Cost effective infrastructure				35%		65%
Safe infrastructure						
Journey accessibility and reliability						

'Assessments' would be an ongoing monitoring and feedback program and as such are likely to be a small portion of the 'post-development' activity in terms of investment requirement. Furthermore, if a view was taken that transport (as a whole) was a complex issue, and under great pressure to change, then Chao and Kavadias' work (2008) suggests something along the lines shown in Table 7.

Table 7: Further refinement of an aspirational resource allocation

Goals	Feasibility	Basic	Applied	Development	implementation support	Assessments
Cost effective infrastructure		35%			65%	
Safe infrastructure						
Journey accessibility and reliability	25%			10%	55%	10%

The discussions which led to the concepts incorporated into Table 7 (but not necessarily the allocation shown) show that this framework does meet the stated requirements of agencies in terms of a tool to assist with strategic management of their investment, specifically:

- it describes an appropriate range of activities, from idea to impact
- using the definitions in Tables 2 and 3 (adapting NASA's TRL scale), better definitions of research activities are provided
- it explicitly links strategic objectives and investment allocation, which is known to be a success factor in both private sector and public good R&D
- it provides some guidance on the relative balance between research and development, although it is not fine enough to give guidance on the relative investment in each activity.

It is suggested that the 'portfolio balancing' activity would be the means of assessing allocations between the three research activities, with investors ensuring they are content

with the balance between long-term (feasibility) prospects, immediate prospects (applied) and those in between (basic).

6 Conclusions and next steps

This paper has described an initial study of the feasibility of managing R&D investment in a strategic sense, with a view and stimulating discussion and progression towards an acceptable investment framework. The main findings of the study are as follows:

- funders want a model that covers a spectrum of activities, ranging from proving of concepts (feasibility research) to post-implementation assessments of innovations and the benefits they deliver
- the model needs to make clear distinctions between the different types of research activities in order to have a better understanding of what is spent on research-, development- and implementation-related activities
- the model should assist in supporting a balanced portfolio approach to allocating resources to R,D & I activities in a way which promotes the prospects of successful innovation.

The paper has also shown that:

- the NASA Technology Readiness Level scale, suitably adapted, provides a means of describing the full spectrum of activities as well as definitions of each activity. A more comprehensive study and analysis may yield similar systems of relevance elsewhere.
- private sector R&D resource management, and the analysis thereof by various researchers, provides some useful guidance in terms of allocating resources for optimum returns in transport and other public-good research.

The model described in this paper comprises a matrix of strategic transport objectives and activities in the innovation chain, from feasibility research and post-implementation assessments. Other models may also exist and should be considered in a rigourous framework or model development ; for instance the CSIR method (Rust 2010) is based on investment in capabilities and technology platforms.

Partial guidance on the balance between various zones of this matrix is available. However, in order to progress the development of this framework it will be necessary to:

- agree on the basic dimensions of the framework
- agree, at a national level, on the definitions of the 'strategic buckets' in terms of strategic transport objectives, or another criterion if a better one is found to exist
- determine the relative balance of investment between these categories
- establish the current investment in these activities as a baseline
- determine whether or not the current balance is appropriate and, if not, what distribution would better meet strategic needs.

Australia is in need of a methodology for allocating research funding in transport to achieve the best outcomes for the nation. The appropriate methodology requires further research and a commitment from government and policy makers to embark on a fundamental rethink of the present ad hoc approach. It is hoped that this paper will help initiate that rethinking process.

7 References

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