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INFORMATION SYSTEMS FOR DATA CENTRES: DESCRIPTION AND OPERATIONAL CHARACTERISTICS

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Abstract

Information systems are widely used in data centres for a variety of reasons. There is, however, limited literature on the role of information systems for automating data centres. In particular, there is a lack of research on the matter of definition and description as well as the data centre processes that information systems support. Furthermore, among information systems that are specific to data centres, there is limited knowledge as to how these systems are used to automate data centres and improve their sustainability. To address these concerns, this paper investigates nineteen information systems that are being used within data centres identified from five case studies and a review of practitioner literature. The paper draws from existing research on information systems classifications, examines the dimensions, operational characteristics and value attributes of the nineteen systems and develops and refines a characteristics-based framework for describing data centre information systems. The application of the framework shows that data centre information systems can be classified and described based on their role, portfolio, managerial function, product utility and value chain.

Keywords: Data Centre Information Systems Classifications, Data Centre Automation, Data Centre Sustainability, Green IT/IS

1 INTRODUCTION

The role of information systems (IS) and information technology (IT) for improving the sustainability of business operations is attracting the attention of policy makers, practitioners and researchers alike (Melville 2010). Sustainability is a broad concept which can be approached from the economical, environmental and social dimensions (Elkington 1997; Searcy et al. 2008). In the business context, economic sustainability refers to the capability of an organisation to secure its long-term economic performance through maximising shareholder's returns. The environmental sustainability is about the ability of an organisation to use natural resources to meet its current needs without compromising its future needs as well as the needs of other organisations. The social sustainability refers to an organisation's responsibility and commitment with respect to its obligations to communities and society. These three dimensions are highly interlinked in which improving one will have a direct impact on the other.

IT and IS have multifaceted effects upon sustainability. The use of IS and IT lead to positive economic, environmental and social gains. These include profit maximisation, dematerialisation and virtualisation, and social responsibility enhancement (Berkhout & Hertin 2004 However, IT and IS also lead to some unintended side-effects of large operation cost, energy consumption, electronic waste and social value degradation (Köhler & Erdmann 2004; Searcy et al. 2008; Lamb 2009). The negative side-effects of IT coupled with the increased dependency on IT and IS have elevated the importance of sustainable IT/IS management in modern organisations. Sustainable IT/IS management is in fact one of the strategies that offers opportunities to develop IT and IS solutions that are economically, environmentally and socially sustainable (Berkhout & Hertin 2004; Lamb 2009). A sustainable IT and IS can therefore yield to substantial economic (e.g. reduction in energy cost, optimisation of resource, performance and productivity), environmental (e.g. reduction of carbon emissions, enhancement of compliance, and enhancement of corporate environmental responsibility and social (e.g. reduction of final service and product cost to the society, and enhancement of corporate social responsibility) benefits (Berkhout & Hertin 2004; Lamb 2009; Schulz 2009).

One of the areas where the role of IS for sustainability can be observed is Data Centre (Lamb 2009). Data Centres refer to business facilities that contain large information and communication technology (ICT) infrastructure such as computer equipment and servers to store, manage, process, and exchange digital data and information. A Data Centre could either corporate or co-located Data Centre (Alaraifi et al. 2010). A corporate Data Centre is a facility that serves the connectivity and information processing needs of a single organisation. On the other hand a co-located Data centre is a facility that hosts clients' IT equipment and supplies fully redundant subsystems (e.g., cooling, power generation, physical security) to the hosting clients' equipment. As cloud computing and infrastructure as service models get widely diffused, the automation and sustainability of Data Centres is becoming important (Schulz 2009).

