Infrastructure asset: developing maintenance management capability

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Abstract
Purpose – Maintenance management is a core process in infrastructure asset management. Infrastructure organisations must constantly strive to ensure the effectiveness of this process in order to obtain the greatest lifetime value from their infrastructure assets. This paper aims to investigate how infrastructure organisations can enhance the effectiveness of their maintenance management process.
Design/methodology/approach – This study utilised multiple case studies as the research approach. The case organisations were asked to identify the challenges faced in the maintenance process and the approaches they have adopted to overcome these challenges. Analysis of these findings, together with deductive reasoning, leads to the development of the proposed capability needed for effective maintenance management process.
Findings – The case studies reveal that maintenance management is a core process in ensuring that infrastructure assets are optimally and functionally available to support business operations. However, the main challenge is the lack of skilled and experienced personnel to understand and anticipate maintenance requirement. A second challenge is the reduced window of time available to carry out inspection and maintenance works. To overcome these challenges, the case organisations have invested in technologies. However, technologies available to facilitate this process are complex and constantly changing. Consequently, there is a need for infrastructure organisations to develop their technology absorptive capability, i.e. the ability to embrace and capitalise on new technologies to enhance their maintenance management process.
Originality/value – The paper provides an in-depth analysis of three case studies that reveal that an infrastructure organisation cannot avoid the need to introduce technologies to monitor the condition of its assets and to predict when assets will fail. It suggests that organisations must be proactive in searching for the best technologies for their purpose.

Keywords Capability, Maintenance, Assets management, Infrastructure, Maintenance programmes, Economic value analysis
Paper type Case study

Introduction
Infrastructure assets play a vital role to support a nation's economic growth (Hardwicke, 2005) and social development (Jonsson, 2005; van der Mandele et al., 2006). The infrastructure industry is characterised by the provision of public goods requiring large capital investment, multiple stakeholders and a monopolised market (e.g. see Firth et al., 1999). These complexities imply that the provision of infrastructure will necessarily be subjected to the kind of intervention that has not always been imposed on other facilitators of economic activity. For this reason, the ownership has, traditionally, often been in the hand of government or semi-government organisations to minimise the effect of market failure and externalities. The provision of infrastructure by the public sector role is critical to achieving development objectives such as national security and public service obligations (Grimsey and Lewis, 2004; Howes and Robinson, 2005).

However, in the last decade or so, the high cost and myriad problems associated with government-owned infrastructure have caused many countries to reform the institutional options for the provision of infrastructure services (Kessides, 2004). The reform entails a combination of competitive restructuring, privatisation, and establishment of regulatory mechanisms (Kessides, 2004). In fact, the late 1990s were characterised by a significant shift from the public to private sector for the provision of infrastructure services. A key argument for privatisation is that private owners and operators who face stiffer market competition, have stronger incentives to control costs, respond to consumer needs, and adopt new technologies and management practices (Grimsey and Lewis, 2004). Under such dynamic business environments, infrastructure organisations need to maximise the investments they have made in their existing infrastructure assets in order to reduce their capital and operating expenditures. To create sustained competitive advantage, which in turn leads to superior performance, infrastructure organisations need to focus on customer needs and accountability of results to deliver services (Manning, 2002).

Accountability is a requirement for any organisation, public or private. Those in charge of economic resources must give account of their stewardship, irrespective of whether the transactions and resources in question are those of a government or a private sector entity (Grimsey and Lewis, 2002). In the twenty-first century, the various stakeholders for infrastructure will continue to demand value for money for their investment in infrastructure. To satisfy the needs and conflicting demand of the various stakeholders, infrastructure organisations have to explore ways to create value from their infrastructure assets. This has placed pressure on these infrastructure organisations to better manage the performance of infrastructure assets to meet the rising expectations of stakeholders. The strive to improve effectiveness and overall operating performance requires clear understanding of how to manage an ageing asset portfolio in a way that allows their current performance to improve while also investing in new assets to meet future needs.

Extant literature in strategy suggests that to improve an organisation's performance, there is a need to focus on factors internal to the organisation in addition to the industry structure. For example, Ravichandran and Lertwongsatien (2005) argued that the focus on organisation resources and capabilities can provide the appropriate theoretical lens to examine how factors internal to an organisation can be a source of competitive advantage. An organisation can only gain advantage and achieve superior performance when it has the right capabilities (Smallwood and Panowyk, 2005). Capabilities represent the ability of the organisation to combine efficiently a number of resources to engage in productive activity and attain a certain objective (Amit and Schoemaker, 1993). Hence, the strategy and processes must be supplemented with the right capabilities to execute them before value can be created.

