CRC Construction Innovation

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Report
Enabling Team Collaboration with Pervasive and Mobile Computing: Cost Benefit Analysis Methodology

Research Project No: 2002-057-C-02

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EXECUTIVE SUMMARY

Construction is an information intensive industry in which the accuracy and timeliness of information is paramount. It observed that the main communication issue in construction is to provide a method to exchange data between the site operation, the site office and the head office. The information needs under consideration are time critical to assist in maintaining or improving the efficiency at the jobsite. Without appropriate computing support this may increase the difficulty of problem solving.

Many researchers focus their research on the usage of mobile computing devices in the construction industry and they believe that mobile computers have the potential to solve some construction problems that leads to reduce overall productivity. However, to date very limited observation has been conducted in terms of the deployment of mobile computers for construction workers on-site. By providing field workers with accurate, reliable and timely information at the location where it is needed, it will support the effectiveness and efficiency at the job site. Bringing a new technology into construction industry is not only need a better understanding of the application, but also need a proper preparation of the allocation of the resources such as people, and investment.

With this in mind, an accurate analysis is needed to provide clearly idea of the overall costs and benefits of the new technology. A cost benefit analysis is a method of evaluating the relative merits of a proposed investment project in order to achieve efficient allocation of resources. It is a way of identifying, portraying and assessing the factors which need to be considered in making rational economic choices. In principle, a cost benefit analysis is a rigorous, quantitative and data-intensive procedure, which requires identification all potential effects, categorisation of these effects as costs and benefits, quantitative estimation of the extent of each cost and benefit associated with an action, translation of these into a common metric such as dollars, discounting of future costs and benefits into the terms of a given year, and summary of all cost and benefit to see which is greater.

Even though many cost benefit analysis methodologies are available for a general assessment, there is no specific methodology can be applied for analysing the cost and benefit of the application of mobile computing devices in the construction site. Hence, the proposed methodology in this document is predominantly adapted from Baker et al. (2000), Department of Finance (1995), and Office of Investment Management (2005). The methodology is divided into four main stages and then detailed into ten steps. The methodology is provided for the CRC CI 2002-057-C Project: Enabling Team Collaboration with Pervasive and Mobile Computing and can be seen in detail in Section 3.

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1 Introduction

The purpose of this paper is to perform a cost benefit analysis methodology for the CRC CI 2002-057-C Project: Enabling Team Collaboration with Pervasive and Mobile Computing. The methodology focuses on the deployment of mobile computing devices in the construction sites in order to assist workers not only for communicating, but also for accessing up-to-date documents/information and improving the costly and time-consuming process of data collection and analysis at the interface between physical site operations, construction management activities and consultancy practice or other project activities. The methodology consists of three sections: Introduction, Research Project Background and Methodology-the Key Steps.

Introduction in Section 1 describes the terminology, principles, and also the benefit of conducting cost benefit analysis in the construction industry. The step-by-step of conducting cost benefit analysis for the CRC CI 2002-057-C Research Project, as a summary of a methodology, is also illustrated.

The research project background is explained in Section 2. The project background describes detailed explanations about the research project includes the aims and objectives, the significance, the strategies and deliverables and also all project partners involved.

Section 3 provides the key steps as a methodology for carrying out cost benefit analysis to be adopted for the specific research project: CRC CI 2002-057-C. The methodology contains ten steps which explain detailed information through several processes such as determining the project scope and objectives, quantifying costs and benefits, carrying out sensitivity analysis and finally reporting the cost benefit analysis results.

1.1 What is Cost Benefit Analysis

The term cost benefit analysis is used frequently in business planning and decision support activities. Typically, the cost benefit analysis is used to compare between positive and negative impacts of the application of a new alternative leading to assist decision-makers to facilitate the more efficient allocation of resources (Boardman et al., 1996).

To date, there are many literatures describe the term of cost benefit analysis and in various ways, they say about the same thing: “Benefits-cost analysis is a method of evaluating the relative merits of alternative public investment projects in order to achieve efficient allocation of resources. It is a way of identifying, portraying and assessing the factors which need to be considered in making rational economic choices” (Weick, 1993).

Cost benefit analysis has been applied as a potential tool in a wide variety of project such as river developments (Weick, 1993); transportation (Benefits

Cost Analysis Guidance, 2005); investment in human capital; economic development schemes; mobile computing (Common Management System, 2002; IDC, 2002); and IT projects (Baker et al, 2000; Office of the Deputy Chief Information Officer, 1999).

The application of the cost benefit analysis into the CRC CI 2002-057-C research project is to perform an analysing of the costs and other benefits that could be realised by the deployment of mobile computing devices in the construction sites in order to support data transmission amongst construction personnel, especially construction site workers.