Data Centre can leverage the power of IS to improve not only their operational and cost performance but also their environmental footprint. For example, Schulz (2009) proposes that IS solves various Data Centre problems such as resource inefficiency and infrastructure utilisation. Krauter et al. (2002) and Siddiqui and Fahringer (2010) show that the use of IS improves resource on-demand provisioning, share balancing, resource efficiency, optimisation, infrastructure monitoring and security, capacity planning, lifecycle management, and quality of service. This implies that Data Centres (as IT spaces) provide unique opportunities to study how IS can be used to address the management and sustainability of IT. Despite such possibilities, there is limited literature on what types of IS are used in Data Centres. In particular, there is a lack of research around matters of definition and description as well as the Data Centre processes that the IS support. Given that both academics and practitioners are interested to examine the characteristics of IS and to assess their values to organisational operations (Agarwal et al. 1997), this paper explores the characteristics of IS used in Data Centres. It builds on existing research in IS to develop and refine a characteristics based framework by examining the role, portfolio, managerial function, product utility and value chain of nineteen Data Centre specific IS.

The remaining part of the paper is organised as follows. The next section reviews the IS literature to develop a characteristics based framework to explain the IS used in Data Centres. Section three details the research method followed to undertake the study followed by the findings and discussion. The paper concludes by highlighting the contributions of the study and avenues for further studies.

2 RELATED LITERATURE

This section reviews the characteristics of IS in order to develop an IS characteristics based classification framework that can guide the analysis of IS used in Data Centres**.** There are two main perspectives for approaching IS: *attributes and functions* (Ein-Dor & Segev 1978). Whereas the attributes of IS focus on the components of the system including hardware, software, keyboard and monitor, the functions focus on what an IS does such as input, processing, output, interface, storage. This study focuses on the latter definition of IS to explore some of their distinguishing characteristics. The function oriented approach allows more feasibility for comparing the performance of innovation within different organisational settings and allows more systematic methods of mapping the determinants of an innovation (Hekkert et al. 2007).

IS functions are numerous including the creation, exchange and supply of information and knowledge, the automation of business processes, and the support of managerial activities in organisations (Chen et al. 2008). Our review of the IS literature has identified five major dimensions to explain IS functions. These are IS role, management level, value-chain, and portfolio product-utility. Each of these dimensions is discussed next.

2.1 IS Role Proposition (ISRP)

IS play three intrinsic roles including automation, informatisation and transformation (Zuboff, 1988). Automation and informatisation refer to the substitution and augmentation of human efforts respectively, whereas transformation refers to restructuring human efforts (Cash et al. 1994). For many organisations, automation of manually-performed operations is considered as the first role of IS. Automation serves as a vehicle for cost reduction and operational efficiency by replacing expensive human labour and enhancing organisational ability of information processing (Chen et al. 2008; Alaraifi et al. 2010). Through informatisation, IS improve the upward and downward link between organisational members allowing for codified knowledge and boundary spanning capabilities (Chen et al 2008). Upward informating is often associated with organisational control enhancement, and downward informating is typically associated with stakeholders' control enhancement over products and by-products (Schein, 1989). Transformation is the ultimate role of IS for many organisations as it can fundamentally change the nature of products or services and organisation's relationship with its stakeholders (Watson et al 2010; Zuboff, 1988). Although the transformation role is not distinctly defined in the IS literature (Alaraifi et al. 2010), some researchers argue that in the long-run, automation can lead to transformation by helping organisations generate long-term benefits through transforming the way they conduct their businesses (Chen et al. 2008).

2.2 Management Level Perspective (MLP)

One of the important functions of IS in modern organisations is their ability to provide support to the managerial activities such as coordination, control, audit, and business intelligence (Espejo & Harnden 1989). With the complexity of organisational structures, most organisations tend to cope up with communication systems (e.g., groupware systems) that facilitate effective networking between various levels of organisations (Teng & Ramamurthy 1993). In addition, organisations utilise the advances in business intelligence and decision support systems to aid management's decision making process (Alter 1999; Bradley et al. 2006). Based on the management level that they support, IS that either automate or informate or transform, can be classified as operational, tactical and strategic.

IS has a long history of use in support of operational level tasks including automating basic, routine and transactional events. Management information and decision support systems aid tactical managers to inform-down operational activities; inform-up top level managers and make decisions. Strategic level systems such as executive support systems allow senior level managers to direct the entire organisation including support for business growth, business alliance and building external linkages (Shang, & Seddon 2002; Bradley et al. 2006).