As the traditionally government owned infrastructure organisations move towards privatisation, the asset manager are faced with the strategic decision on the right capabilities that they should invest in. In other words, how should infrastructure organisations allocate their scarce resources to develop the right capabilities? This paper uses multiple case study approach to investigate how infrastructure organisations can create competitive advantage and sustains their performance by examining the capabilities needed for effective management of their maintenance process for both public and private infrastructure organisations.

This paper is organised in the following manner. The next section will examine the management literature on how organisation can create value through their business processes. Following this, the research method is explained. The findings of the case studies with regards to the challenges and approaches that can be adopted in the maintenance management process are then elaborated. This is followed by a discussion of the capability needed for the effective management of the maintenance process. The paper concludes by suggesting the implications for asset managers.

Improving organisation performance

Literature in strategic management has argued that an organisation must create value better than rivals if it wants to sustain its competitive advantage. This can only be realised either when an organisation gains an advantageous position in an industry or when it mobilises and deploys core competencies (Prahalad and Hamel, 1990; Wernerfelt, 1984) that enable it to offer superior products to customers relative to its competitors (Lado et al., 1997).

In a dynamic and fast-changing environment as a result of deregulation and privatisation experienced by infrastructure organisations, Ma (2000) suggests that kinetic advantages, which are often knowledge-based and capability-based (Juga, 1999; Kay, 1999), will more likely to produce sustainable superior performance. The reason is that one can hardly actually plan ahead due to abrupt business environmental changes (Hamel, 2000; Mintzberg and Westley, 2001). Deliberate strategy to obtain strategic fit will create a tension to the organisation (Zajac et al., 2000). This tension magnifies when business environments change to a new level while the organisation still possesses the same stock of resources or old capabilities. In such situation, the organisation will not be able to sustain its competitive advantage unless new stocks of resources and capabilities are obtained. When organisations are unable to develop required capabilities in transforming resources into valuable services, the acquired resources are likely to become overhead, rather than assets to the organisations (Amit and Schoemaker, 1993).

If the essence of strategic management is to achieve sustainable competitive advantage to obtain sustainable superior performance (Teece et al., 1997), then it is important to study which resources and capabilities will allow infrastructure organisation to generate competitive advantage. Scholars have proposed that to maintain competitive advantage, organisations should develop capabilities for improving core business processes (Hammer, 2001; Zott, 2003). DeToro and McCabe (1997) state that core processes are those processes that are strategically important to the organisation's success, and have a high impact on customer satisfaction. Infrastructure organisation will have many processes as are necessary to carry out the natural business activities defined by the life cycle of the infrastructure assets. However, many scholars acknowledged that not all business processes would be a source of competitive advantage. For example, Kaplan and Norton (2004) suggested that managers must identify and focus on critical few internal processes that have the greatest impact on strategy and can create value to the organisations. Hence, organisations need to develop and deploy a range of capabilities around the core processes, which can be helpful in responding to different challenges in the markets (Collis, 1994; Porter, 1991).

In addition, each core processes may require many capabilities. Collis (1994) warned that it may well be impossible to list the complete set of all capabilities that can be sources of superior performance because they can be found in every single activity the organisation performs. Similarly, Ethiraj et al. (2005) argued that not all capabilities provide the same marginal contribution to performance. They further argue that if different capabilities have different costs and benefits associated with the development and acquisition, managers should pay attention to understanding these trade-offs in making investment in capability development. The organisation should therefore invest in those capabilities within the core processes that can contribute to the overall performance of the organisation.

Infrastructure assets must be maintained adequately so that it can continue to deliver the desired levels of service, condition and performance to support business operations. The effectiveness of the maintenance management process is thus fundamental to the performance of infrastructure asset because it occupies the longest phase of the infrastructure asset's life cycle. It typically starts from the moment the infrastructure asset has been constructed and fit for service to the end of the asset life (NPWC, 1996). The maintenance process was seen as a hygiene function until the 1990s, when globalisation triggered a search for newer sources of competitive advantage (Banerji, 2008). This is a major paradigm shift as asset managers realised that maintenance aimed at optimising business value involved trade-offs between cost and asset health. In fact, effective maintenance management is recognised at all levels of the industry and is becoming a key business driver because of the increasing demand pressure on infrastructure assets.

Research method
In identifying capabilities that are the sources of performance difference, they need to be contextually grounded (Ethiraj et al., 2005). Due to the context specificity of capabilities, this paper uses a multiple case study method to identify the capability/ies needed in the maintenance management process of infrastructure organisations to enhance their competitive position and thus sustain their performance.
In a multiple case study method, cases chosen should based less on uniqueness of a given case, and more on the contribution to theory development within the set of cases (Eisenhardt, 2007). Hence, I have chosen the cases based on a typology of organisations that manage infrastructure assets namely:

. infrastructure types (namely, water, airport, seaport, rail, road);
. level of privatisation (government owned corporation, government owned department, full privatisation)
. spread of infrastructure (co-located or spread over large geographical areas).