1.2 Principles of Cost Benefit Analysis

The computation of all components of benefits and costs and the choosing of an appropriate method of measurements are found to be a major problem in conducting cost benefit analysis (Watkins). With this in mind, it is important to understand the basic principles of cost benefit analysis. One of the potential basic principles is a unit of measurement. The most convenient common unit of measurement is money. Once all related benefits and costs of the project are identified, they should be measured in terms of their equivalent money value. In some cases, a proposed alternative project or activity/program may provide benefits or costs which are not directly expressed in terms of money, but all benefits received and costs expended must be generated into money value. In other words, under the cost benefit analysis methodology, all potential gains and looses, all related benefits and costs, including those that are indirect and intangible need to be considered. Nas (1996) stated that valuing benefits and costs is a demanding task that requires extreme care and creativity.

1.3 Benefits of Undertaking Cost Benefit Analysis

Studies in relation to the use of information and communication technology in construction industry have been conducting since the last ten years. However, investigations into the implementation of mobile computing devices in the construction sites, especially for construction workers, can be said as a new study. Many construction companies use a manual process to carry out their jobs. All information was transmitted by using word processing documents, spreadsheets, files, faxes, and so on. As company business grows and the workload increases, the paperwork multiples accordingly.

The use of mobile computing devices in the construction sites can be considered as a better tool to eliminating paperwork and increasing the speed of data transmission amongst project personnel. The adoption of a new system in a company, such as the implementation of mobile computing devices on-sites, usually requires a rigorous analysis in terms of cash investment, including tangible and intangible costs and benefits.

In this research project, cost benefit analysis can be used as a measuring device to assist stakeholders to identify clearly the whole life cycle costs and

the expected benefits of the implementation of mobile computing devices on-sites to their equivalent money value. The identified cost and benefit impacts will assist decision-makers to provide further required actions related to providing necessary resources in the future.

1.4 Methodology for the CRC CI 2002-057-C Project

This document provides guidance or methodology for preparing a cost-benefit analysis for CRC CI 2002-057-C Research Project: Enabling Team Collaboration with Pervasive and Mobile Computing. Basically, there is no specific approach or methodology to carry out cost-benefit analysis (Solution Matrix Ltd, 2004). The methodology applied will be depended on the scope and objectives of the project, the information available and also the cost of undertaking the analysis (Department of Finance, 1995).

There are many cost-benefit analysis methodologies that have been published, however, most of them do not directly reflect to a proper cost-benefit analysis for the implementation of mobile computing in the construction sites. The cost benefit analysis methodology provided in this document primarily involves four stages as defined by Baker et al. (2000) which are broken down into ten steps, as adapted from Office of Investment Management (2005) and Department of Finance (1995). The ten detailed steps of the cost benefit analysis methodology can be found in Section 3.

2 Research Project Background

On-site construction operations require complex coordination between a number of activities. Effective construction processes depend on good synchronization of materials delivery, movement of equipment and construction tasks. Coordination tasks are often complicated by schedule pressure and productivity demands, worker fatigue, lack of information, data loss during information exchange, and misunderstanding because of poorly defined information occur.

It observed that the main communication issue in construction is to provide a method to exchange data between the site operation, the site office and the head office. Typically, the site office is located in a temporary location within close proximity to the site operation. The foreman or supervisor on-site needs to be free to roam within the boundaries of the site operation. The information needs under consideration are time critical to assist in maintaining or improving the efficiency at the jobsite. Without appropriate computing support this may increase the difficulty of problem solving.

Computer systems can assist on-site staff to plan ahead, evaluate different options, adopt and execute the most efficient construction operations, and solve unanticipated problems (Magdic et al, 2004). One of the latest IT technologies applied in the construction industry is the use of mobile computing on-sites.

The widespread use of mobile computing devices was one of the IT solutions which made it possible to reach nearly any personnel in any process at any time, thus providing significant support for an undisturbed of information. During the past few years another device has evolved to a mature level such as personal digital assistant (PDA). Its speed, memory capacity, communication possibilities, reliability, small size and long power independence, as well as its level of hardware and software standardization, gives the PDA a powerful potential in the information chain of a construction project.

The term mobile computing is quite new and has no clear definition, although some studies have already tried to survey this fast-growing area of information technology. Mobile computing (Rebolj et al, 2000) does not only involve mobile computing devices (laptops, notebooks, PDAs, and wearable computers), which are designed to be carried around, but also the mobile networks to which these computers are connected.