2.3 IS Portfolio View (ISPV)

With respect to the value of IS assets, IS investments can further be classified into strategic, informational, transactional and infrastructure (Weill & Aral 2006). Strategic IS investments refer to IS that help organisations to obtain competitive advantages and position themselves in the industry. Whereas informational investments supply the information needs of typically operational and tactical level managers in various organisational activities such as accounting, reporting or communication. Transactional investments automate routine business processes for the objective of cost cutting. Infrastructure investments, on the other hand, provide flexible base for the utilisation of shared IS services on a long-term basis such as reducing long-term IT costs or facilitating future business initiatives. Thus, building on IS portfolio view, the impact of IS investment can be classified into strategic, informational, transactional and infrastructure.

2.4 Value Chain View (VCH)

The contribution of IS to organisational performance and how it affects critical business activities within an organisation's value system have received considerable attention by IS researchers (Tallon et al. 2000; Gorla et al. 2010). Amongst the various ways used to assess the contribution of IS within an organisation process, the value chain model is the most widely known in the IS research (Tallon et al. 2000). The value chain is divided into a sequence of primary and support activities. Primary activities (inbound logistics, operations, outbound logistics, marketing and sales, and service) involve physical creation of products, sales of products, and after sales support. Support activities such as administrative, infrastructure management, human resource management, research and development, and procurement provide support to the primary activities (Porter 1985). Building upon the value chain model, IS could be classified into two broad categories – those that support primary activities and those that support secondary activities. IS support for primary activities include coordination and communication linkages with supplier through electronic exchange (inbound logistics activities), improvements in the production process of manufacturing techniques through automation (operations activities), enhancement of marketing programs and customer reach (marketing activities), innovativeness and uniqueness in sales channels (sales activities), and development of innovative services (service activities). IS support for secondary activities includes administrative infrastructure management, human resource management, R&D, and procurement (Tallon et al. 2000).

2.5 Products-Utility Focus (PUF)

A further classification of IS can be made in accordance to the products-utility focus using the tool view of technology (Kling 1987). The tool view of information technology can be described as *'A computing resource [that] is best conceptualized as a particular piece of equipment, application or technique which provides specifiable information processing capabilities.' Kling (1987, p. 311).*

Following a tool view, Orlikowski and Iacono (2001) conceptualised IS into four categories; a tool for labour substitution, a tool for enhancing productivity, a tool for information processing, and a tool for changing social relations. Labour substitution, which relates to the automation role of IS, refers to the ability of technology to increase productivity through replacement of labour force by allowing fewer people to perform more work (Chen et al. 2008). Enhancing productivity refers to the use of technology, at operational, tactical and strategic levels, to extend individuals and organisational performance by providing faster, more efficient, and more accurate ways of working (Orlikowski & Iacono 2001). IS is regarded as an information processing tool when it alters and enhances the ways individuals and organisations process information (e.g. email systems alter the way people communicate by enhancing feedback and learning). This is similar to the informatistion and transformation role of IS. IS is also used for changing social relations by altering the social roles, hierarchies, business processes communication within a society (e.g. Internet social networking portals). Thus, based on the IS products-utility focus, IS can be classified into tools for labour substitution, enhancing productivity, information processing, and changing social relations.

By consolidating the different classifications of IS discussed above, a preliminary IS characteristics based classification framework is developed as shown in Table 1.

Dimension	Description	Attribute
IS Role	Focuses on the generic role played by IS	• automation, • informatisation, • transformation.
Management Level	Focuses on the IS advantages based on the management level they serve	• strategic information systems, • management information systems, • operational information systems.
IT Portfolio	Focuses on the domain of IS investment and value within an organisation.	• strategic IS, • infrastructure IS, • informational IS, • transactional IS.
Value Chain	Focuses on organisational activities that can be performed through IS to generate competitive advantage for organisations	• primary activities (inbound logistics, operations, outbound logistics, marketing and sales, service), • support activities (administrative infrastructure management, human resource management, R&D, procurement).
Products-Utility	Focuses on specifiable capabilities of IS to perform well-defined tasks and generate desirable outcome.	• tool for labour substitution, • tool for enhancing productivity, • tool for information processing, • tool for changing social relations.