Table I describes the three case organisations studied.
Semi-structured interviews with managers responsible for the maintenance of infrastructure assets were used to understand the importance of maintenance management process and to identify the essential capability needed to deliver overall improvement to the performance of infrastructure assets. Due to a current lack of understanding of business capabilities in infrastructure organisations, an indirect questioning method was used to elicit these capabilities. The indirect method involved understanding the difficulties and challenges faced in the executing maintenance management process. The approaches taken or deemed necessary to be taken by case participants can then be conceptualised as the core capability/ies needed to successfully manage the infrastructure maintenance management process. The interview data was cross-checked and compared with data from a broad range of sources. All these documents were reviewed to corroborate and augment the evidence gathered from interviews.
A two-stage analysis suggested by Eisendhardt (2002) is adopted for this study; namely:
(1) within-case analysis; and
(2) cross-case analysis.
Within-case analysis is conducted initially by coding, to sort answers according to different components such as importance of the process, the challenges faced, and approaches adopted in maintenance management. This initial coding is useful to identify areas, which will need more data and identify text that is particularly relevant to the study. This process also helps to make the text manageable by selecting only the relevant text for further analysis (Auerbach and Silverstein, 2003). Based on these broad-based nodes, further coding or "coding on", a term coined by Richards (2005), from already coded text is performed. As "coding on" continues, coded text can be analysed through categorisation to reflect conceptual advance. This involved recording the repeating ideas by grouping together related passages into some initial themes. This further coding gave rise to preliminary themes associated with capability for the maintenance management process.
After the within case analysis for each case is done, the cross case analysis is next performed to identify common themes. The emerging ideas and concepts were compared to identify common themes and initial propositions. First, categories or dimensions suggested by existing literature were analysed by looking for within-group similarities coupled with inter-group differences. To examine the subtle similarities and differences, a second tactic is to select pairs of cases and then list the similarities and differences between each pair. These forced comparisons results in new categories and concepts not anticipated initially. A third strategy was to divide the data by data source. These tactics exploits the unique insights possible from different type of data collection. Through these approaches, cross-case analysis can enhance the probability of moving beyond initial impressions, especially through the use of structured and diverse lenses on the data, to capture the novel findings

that may exist in the data. The preliminary findings from the data analysis were compiled into a preliminary report to seek further validation. The report was sent to senior managers of case organisations for feedbacks and comments. Further meetings were arranged to discuss the findings face-to-face. These feedbacks were incorporated to refine the findings.

Table I. Case profile

Type of organisation	Level of privatisation	Value of infrastructure assets/number of employee	Type of services	Key infrastructure assets
Rail	Government owned corporation	7.4 billion/9,000	Operate and maintain the metropolitan commuter system, the regional freight and tourist lines, the heavy haul tracks of the coal and mineral business, and the interstate track	The track; structures such as culverts and bridges, bridges that support the railway and those that run overhead; right of way such as the access road and drainage; signalling systems that control of the safe working of trains; power supply and substations; overhead traction system
Airport	Fully privatised	2.6 billion/230	Responsible for the maintenance and operation of a wide range of air-side and land-side airport activities including parking and retail activities within the terminals, recreation hub, and airport village	The key assets are runways and all the assets on the terminal buildings such as baggage handling system, the check bag screening, aero-bridges, building fabrics, hydraulics, chillers, all the HVAC system, electrical system and communication system
Seaport	Government owned corporation	2.4 billion/300	The maintenance and development of the port and related facilities including operation of the multimodal terminal; leasing and managing land for port-related services; maintaining navigable access to the port for commercial shipping	All port infrastructures that include channels and berths, wharfs and terminals, all services roads, water, power, telecommunications, sewer, and storm waters. Properties include warehouses, buildings, and container handling equipment

Case study findings

Maintenance management is a core process

Maintenance management is necessary to ensure that infrastructure asset is able to do what it is designed for i.e. to support business operations. Maintenance work if not planned and performed well can cause assets to fail and affect business operations.

When failure occurs, it diverts resources to fix the problem at the expense of other assets. In addition, unplanned maintenance work places stress on the budget by having to carry out critical maintenance work that was not budgeted for. For infrastructure organisations, such as airport, this is even more critical where the conditions of the infrastructure assets can have a delicate effect on public perception and passenger experience. This is aptly shared by a manager of the airport case, "we have to make sure that the asset is available whenever it is required . . . we have to present our assets in a very good condition, in a very good way . . . in airport, it is about presentation and public opinion . . . they want good experience in the airport." Similarly, a rail organisation must manage the rail assets to a certain standard that will not affect the rail transit time. This standard includes safety (both occupational health as well as derailment), asset geometry (such as overall tract condition indices) and speed restrictions to the rail network.
The ability to deliver the required maintenance can, therefore, have a significant impact on cost and operations. It is a business objective for any asset manager to focus on investing the minimum levels of maintenance dollars to deliver the services desired by the organisation, while meeting statutory obligations for the organisation's risk management and public liability. The maintenance management process can therefore create value to an infrastructure organisation and is therefore a core process. This is echoed by all managers interviewed and can be best summed up by a manager, "improving our planning of maintenance is significant to create value to our customers . . . we have for some time now increasingly given attention to maintenance planning."