It is reported that "with a large mobile workforce that is expected to travel and to move on from one site to another, effective communication is one of the strategic tools available for gaining employee commitment, improving morale, increasing productivity, quality and safety and introducing new technologies" (Preece et al, 1998). All parties involved in a construction project are producers, suppliers and consumers of information. Owners, contractors, suppliers, and construction managers will benefit substantially from having the means to deliver and access to information wherever and whenever they need to. Therefore, in order to improve transmission speed of information between the site office, the head office and the supply chain, efficient communication systems and resources are required.

The efficiency of these can be improved by using mobile computing devices in the construction sites. On the project sites level, the exchange of information can be eased and also on the industry-offices level the dissemination of knowledge management, specifications/standards/regulations and best practices can be simplified.

2.1 Aims and Objectives

The main stream of this research project is the use of pervasive computing technology in the construction industry – focusing on the implementation of mobile computing devices in the construction sites. It will present a model of team collaboration that relies on continuous communication to people and information to reduce information leakage.

The research project aims to improve the costly and time-consuming process of data collection and analysis/processing at the interface between physical site operation, construction management activities and consultancy practice – project activities that are generally considered by contractors and

consultants to be tedious and error-prone due to extensive information leakage.

The objectives of the research project are to:

- Examine recent developments in information and communication technology (ICT) focusing on mobile computing technologies.
- Collect mobile computing devices information suitable for construction industry.
- Identify mobile computing software available with application to construction industry.
- Survey of information needs of construction sites.
- Identify relevant human-computer interfaces, and wireless mobile computing devices for the use in construction sites.

2.2 Project Significance

Consolidating research from several authors (Capgemini, 2004; Done, 2004; Haas et. al, 2002; Eisenblaetter, 2001; Jadid and Idress, 2005; Rebolj et al. 2000) when mobile computing is used properly in the construction industry, some benefits can be achieved such as improved business productivity, reduces paperwork, eliminates redundancy in project task operations, reduces response waiting time, greatly limits revision of the job tasks, enhance worker efficiency, increase knowledge-sharing amongst workers, customers and partners, improve quality of decision making by informing employees.

Using mobile computing devices remote team members can communicate and access up-to-date information including specifications, standards, regulations and etc. Other benefits of using mobile computing was reported by Daito in Rebolj et al. (2000) and Jadid and Idress (2005) such as eliminating redundancy in project task operations, reducing waiting time respond and limiting job tasks revision.

A recent research project funded by the Office of the Deputy Prime Minister in UK (Capgemini, 2004) identified the potential benefits of the implementation of mobile computing in the six National Projects. On average, by implementing mobile computing, the national annual value added was £150m. Other significant benefits reported by the Council were the reduction in paperwork by over 80% and reduction in response time to service requests by more than 50% (from 45 days to 12 days).

Another research conducted by Haas et. al (2002) reported that a significant benefit of using handheld computers in construction was achieved. Handheld computers application could potentially reduce the delay time by approximately 50 to 95% for a different type of activities during the construction process.

2.3 Project Strategies and Deliverables

The Enabling Team Collaboration with Pervasive and Mobile Computing research project started in September 2004. This research project was divided into three phases:

- **Phase 1: Case analysis**

  The case analysis is related to industry analysis with the following activities:

  - Review of wireless data access providers focusing on coverage in Australia, bandwidth, cost of bandwidth, network reliability, and physical environment limitations.
  - Review of mobile computing devices focusing on feature sets relating to business needs of construction industry and off-the-shelf applications.
  - Survey of industry needs of construction sites with a focus on type/nature, format, frequency, size and length, quality of services, workflow, security, etc.
  - Survey mobile computing software with application to construction industry.

- **Phase 2: Technology adaptation**

  Phase two is to adopt and adapt existing human-computer interface and mobile computing technology to enable remote data acquisition and novel interaction with design construction data. In this phase, training material for mobile computing devices is to be created.

- **Phase 3: Uptake analysis**

  Phase three is to test actual information delivery capabilities of mobile computing devices to theoretical given framework from phase one and validate framework, with the following activities:

  - Identify construction site and specific aspects of a case study.
  - Create study protocol and test equipment.
  - Train users on mobile computing devices.
  - Run study and collect data from retrospective protocols.

By implementing mobile computing devices in the construction sites several potential deliverables are identified such as streamlining and making more efficient the normal day-to-day consulting and construction-related business activities leading to reduce effective cost of data transmission and improve communication to all project participants.

2.4 Project Partners

The Cooperative Research Centre (CRC) for Construction Innovation is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, Construction Innovation is developing key technologies, tools and management systems to improve the effectiveness of the construction industry.