Table 1. A Preliminary IS Characteristics-Based Classification Framework.

The above classification is not intended to provide mutually-exclusive categorisation of IS, but to introduce methods on how different systems can be categorised and to identify the category that can best describe a system based on its functionalities. To this end, the above review outlines as much IS characteristics as possible by combining relevant and credible research on IS classification. Although Table 1 contains a variety of IS classificatory schemes, an IS can be categorised into more than one class at the same time. In addition, the dimensions of the five IS classes interrelate and overlap with each other. For instance, the automation role of IS, which is based on the IS Role proposition, is similar to the products-utility view of IS as a tool for labour substitution. Likewise, the management level view and IT Portfolio view share the concept of using IS as a strategic vehicle. Nevertheless, while none of the five classifications are adequate to capture all the dimensions and value attributes of any IS by its own, consolidating multiple classificatory schemes, with each having different lens allows more rigour in understanding the common IS functions. In other words, the proposed framework avoids the deficiency of using a single IS classification scheme. In the subsequent section, we will apply the characteristics-based classification framework to e analyse Data Centre specific IS**.**

3 RESEARCH METHOD

The research method for explaining the IS used in Data Centres builds on two main sources of data: empirical data gathered from five case studies of Australian Data Centres and a review of the practitioner literature on Data Centre Information Systems (DCIS). There are four main reasons for choosing these two methods. First, there is little or no academic empirical research focusing on the DCIS. . Second, assuming that the benefits of IS investments in Data Centre is of an important concern for Chief Information Officers (CIOs), it was therefore expected that this topic would be discussed in publications targeted at CIOs and IT executives. The practitioner literature allows a reasonable snapshot of how DCIS are currently positioned in the field. Third, given that Data Centre managers are the persons most familiar with DCIS, it was very important to acquire empirical information from case studies of Data Centres. Lastly, consolidating data collected from practitioners' literature together with empirical data ensure that the collection of a representative sample of DCIS. It also improves the practicability of the identified IS and provides systematic comparisons of the DCIS identified from the two sources.

3.1 The Case Study Method

An empirical study comprising face-to-face interviews with five Data Centre managers in Australia were undertaken during the first half of 2010. The Data Centres were identified using the snowballing sampling technique based on the contacts developed through attending Data Centre workshops and conferences. The study was intended to identify all types of IS used in Data Centres. The interviewees were used as key informants to advise not only their own practice but also the practices that they are aware of. As stated by Eisenhardt (1989, p. 533), case studies help to understand the dynamics present either within a single or multiple settings, and as such is relevant for investigating the IS used in Data Centres. Four of the Data Centres kindly offered a tour of their facilities including live demonstration about all existing IS. The collected data were analysed using content analysis techniques. A summary profile of the data collected from the five Data Centres is presented in Table 2.

Case No.	1	2	3	4	5
Data Centre type	Corporate	Corporate	Co-location	Co-location	Co-location
Industry	Education	Education	IT services	Telecommunication	IT services
Targeted business	Internal clients	Internal clients	Large and SME firms.	Large and SME firms.	Public enterprises and agencies.
Age of the facility/infrastructure	Old	Old	New	Old	New
Number of IS in the data centre	11	10	6	6	12
Number of IS known to be used by peer data centres	14	13	9	9	13

Table 2. Profile of Case Data Centres.

3.2 The Practitioner Literature Review Method

The practitioner literature review was done based on the protocol of Corbett (2010). As a result, we examined DCIS published in The CIO Magazine, a trade journal targeted at CIOs and IT executives. The CIO Magazine is a respected and broad-reaching magazine, widely distributed among CIOs, IT managers and other executives and provides a balanced view of emerging industry concerns and practices. Thus, it can be an accepted source for IS research publications in the case of scarce academic literature (Corbett 2010). The Magazine aims at educating C-level executives from IT and business background about the various roles played by IT in achieving multidimensional objectives of modern organisations in the current context, and into the future.