Challenges in maintenance management process
To ensure that maintenance can be planned and carried out on a consistent and sustainable basis to achieve its objectives, all maintenance activities need to be captured via a common system (Killick and Thomas, 2008). In the planning of maintenance, two main approaches are evident from the cases. First, maintenance activities are planned based on some rules and standards. This can be regulation mandate or manufacturers' recommendation. Second, maintenance activities are planned based on the assessed risk of asset failure based on conditions of the infrastructure assets. This includes predicting essential maintenance work that needs to be carried out to prevent failure of critical assets so as not to affect business operations. The two approaches are summarised in Table II.

Table II. Maintenance planning methods

Cases	Rule based planning	Risk based planning
Rail	"Some of the maintenance is cyclical and programmed which is more rule based and does not depend on finding defects such as rail grinding to be done after so many thousand tonnes over the track"	"We start with the plan to monitor the condition and as defects are found, we prioritise and plan to fix the defects within the time frame of priority … nearly all our maintenance depends on the result of condition monitoring and inspection" "We are doing probabilistic maintenance planning with our rail asset especially those that cannot afford to breakdown such as our signalling system"
Port	"We try to first meet all the standards and requirements … this is the cyclical maintenance that is rule based and standard and we know when they are exactly required"	"We need to include in our planned maintenance work based on the result of planned general inspection … from PGI we will know which type of maintenance work must be done by a certain time" "We do risk assessment based on past data to assess the likelihood of asset failure … and see how we can plan the maintenance to prevent the failure of such assets"
Airport	"We review the manufacturers' manual to find out what maintenance works are required" "We have guidelines and regulations that dictate the type of maintenance to be carried out"	"To ensure that we are able to plan well, there is a bit of data capture and analysis of those data… for example, on the runway we need to do friction testing because of the rubber build up" "We will do failure analysis to see whether the assets is going to fail" "We also do risk assessment to plan based on probabilistic"

In general, there is no issue in capturing cyclical maintenance works as they are based on certain rules and standards developed in the past. For example, in the case of rail grinding, a rule-based cyclical maintenance can determine the grinding needs to be done after a certain amount of tonnes travelled over the track. This is determined based on their past experiences.
However, maintenance activities based on the assessed risk of asset failure are more difficult to be determined. To facilitate planning of these maintenance activities, infrastructure organisations need to collect data on the conditions of their asset. This will require constant monitoring of the conditions of the infrastructure assets and rigorous review and analysis of these data, to ensure the right mix of maintenance activities are delivering the improvements needed to provide sustained business success. Collectively, the data from the three detailed case studies revealed that condition monitoring and analysis of risk of asset failure is done regularly. For example, the condition of infrastructure assets at rail case is monitored via a scheduled inspection regime. This is shared by a manager, "we are stepping up the amount of our track recording data so that we can use it in a more predictive way." Similarly, to capture critical maintenance works, airport managers utilises scenario planning to assess the potential risks of failure as shared by a manager "we are currently doing a lot of scenario planning to assess possible asset failures and the effect on business continuity."
Hence, data from the case organisations suggest that they are moving away from the traditional time-based-maintenance approach to a more pro-active condition-based-maintenance philosophy. Through this process, infrastructure organisations are better prepared for infrastructure asset failure by building in such risks into the maintenance plan so that the effect will be minimised. Interviewees concurred in their views of the importance of condition monitoring as shown in Table III.

Table III. Importance of monitoring the conditions of assets

Case	Evidence
Rail	"The most critical piece of information is how much longer a particular asset is going to be remaining in service … we need to collect more data on the conditions of the assets" "We need to monitor the condition during the good times to assess what adjustments are to be made and understand what are the triggers of asset failure" "we need information on condition assessment and risk assessment … to prioritise what we need to do first … this will help us decide what our maintenance strategy is"
Port	"With the information, we can make predictions on how the asset is performing, whether we need to change. This will allow us to predict when something is about to breakdown and depending on the expected usage or demand on that plant we might modify our maintenance regime, we might run it to failure because we might have decided that that a piece of equipment is becoming redundant and we need to chuck it out and put a new one in, retrofit or something else"
Airport	"We have condition monitoring, we know the condition of our assets and we know where the faults (are) going to be and when they are going to arrive so we can plan our maintenance to get that repair so that it doesn't breakdown at a critical period"

Given the large quantity of assets that the case organisations are responsible for, collection and interpretation of condition data is both tedious and complex. In addition, there is a need to analyse these data and make informed judgements. These analyses require the skill and judgement of asset manager. To formulate an effective maintenance plan thus requires experienced staff, who not only understand the asset and performance requirements, but also have the ability to analyse the risk involved. In other words, infrastructure organisations need to have experienced personnel who know and understand well both the asset and its relation to operations. This sentiment is best summed up by one manager, "these managers, with their experience and understanding of our assets and operations needs, are key to ensure that we make the right judgement and assessment". Table IV summarised the importance of having competent personnel in analysing asset condition data and risks.