The CRC for Construction Innovation research focuses on the following three core areas integrally underpinned with advanced applications of Information and Communication Technology (ICT):

- A: Business and Industry Development
- B: Sustainable Built Assets
- C: Delivery and Management of Built Assets.

The research project number 2002-057-C: Enabling Team Collaboration with Pervasive and Mobile Computing is one of the CRC for Construction Innovation research projects that is led by Queensland University of Technology in conjunction with some organisations: Commonwealth Scientific & Industrial Research Organisation (CSIRO), The University of Sydney, John Holland Group Pty. Ltd. and Woods Bagot Pty. Ltd.

- **Commonwealth Scientific & Industrial Research Organisation (CSIRO)**

  CSIRO is one of the world's largest and most diverse scientific global research organisations which is working from sites across the nation and around the globe. The organisation focuses on providing new ways to improve human quality of life, as well as the economic and social performance of a number of industry sectors through research and development. These sectors are:

  - Agribusiness
  - Energy and Transport
  - Environment and Natural Resources
  - Health
  - Information, Communication and Services
  - Manufacturing
  - Mineral Resources.

- **The University of Sydney**

  The University of Sydney, founded in 1850, is Australia's first university. Over the past 150 years, the University has built an international reputation for its outstanding teaching and as a centre of research excellence.

As one of Australia's leading universities, the University of Sydney is a key member of the Group of Eight of Australia's major research intensive universities and the Association of Pacific Rim Universities (APRU). For the past four years, Sydney has led the nation in winning competitive funding from the Australian Research Council (ARC). The University has nine of the Federal government's 49 prestigious Federation Fellowships and performs strongly in research conducted collaboratively with industry.

- **John Holland Group**

  John Holland Group is one of Australia's oldest and most respected general contractors. Since its establishment in Victoria in 1949, the John Holland Group has expanded operations across Australia and is now one of the largest contractors in the nation.

  As one of the nation's largest and most experienced contractors, John Holland capabilities span all facets of civil engineering and building construction, with specialist businesses operating nationally in the tunneling, water, structural mechanical process, mining and telecommunications sectors. John Holland is also Australia's leading rail contractor, refurbishing and maintaining railway lines throughout the country.

- **Woods Bagot**

  Woods Bagot, established in Adelaide in 1869 has grown to be one of the larger architecture firms in the world. The company now has 12 offices in Australia, Asia, Middle East and Europe.

  Woods Bagot has grown through excellence, innovation and the desire of their skilled people to constantly create quality design. The company's core disciplines are architecture, interior design, urban design and landscape architecture, and strategic planning and consulting. They specialise in the design of facilities for education, transport, retail, residential, hospitality, sport and leisure, health, specialist and IT, defence and commercial clients in the private and public sectors.

- **Queensland University of Technology**

  Queensland University of Technology (QUT) is a leading Australian university with a colourful history dating back to the beginning of technical and teacher education in Queensland when the Brisbane School of Arts was established in 1849.

  In 1908 the Central Technical College began offering technical education courses on the site of QUT's present Gardens Point campus, continuing the Central Technical College's tradition of

vocation-linked education. The Central Technical College's courses became the responsibility of the Queensland Institute of Technology (QIT) in 1965 when it was established to meet the growing needs of industry. While still an institute of technology, QIT had a strong research and development profile as well as a record of effective teaching.

The Queensland University of Technology was created in January 1989 by redesignation of the Queensland Institute of Technology. In May 1990, QUT amalgamated with the Brisbane College of Advanced Education (BCAE) which specialised in courses in arts, business, education and social sciences. The institution resulting from the amalgamation of BCAE with QUT retained the title Queensland University of Technology.

3 Cost Benefit Analysis Methodology – the Key Steps

Office of Investment Management (2005) stated that a cost-benefit analysis is a tool for assisting project managers when they are evaluating and computing different alternatives. Results from a cost-benefit analysis, along with public input and environmental documentation, can be used to evaluate both the monetised and non-monetised effects and impacts of alternatives when a decision needs to be made.

There are some important issues that project teams should consider to answer before undertaking cost benefit analysis (Office of Investment Management, 2005):

- What additional benefits will result if this alternative is undertaken?;
- What additional costs are needed to implement this alternative?; and
- From an economic perspective, are the benefits worth the investment?

As there is no specific cost-benefit analysis methodology related to the implementation of mobile computing in the construction sites, the methodology proposed in this document is referred to some methodologies from several books, papers and other industry documents. However, predominantly the four stages of this methodology proposed, which are broken down into ten steps, are adapted from Baker et al. (2000), Department of Finance (1995), and Office of Investment Management (2005). The methodology stages and steps can be viewed in Figure 1.