The data were gathered online from the CIO Magazine archives (www.cio.com/magazine) covering all articles published from January 1, 2007 to December 31, 2010. The analysis was undertaken in four stages: article identification; screening; analysis and interpretation. To identify the articles, keywords of "data centre information systems", "infrastructure management", "management systems", "data centre automation" or "monitoring systems" were used, leading to a total of 31 articles identified as shown in Table 3. To screen and select the relevant articles, the full text of the articles was reviewed. In this process articles that relate to Data Centres but that do not mention any IS were excluded. This process eliminated 16 articles leaving only 15 relevant articles for analysis. To analyse, preliminary coding of identified IS into general categories is undertaken.

The analysis stage involved reading each article thoroughly and conducting a preliminary coding of key themes of IS. Categories of DCIS were derived inductively using 'open coding' (Strauss and

Corbin 1990). To interpret, the dimensions and attribute of the systems were identified vis-à-vis the preliminary IS classification framework as in Table 1. In the next section we discuss the findings of the study.

	2007	2008	2009	2010	Total
Number of issues	24	23	18	17	82
Number of articles	314	258	289	270	1131
Articles related to data centres (DC)	7	11	7	6	31
Articles related to DCIS	3	5	3	4	15
% of DCIS articles to total articles	0.96%	1.94%	1.04%	1.50%	1.33%
% of DCIS articles to DC articles	42.9%	45.5%	42.9%	66.7%	48.4%

Table 3. Profile of Sample CIO Articles.

4 RESEARCH FINDING

From the case studies in Table 2 and the practitioner literature review in Table 3, a total of 19 DCIS were identified as shown in Table 4. From the initial findings, a number of observations can be made. First, while corporate Data Centres (Cases 1 and 2) use IS in both the ICT and facility (power, cooling, and security) infrastructure domains, co-location Data Centres (Cases 3, 4, and 5) use IS to manage mainly the facility infrastructure. This implies that corporate and co-located Data Centres have two different business objectives that shape their usage of IS. Second, the extent of DCIS use by the five cases was found to be varying from one case to another. For instance, while Case one applied Power Management Systems for monitoring energy consumption at the entire data centre level, Case five shows relatively higher utilisation of these systems for managing the capacity of Power Distribution Units (PDU), and for measuring the energy at the rooms level, Computer Room Air Conditioning (CRAC)s level and Racks level. This implies that data centre managers appear to have different perceptions of DCIS capabilities and value that influence the extent of use (Alaraifi et al. 2011). Third, in the CIO Magazine, reference to DCIS within the Data Centre specific articles increased from 43% in 2007 to 67% in 2010, averaging 48%. This implies that the use and value of DCIS is becoming more important to practitioners.

System	CIO	Case Studies				
		1	2	3	4	5
Infrastructures Performance Monitoring	✓	✓	✓	✓	✓	✓
Property Management	✓	✓	✓	✓	✓	✓
Energy Monitoring	✓	✓	✓	✓	✓	✓
Power Management	✓	✓	✓	✓	✓	✓
Cooling Management	✓	✓	✓	✓	✓	✓
Heat Dissipation Modelling	✓	☒	✓	☒	☒	✓
Server Monitoring	✓	✓	☒	☒	☒	✓
Network Storage Management	✓	☒	☒	☒	☒	☒
Help-Desk Management	✓	✓	✓	✓	✓	✓
Database Management	✓	✓	✓	☒	☒	☒
Dynamic Virtual Computing Management	✓	✓	✓	☒	☒	☒
Workflow Management	✓	✓	✓	✓	✓	✓
Disaster Recovery and Data Migration	✓	✓	✓	☒	☒	☒
Virtual Switching	✓	☒	☒	☒	☒	☒
Remote Infrastructure Management	✓	☒	☒	☒	✓	✓
Dynamic Workload Balancing	✓	✓	✓	☒	☒	☒
Applications Service Level Management	✓	☒	☒	✓	✓	✓
Capacity Planning	✓	✓	✓	☒	☒	✓
Environmental Control	☒	✓	☒	☒	☒	✓
Total from CIO= 18 Total from Case Studies= 17 Aggregate Total = 19 Matching (Case Studies/Articles) =89%						

Table 4. List of Information Systems in Data Centres.