Table IV. Importance of competent personnel

Cases	Evidence
Rail	"… but experienced people are still important in the railway business … you still need somebody to interpret it." "A lot of maintenance decisions are based around judgement and experience … experienced people are in the field making judgements and collecting accurate data about the condition of the assets but we also need experienced people to assess those data to make good decisions"
Port	"To do planning well, we need to have experienced people and good people … they need to understand the asset well and know everything about the details of the asset." "It is not just the collection of it but also the analysis of it … that becomes a critical part of it"
Airport	"Our maintenance planner must understand the asset as well as the operations staff so that they can know what is required … with the knowledge of operations and assets, they will be better in analysing the risk … besides operations they also need to assess the safety and environmental issues … you need many years of experience" "People skills are important in the analysis … they need to understand the asset and what they are looking for … you need the right technical people who know the asset and how it will operate and what effect is of the asset on the business operations"

However, with the shortage of skilled staff in a tight labour market where employee movement is not uncommon despite the best human resource policy, these organisations must ensure that they do not rely solely on an individual employee to carry out this task well. Hence, a key challenge in the maintenance management process is to deal with the lack of skilled and experienced personnel. This observation is summarised in Table V.

Table V. Lack of experienced Personnel

Cases	Evidence
Rail	"Getting the right people will continue to be an issue not only for skilled workers and tradesmen but also professional engineers"
Port	"Getting the right and good people will continue to be an issue … and how to get them and keep them in the current infrastructure boom"
Airport	"Experienced people are now difficult to find … you need the right technical people who know the asset, how it operates and how it will affect the business operations"

In any business that operates at full capacity, lost operating time equates to lost revenue that can never be recovered. Optimising maintenance activities in order to minimise downtime will always be one of the major sources of value add. However, the increasing demand for infrastructure assets to provide business continuity has reduced the availability of asset downtime to carrying out condition monitoring as well as the necessary maintenance work. Hence, a second key challenge identified across all the three cases is the reduced window of time available to carry out inspections on the condition of infrastructure assets and to carry out maintenance works. For example, the demand on the rail network in recent years has reduced the time available to carry out inspection and maintenance work. This has prevented access by maintenance personnel to access the network to collect important condition data to facilitate risk assessment. The cross case evidence of reduced window for maintenance is described in Table VI.

To sum up, the challenge is to ensure that all critical maintenance works are consistently identified, so as to gain access to collect condition data and to have the right people with the necessary experience to make judgements and to analyse the risk.

Table VI. Reduced window period for maintenance

Case	Evidence
Rail	"There is an increasing pressure all the time to reduce the inspection on the track as more and more trains are running . . . we have to find ways of carrying out inspection without interfering with the train tracks"
Port	"The biggest impact is the availability of time for maintenance . . . we need to make sure our assets provide continuity to the business . . . we have to work with the operators . . . business comes first and ships work 24 hours a day, 7 days a week, we need to make sure our assets provide continuity to the business . . .to monitor conditions of asset manually, we need downtime and this is increasingly difficult to get"
Airport	"We now have aircraft leaving until 1:30 am and we have our first arrival at 4:00am . . . so the available window for maintenance of these assts has been significantly reduced"

Additionally, the limited window for maintenance challenges the maintenance department to devise innovative ways to deliver performing assets without disrupting business continuity. The above challenges are evident in all the cases and are summarised in Table VII.

Table VII. Summary of challenges in the maintenance management process

Challenges	Lack of skilled and experienced personnel to assess conditions of infrastructure assets	Reduced window period for condition inspection
Rail	"The most critical piece of information is how much longer a particular piece of asset is going to be remaining in service . . . that takes a lot of experience and judgement"	"We are under increasing pressure all the time to reduce the inspection on the track as more and more trains are running . . . we are consuming capacity for inspection"
Port	"We need to have experience and good people"	"The biggest impact is the availability of the asset for maintenance . . . we need to make sure our assets provide continuity to the business . . . we have to work with the operators"
Airport	"We still rely on the expertise of our personnel who do the inspection and know the asset and system well . . . experience counts a lot and is built up over many years"	"The available time windows for maintenance of these assets has been reduced significantly"

Approaches adopted to overcome the challenges

One of the ways to overcome the challenges identified is to introduce more technologies into the maintenance management process. The trend towards using more technologies for condition monitoring is apparent in all case organisations. For example, more inspections at the rail case are carried out by machines to replace manual inspection as noted by a manager:

> There are quite a number of systems around that rely less on experience and someone working the a track and testing the sleepers . . . we also have track recording geometry car which travels over the track . . .we have a non-destructive testing machine that goes on track to check for defects and fatigue.