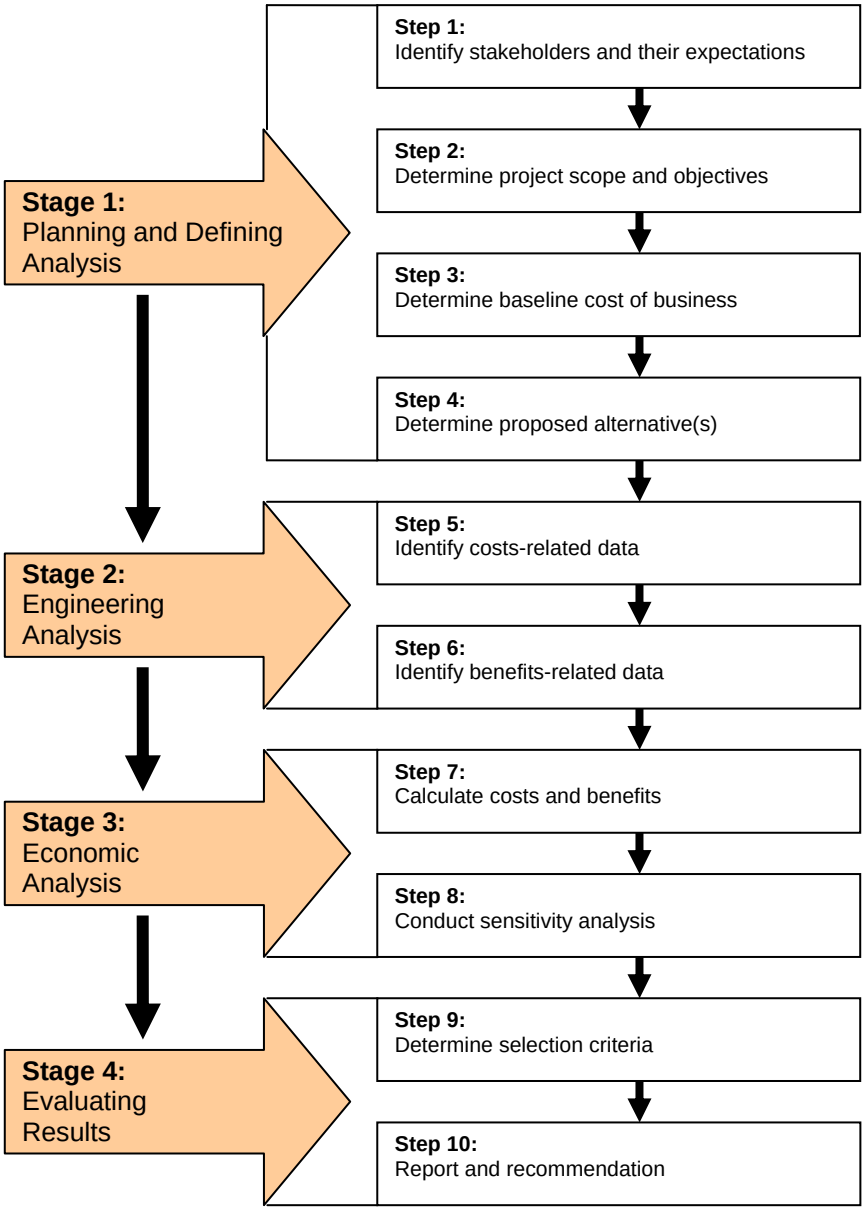

Figure 1. Stages and Steps of Cost-Benefit Analysis

3.1 Step 1: Identify Stakeholders and their Expectations

Stakeholders can be identified as individuals or organisations that are actively involved in the project or who will be affected by the completed project. Baker et al. (2000) argued that the type of stakeholders and their expectations should be clearly identified before conducting cost-benefit analysis. By knowing stakeholders' expectations, detailed project scope and

objectives can be determined leading to determine the level of detail needed in the cost-benefit analysis. Stakeholders can be categorised into internal and external stakeholders. Internal stakeholders include project teams and clients, whereas external stakeholders are identified as other project participants such as subcontractors, suppliers etc.

3.2 Step 2: Determine Project Scope, Objectives and Deliverables

In order to produce an appropriate cost-benefit analysis result, the determination of the scope, objectives and deliverables of the project is very important. Basically the determination of the scope, objectives and deliverables depend on the stakeholders' needs, as stated in the previous step. Project scope can be described as the work that must be done in order to deliver a product with the specified features and functions to accomplish a major goal that supported by several objectives. The scope should contain both what the project will and will not deliver. The objectives of the project are usually more precisely and must be action oriented. Project deliverables are to be defined to measure the outputs of the project objectives.