Five main reasons were observed for the increased use of technologies to replace human inspection to monitor the conditions of infrastructure assets and to facilitate the assessment of risks of asset failures. First, with the increasing shortage of skilled personnel as discussed earlier, the cost of a competent maintenance engineer has spiralled upwards and is deemed to be expensive. Second, the nature of some infrastructure assets such as rail network assets that are spread over a big area geographically has created a stronger case for automation to replace the otherwise costly human inspection. For example, a manager noted:

> . . . a railway is such a long and disparate asset, . . . and are spread over thousands of kilometres . . . so at the end you need automation to lighten the load.

Third, automation can reduce the inconsistency and subjectivity experienced by a heavy reliance on people. This is noted by a manager interviewed:

> . . . when you cannot get enough skilled and experienced personnel to arrive at a good judgement of the condition of the assets, you tend to have inconsistency.

Fourth, automation will also provide better data, more real time information and the ability to manipulate and use the data to forecast trends. This is shared by a manager:

> We are currently spending more time to analyse the data from the database associated with a resurfacing machine, and with the data we got, we can overlay the inspection data from the track recording car to see what deterioration rates and where resurfacing is needed.

Fifth, technologies can be effectively used without affecting business operations. For example, the rail case has been using specially fitted camera on the train to monitor and collect conditions data of the track. This can minimise the disruptions to train operations.
Hence, technologies are an important driver to create value in the maintenance management process as it introduces new scientific knowledge to enhance the ability to monitor the conditions. The cross-case approaches discussed, to overcome the challenges in maintenance management is summarised in Table VIII.

Table VIII. Summary of approaches adopted for the maintenance management process

Approaches	Use of technology to assess condition and risk of asset failure	Use of experienced personnel to supplement/complement technological input
Rail	"We try to be proactive . . . the opportunity to bring new technology in can vary . . . it is important to have somebody actively looking at and understanding what is available . . ." "I see there is a trend towards automation of process and consideration of whether it is more reliable and less expensive than human processes . . . we could be using technology more to our advantage"	"Even if we have automation technologies, you still need somebody to interpret it and I don't think it will ever replace the people" "The reality is a lot of maintenance decisions are based around judgement and experience . . . you have to be careful not to get into a situation where you think you are replacing people and expertise with technology because you have to make judgements"
Port	"There is not a lot of automation . . . automation can improve productivity" "We have cutting edge technology that can continuously monitoring the depth of the channel"	"Technology cannot help very much here not as much as the experience of the people . . . if there is a crack, we need people with experience to analyse why it is cracking and how to resolve it"
Airport	"We are at the moment having the capability to adopt more automation . . . technology to assist in condition monitoring . . . technology will bolster it and complement human inspection" "We have recently formed a research and innovation group, and they will look at those issues and give us the updates"	"These managers with their experience and understanding of our assets and operational needs are key to ensuring that they make the right judgement and assessment" "People skills are important in the analysis . . . they need to understand the asset and what they are looking for . . . you need the right technical people who know the asset and how it will operate and what effect of the asset will have on the business operations"

Capability for the maintenance management process

To overcome the challenges of the lack of skilled personnel and the reduced window period for inspections and condition monitoring, the data from this research revealed that case organisations have increasingly used technology supplemented with skilled personnel. There are currently a variety of diagnostic tools available to assist asset managers in determining the maintenance regime required to deliver the appropriate levels of service at an accepted level of risk. A fairly efficient factor market exists for technologies to support maintenance management process such as simulation, and modelling cost/risk estimation tools and sophisticated reliability modelling aids that can handle almost any level of sophistication. For example, a variety of new maintenance tools are being considered by a growing number of organisations such as reliability centred maintenance methods, failure mode effect and criticality analysis and statistical analysis using age profiles, etc. (Eby and Bush, 1996).

The availability and continual development of many new technologies with different capabilities represents an under-utilised avenue to address the challenge of finding experienced maintenance personnel. In an environment that is constantly changing, the key source of competitive advantage is the rate at which organisations develop or acquire new technological capabilities, not the technologies they can currently access (Helfat, 1997; Lei et al., 1996). Thus, while technology resources may be valuable resources, they will not explain sufficient variation in the performance of the maintenance management process.

In order to embrace the use of technology, infrastructure organisations must first be willing and proactive in bringing in new technology. This is termed "technology proactivity" by Miles and Snow (1978) and is defined as the organisation's ability to initiate changes in its strategic technological policies rather than to react to events.

According to Miles and Snow (1978), the most proactive organisations act quickly to take advantage of technological opportunities that emerge in the market through the development of new products, markets and technologies. Thus they argue that an organisation with more technology proactivity will be more innovative than an organisation following other kind of strategies (Correa, 1998). Garcia-Morales et al. (2007) has shown empirically that technology proactivity influences organisational learning and innovation positively which results in sustained superior business performance.

Despite the widely available technologies to support maintenance management, all three case organisations acknowledged that there is scope for greater use of technology and accepted the need to embrace more technologies to supplement the human inspection and judgement. In fact, to enhance their knowledge of technology available, some of the case study organisations interviewed have recently been getting involved in some forms of research into new technologies, benchmarking, and strategic partnership development with technologies companies. This is summarised in Table IX. These initiatives suggest that infrastructure organisations have realised the importance of being proactive in acquiring new technology to enhance their performance. Technology proactivity is thus an important first step in exploiting technology to enhance the maintenance management process.

Table IX. Proactive in searching for technology

Case	Evidence
Rail	"One of the best ways to do this research is to go and visit other railways and see what other railways do . . . we spend most of our time distracted by actually doing it and solving the problems ourselves"
Port	"We have got an advantage here that we can look at other world examples . . . we can look and follow and see what sort of technology is appropriate for the port here"
Airport	"We have some strategic partnerships with major technological providers and we are putting up a tender for one of them to be our strategic technology partner to advise us"

The success of tools and technologies in the development of organisational capabilities is likely to depend on the organisation's information processing and decision making capacity. This is especially true when technologies and techniques are too complex to be "mastered". Data from the interviews also reveal that despite the advancement in maintenance management technology, significant human input and judgement are still required. While technology may be useful for processing and analysing data, engineering knowledge, expectations, inference and range estimating are the prime source of information that needs to come from experienced maintenance personnel. Most interpretation will still require human judgement and common sense.

Hence, while new technology is deemed to be important by all three of the case study organisations, this does not negate the need for human input. The goal of technology should be to allow participants to bring and integrate diverse bodies of knowledge to make better use of existing capabilities and provide opportunities to quickly develop potential capabilities to meet changing market realities. At the same time, however, tools and technologies do not inherit organisational capabilities. It is only through people that tools and technologies get a "meaning" (Davenport et al., 1997). Therefore, too much emphasis on technologies, without paying adequate attention to people's perceptions about technologies and market realities, is likely to create irrelevant knowledge (e.g. see Berggren, 1992). The case study organisations were observed to prepare their personnel to be ready to embrace new technologies through sharing knowledge with each other. This is illustrated in Table X.

Table X. Preparing personnel to embrace new technology

Case	Evidence
Rail	"So a lots got to do with centralisation and sharing of knowledge . . . we have our own people to share their experiences on any new innovation developed in one part of our state with those across the state . . . we also attend conferences on railway maintenance . . . and are looking at the various business symposium around the world and send our guys there to look at what is new"
Port	"We have cutting edge technologies that we get from US when our senior management learnt about it in one of the conference"
Airport	"We attend forums and also formed strategic partnership with institute of higher learning to investigate and conduct research and worked with major technology providers to form strategic partnerships to develop the appropriate technology and explore solutions"

The propensity to embrace and use new technologies for accomplishing goals and preparing people who are ready and capable to embrace the new technologies can be termed technological absorptive capability (TACAP). Cohen and Levinthal (1990) have offered the most widely cited definition of absorptive capability (ACAP), viewing it as the organisation's ability to value, assimilate, and apply new knowledge. Zahra and George (2002) further reconceptualised ACAP as a set of organisational routines and processes by which organisations acquire, assimilate, transform, and exploit knowledge to produce a dynamic organisational capability that influences the organisation's ability to create and deploy the knowledge necessary to build other organisational capabilities (e.g. technological, marketing, distribution, and production). This basket of diverse capabilities give the organisation a foundation on which to achieve a competitive advantage that yields superior performance (Barney, 1991).