When scoping the project, the clearly understanding and identification of the business interest is a must. This process usually includes some issues in order to solve certain business problem, to improve a certain process and also to make a task more efficient.

3.3 Step 3: Determine Baseline Cost of Business

The third step in the cost-benefit analysis methodology is to determine the baseline cost of business or the current process of the implementation of mobile computing devices in the construction industry to support data transmission amongst project participants. The baseline should explain the real current processes of data transmission including all cost associated with the process. Some important issues to be addressed related to baseline cost of business are as follows:

- **Information/data characteristic:**
    - Information flow,
    - Information needs on construction sites,
    - Size and/or length of information,
    - Frequency of data transmission (how often and when),
    - Importance of information,
    - Transmission time of information,
    - Forms of documents circulating on-site (printed forms, electronic forms), and
    - Nature of information (texts, graphics, drawings, photos, etc).

- **Communication network:**
    - Number of entities and individuals need to communicate together,
    - Centralised or decentralised network,
    - Procurement system ,
    - Communication media used,
    - Level of security, and
    - Project collaboration system (to communicate to other project participants).

- **Integrated management system:**
    - Types and numbers of existing hardware used,
    - Types and numbers of existing software used,
    - Other equipment required to support current operation system,
    - System capabilities (storage space, processing speed, online access, bandwidth, data synchronisation), and
    - Document management system; automation data flow amongst project participants.

- **Human resources characteristics:**
    - Appropriate skilled personnel in computer literacy and ICT knowledge

3.4 Step 4: Determine Proposed Alternative(s)

A proposed alternative is a specific product and/or system that will be implemented into the baseline or current process. The proposed alternative can be either implemented as a part of the existing system or as totally a new system replacing the existing one. The proposed alternative must have a specific characteristic to support the project objectives leading to improve existing process. In addition the alternative should detail the estimated costs and expected benefits that the proposed alternative will target

In the context of cost-benefit analysis, the deployment of mobile computing devices is identified as a specific alternative system of data transmission improvement in the construction sites. These improvements would change data access speed and operating time and costs from the baseline.

3.5 Step 5: Identify Costs-related Data

The fifth step of undertaking cost-benefit analysis is to identify cost data. Baker et al. (2000) considered two different types of cost data to be identified such as cost categories and full lifecycle costs. The cost categories include all necessary costs incur during the preparation and implementation

of the proposed alternatives, whereas the lifecycle costs express how much it will cost to maintain the proposed alternative after implementation.

Typical cost categories are as follows (Baker, 2000; Remenyi et. al., 1998):

- Software including configuration and customisation;
- Hardware;
- Integration with other systems (other hardware needed);
- Local-area and/or wide-area network;
- Data;
- Internal staff;
- Training;
- Delivery services (project management, change management, etc.);
- Support and maintenance, either due to in-house specialist or third-party vendors;
- Consumables such as disks, floppy diskettes, magnetic tape, printer ribbons, toner cartridges;
- Cost involved in upgrading software and hardware; and
- Redesign and convert existing documents (if not appropriate) into more appropriate data formats, which are supported by the selected application software.

As Office of the Deputy Chief Information Officer (1999) identified that this is the most important step, they identified six sources of data that must be collected from. The sources of data are as follows:

- **Historical organisation data:**
    - By making any necessary adjustment, historical data can be used to estimate future expenses of the implementation of proposed alternative systems.

- **Current system costs:**
    - The current process costs of the organisation can be used as a guidance to estimate the costs of the proposed alternative to be implemented. Assuming percentage increases and decreases from the current system will be useful to estimate the proposed alternative.

- **Market research:**
    - Market research is to be conducted properly to obtain realistic prices of hardware, software, etc from multiple sources. The information can be used to provide cost estimation for future expenses on the proposed alternatives.

- **Publications:**
    - Valuable information from trade journals, industry publications are found to be one of good sources of cost data. The publications usually provide general cost data.

- **Analyst judgment:**
    - When data is not available to provide an adequate cost estimate, the judgment and experiences of the cost-benefit analysis team members is needed. In some cases, the discussion can be conducted with other specialist, both in government and industry, in order to identify strengths and weaknesses of estimating logic.

- **Special studies:**
    - For large and specific projects, special studies such as in-house studies are to be carried out to assist in collecting cost data. It is important to note that before spending hundreds of millions dollar on IT investment for data transmission improvement, special studies should be considered to provide more detail information leading to support an appropriate decision.

3.6 Step 6: Identify Benefit-related Data

The next step in undertaking cost-benefit analysis is to list all benefits or advantages that the project will target. Baker et al. (2000) argue that it is useful to group a lengthy list of benefits into several different benefit categories. The identified benefit data should be scheduled over the expected project implementation and maintenance duration.

In the case of deployment of mobile computing in the construction sites, the set of benefits categories are as follows:

- **Labour efficiency/Improved productivity**
    - Reduce a number of crew, and
    - Increase labour productivity.

- **Equipment efficiency**
    - Better equipment management.

- **Time and cost savings**
    - On-site data collection: download/upload times for documents from the Internet,
    - Data entry and avoid data re-entry,
    - Timesheets recording,

- Progress reporting, and
- Reduce paperwork.

- **Data access and transmission**
  - Speed up data access to specifications, standards (QA/QC), shop drawings, regulations, supplier information, tools and methods, work package information (updated schedule), contract documents, subcontractor information, health and safety regulations, etc.
  - Speed up data transmission to all project participants such as Clients, Consultants, Architects, Subcontractors, Project Managers, etc.

- **Procurement system**
  - Access to material management,
  - Material location and material order status,
  - Request materials to site,
  - Request equipment to site, and
  - Equipment location.

3.7 Step 7: Calculate Costs and Benefits

The calculation of costs and benefits has to be done after identifying cost and benefit-related data. The cost and benefit data need to be monetised and aggregated for the economic valuation analysis. Adopted from Office of Investment Management (2005), the economic valuation should be included different types of costs such as:

- **Estimating capital cost**
  - Capital cost is the total of the investment required to prepare the proposed alternative. Capital cost can be broken down into several work packages to make it easier to calculate remaining capital cost.

- **Maintenance cost**
  - During the implementation of proposed alternative, it is important to account future operating and maintenance costs of the facility. In some cases, a major rehabilitation cost, such as future investment, is needed to maintain the serviceability of a major facility. This should be included as well in the analysis.

- **Remaining capital value**
  - Many components of a proposed alternative retain some residual useful life beyond the cost-benefit analysis period

(typically 10/20/30 years). At the end of the analysis period, the facility that has been put in place generally has not been completely worn out, and will continue to provide benefits to construction personnel in the future. It is important to reflect this value in the analysis.

The calculation of costs and benefits should consider two parts: construction user benefit calculation and cost calculation. Detail of these calculations is described as follows.

- **Construction user benefit calculation.**

  There are four steps in calculating total construction user benefit:

  - Assemble and generate all cost and benefit data for the Baseline and proposed Alternative. The spreadsheet can help simplify calculations and organises the results.

  - Compute the difference in all cost and benefit data between the Baseline and the proposed Alternative.

  - Compute the total benefit for all cost and benefit data during the analysis timeframe. The total benefit is calculated as follows:

    - Find the annual savings for each year in the analysis period.
    - Discount the annual benefits back to the year of analysis.
    - Find the overall savings for all cost and benefit data by summing the present value of the annual benefit for each year in the analysis timeframe.

  - Find the total construction user benefit of the proposed alternative as compared to the Baseline by summing the overall savings for all cost and benefit data.

- **Cost calculation**

  There are four steps in calculating agency cost:

  - Construction costs for the proposed alternative should be estimated and allocated to the anticipated year of expenditure. In the case that the expenditures cannot be scheduled properly during the implementation of the proposed alternative, the cost should be divided over the time of the implementation period.

- Maintenance costs for both the baseline and the proposed alternative are essential to be included in the estimation during the time period of implementation.

- At the end of the cost-benefit analysis period, the remaining capital value should be evaluated and discounted to the year of analysis.

- The last step is the calculation of the total present cost for the Baseline and the proposed Alternative. Table 1 shows the calculation of the present cost.

Tabel 1. Example of Total Present Cost

Year	Capital Cost		Maintenance Cost		Remaining Capital Cost		Present Value of Net Annual Costs
	Baseline	Alternative	Baseline	Alternative	Baseline	Alternative	
1							
2							
3							
4							
5							
etc							

Source: Office of Investment Management (2005)

3.8 Step 8: Conduct Sensitivity Analysis

The parameters used to generate costs and benefits during the NPV calculations are always in some degree uncertain and it will affect the cost-benefit analysis' results. Where the NPV is shown to be sensitive to changes in a parameter, it is useful to find out how sensitive a cost-benefit analysis' result is to variations or errors in the data and assumptions. Sensitivity tests can be done to acknowledge the underlying uncertainty. The sensitivity analysis describes a process of establishing the extent to which the outcome of the cost-benefit analysis is sensitive to the assumed value of the inputs used in the analysis. In this case the analysis is used to test how sensitive the NPV of the proposed alternative is to the choice of discount rate.