TACAP for maintenance management should thus include all the four dimensions as proposed by Zahra and George (2002). It indicates the capability to evaluate the potential performance of external technologies and to select those that are most efficacious, as well as the capacity to operate with and use this technology to obtain competitive advantage (Cohen and Levinthal, 1990). Considering that future maintenance activities will rely upon technology to remain viable, creating a capability in the form of technology absorptive capability should be deemed a strategic priority. Hence, asset managers need to dedicate time and effort to increase technology absorptive capability. Figure 1 illustrates the importance of TACAP for the maintenance management process. The case studies in this paper comprised infrastructure organisations of various ownership structure managing different types of infrastructure assets. They included both private organisation as well as commercially oriented government-owned-corporation. Through the cross-case analyses of the maintenance management processes in each organisation as discussed above, common themes emerged and the study concluded that TACAP is important to enhance the performance of the maintenance management function – regardless of the ownership structure and type of infrastructure assets. However, Moore (2000) cautioned that capabilities for private and public organisations should be different. His reasoning is that strategy adopted by for-profit private organisations fails to take account of two crucially important features of non-profit public organisations:

(1) the value produced by non-profit organisations lies in the achievement of social purposes rather than in generating revenues; and
(2) non-profit organisations receive revenues from sources other than customer purchases.

Figure 1. Capability for the maintenance management process

His alternative strategy model for government managers is that they should focus attention on three key issues:

(1) public value to be created;
(2) sources of legitimacy and support; and
(3) operational capacity to deliver value.

Alternatively, Mizik and Jacobson (2003) proposed that organisations could achieve sustained competitive advantage and thus create value in two fundamental directions. The first involves the creation of customer value (i.e. innovating, producing and delivering products to the market); the other focuses on appropriating value in the market place (i.e. extracting profits). They further argued that although both value creation and value appropriation are required for achieving sustained competitive advantage, an organisation has significant latitude in deciding the extent in which it emphasises one over the other. To create value, asset managers must invest their resources to develop or acquire value creation capabilities. To appropriate value, on the other hand, they will need to develop capabilities that facilitate value appropriation.
Notwithstanding the ownership structure of infrastructure organisation, what is clear from the preceding discussion is that both private and public organisations must operate in a way to create value and sustain itself in the immediate future (Andrews, 1971; Barnard, 1966). While value appropriation is more applicable for private organisations, value creation is applicable to both private and public organisation. TACAP falls under value creation capabilities as it involves the using

of technology to innovate, produce and deliver new products or processes. It can thus be implied that TACAP is applicable to both private and public organisations.
The results from this study are particularly timely given that many governments have begun the process of privatising their infrastructure organisations. Applying these findings, it is anticipated that the restructuring will not affect the core capabilities needed for effective management of their maintenance process. Instead, the affected government owned corporations should continue to invest in developing the identified capabilities, i.e. the TACAP to enhance the performance of their infrastructure. Hence, concepts from the for-profit strategy literature have become increasingly more relevant for infrastructure organisations regardless of whether they are public (Llewellyn and Tappin, 2003) or private.

Implications for managers
This paper identified TACAP as the core capability needed in the maintenance management process. While the results of this study might have shown that TACAP to be important for an effective maintenance management process, a first step towards the development of this capability may be to radically amend many asset managers' appreciation of this capability in contributing value to their organisation and how to communicate to the managers in the top echelon and other functional areas. Once management understanding and acceptance of the contribution of this capability to the business goals of the organisation is secured, asset managers must then make an assessment about the current strength of this capability they possess. The challenge is to measure the parameter of this capability. Some infrastructure organisations might be unaware of the capability parameters they already possess such as their relationship with strategic technology partners and other stakeholders.
The next managerial implication is how to leverage the TACAP for improving the performance of infrastructure assets. Consideration of how TACAP might be leveraged in developing new products or solutions and establishing new modes of differentiation could lead asset managers to identify new opportunities or ways to exploit existing opportunities better. The other fundamental strategic choice that asset managers face is the optimal allocation of the scarce resources among competing initiatives to acquire TACAP. Asset managers need to purposefully build TACAP by focusing on resources that are interconnected, deeply rooted within the organisation's relationships and knowledge base, and span the organisation's business functions and hierarchy. For example, the development of TACAP requires the integration of people and technology. This is useful in helping managers to consider and identify the resources they need in order to develop this capability. It is important that asset managers have a full appreciation of the resources that facilitate/impede the development of this essential capability, which may in turn have an impact on the performance of the infrastructure asset and organisation to remain competitive in today's business arena.

Conclusion
To ensure an effective maintenance management process, the in-depth analysis of the three case studies revealed that an infrastructure organisation cannot avoid the need to introduce technologies to monitor the condition of their assets and to predict when assets will fail. This development suggests that organisations must be proactive in searching for the best technologies for their purpose. Moreover, they must ensure that their people are well trained to exploit and utilise the new technologies introduced.
Hence, infrastructure organisations must invest their scarce resources to develop their TACAP through acquisition, assimilation, transformation and exploitation of technology available to strengthen their maintenance management process. Effective maintenance management, being the core process of infrastructure management, can thus create value to infrastructure organisations regardless of ownership structure. It is hoped that the theoretical justification for effective development of TACAP will heighten the awareness of the importance of developing this capability amongst practitioners.

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