According to Office of the Deputy Chief Information Officer (1999) there are three steps required to carry out sensitivity analysis: identification of input parameters, repetition of the cost analysis, and evaluation of the results.

3.9 Step 9: Determine Selection Criteria

The selection criteria are conducted to show whether the proposed alternative is economically justified compared to the baseline. Office of Investment Management (2005) defines two criteria to justify the results of the cost-benefit analysis: benefit-cost ratio and net present value. When multiple alternatives are being considered, an incremental benefit-cost ratio analysis can be used to determine which alternatives are the most economically desirable.

- **Benefit-cost ratio**

  Benefit-cost ratio can be obtained by dividing the sum of the discounted benefits with the sum of the discounted costs, and is represented by the following formula:

$$B/C = \frac{PV(Benefits)}{PV(Costs)} \quad \text{..... (1)}$$

  B/C = Benefit-cost ratio
  $PV_{(x)}$ = Present Value of x

  If the result is greater than or equal to 1.0, the proposed alternative is economically justified.

- **Net present value**

  All cost and benefits that might be incurred in the future years should be discounted to the base year using the adopted discount rate. The net present value can be obtained by subtracting the sum of the discounted benefits with the sum of discounted costs, and is represented by the following formula:

$$NPV = \cdot PV(Benefits) - PV(Costs) \text{ ..... (2)}$$

  NPV = Net Present Value
  $PV_{(x)}$ = Present Value of x

  If the sum of the discounted benefits is greater than the sum of discounted costs, the net present value is positive and the proposed alternative is deemed to be economically justified.

3.10 Step 10: Report and Recommendation

As the cost-benefit analysis is known as a decision-support tool, the results should be well documented and reported to the decision-makers. The report must be able to convey and interpret the main findings in a style that is user-friendly and meaningful to the decision-makers. The report should have a concrete recommendation including particular assumption used when calculating the cost-benefit analysis.

Campbell and Brown (2003) recommend that the report should consist of an Executive Summary; four main sections: Introduction, Methodology, Analysis and Conclusion; and Appendices containing necessary spreadsheets tables.

- **Executive Summary**

  The executive summary, which manages to highlight the main issues, summaries the main findings, and make a recommendation in one page, should be written after a draft of the report has been completed. It begins with the introduction of the project, including its aims and objectives and all project participants, and then describes the options, discusses the form of analysis undertaken and the main findings and concluding by some recommendations.

- **Introduction**

  The introduction section contains a brief summary of the project and provides the readers with a fairly general description of what the project is about and what decision the analysis intends to inform.

- **Methodology**

  It is necessary to include the methodology and all assumptions used in the analysis into this methodology section. This section should detail information in relation to: source and types of data; any verification process that is followed; timeframe; tool and method of analysis.

- **Analysis**

  This section contains the process and the findings of the analysis. Tables can be used to summarise the findings and discussion should be followed to interpret all data being analysed.

- **Conclusion**

  The conclusion should synthesise the main findings, discuss their relevance and explore their possible implications for the purpose of decision-making. Attention is also drawn to areas where further, more detailed work might be undertaken before a final decision is reached. A fairly concrete recommendation should be included as well in this section.

4 Summary

The exchange of data and information amongst construction personnel should be managed properly to maintain or improve the efficiency at the jobsite. The use of mobile computing devices is now become a basic need for construction personnel to communicate, especially for those who work on-site. The application of mobile computers within construction industry has been carrying out since the last ten years. However, the deployment of mobile computing devices for construction workers on-site is found to be a new technology applied.

A cost benefit analysis methodology provided for this particular CRC CI research project is a measuring device to assist stakeholders to identify

clearly all potential costs and benefits associated with the deployment of mobile computing devices in the construction sites. As the most common unit of measurement of the cost benefit analysis is money, all related costs and benefits, tangibles and intangibles, of the alternative project identified should be measured in terms of their equivalent money value.

As there is no specific approach to undertake cost benefit analysis, the methodology applied will be depended on the certain circumstances such as the project scope and objectives, the information available and also the cost to undertake the analysis. The methodology proposed in this document is referred to some methodology from several potential resources. The methodology consists of four main stages and is broken down into ten detailed steps which are adapted from Baker et al. (2000), Department of Finance (1995) and Office of Investment Management (2005). This cost benefit analysis methodology will be conducted in the CRC CI 2002-057-C research project case studies in Australia and report and recommendation will be completed in accordance with the ten-detailed-step provided in the methodology.

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