Using the process of open coding (Strauss & Corbin 1990), we extracted themes and ideas that represent the phenomena, and then grouped together the relevant ideas. To this end, 19 DCIS were analysed and then coded according to the dimension and value attributes of the system. The process identified that although different names or labels are applied, a number of the DCIS are essentially similar systems. For instance, Power Management and Power Capacity Planning systems are both targeted at the management of energy activities which reveal overlapping objective and functionality. Thus, the 19 DCIS were consolidated into nine main categories to create a high-order category. Table 5 describes each of these categories.

Category	Systems Included	Description
Management Accessibility Support Systems	• Infrastructures Performance Monitoring. • Remote Infrastructure Management.	IS that provide Data Centre managers and operators a consolidated access to different Data Centre platforms so that they can effectively supervise and monitor (either onsite or offsite) the operations of various systems (e.g. server, power. etc) and ensure the systems' availability, reliability and responsiveness.
Facility Site Management Systems	• Property Management. • Environmental Control.	IS that allow the monitoring and control of the Data Centre facility infrastructure including lighting and security
Cooling and Thermal Management Systems	• Cooling Management.	IS that improve the air distribution, and cooling platform efficiency and that provide the management of air, liquid and free air cooling systems. Such systems automate switching between different cooling options, offer detailed analysis of thermal activities and modify conditions for a dynamic distribution of cooling capacity.
Energy Management Systems	• Power Management. • Energy Monitoring. • Power Capacity Planning.	IS that allow the management of energy activities and transmission (including power coming to the facility and going to equipment), with detailed measurement; offer control of energy switches and power generators; and improve the energy efficiency and the performance of PDU through capacity planning.
Physical Computing Management System	• Server Monitoring. • Storage Management. • Dynamic Workload Balancing. • Servers Capacity Planning.	Information systems that enhance the management of major IT resources including servers, network and storage; that provide detailed readings of the activities of the entire IT infrastructure, improve the efficiency of IT resource, and allow jobs balancing and load distribution among IT platforms to increase the availability and improve performance.
Virtual Computing Management Systems	• Dynamic Virtual Computing Management. • Virtual Switching. • Servers Capacity Planning.	IS that enhance the management of virtual machines (e.g. servers, storage) and cloud computing; that provide real-time details about the performance and activities of virtual machines; and that automatically balance the capacity in the virtual environment.
Data Management Systems	• Database Management. • Disaster Recovery and Data Migration.	A set of systems that allow management and organisation of data flow including the creation, maintenance, storage, use and replication of data.
Workflow Management Systems	• Workflow Management. • Help-Desk Management.	IS for managing different types of jobs or processes including technical support and service organizations within Data Centres
Service-level-Management Systems	• Applications Service Level Management.	IS that provide managers with proactive monitoring of Business Transaction and Application to easily define and document effective SLAs for the IT/Business relationship with customers.

Table 5. The DCIS Description.

In the following section, the nine DCIS categories are examined using the five IS characteristics derived from the literature review as shown in Table 1. The aim of this step was not merely intended to show how the DCIS fit the five IS characteristics but also to examine whether the DCIS have any unique dimensions or value attributes that were not captured by the five IS characteristics.

5 DISCUSSION

Our analysis illustrates that all the nine categories of DCIS can fit the five IS characteristics. With respect to the *IS role*, our findings indicate that Data Centres are using IS to automate their business processes and resource management. For instance, Management Accessibility Support systems automate the process of infrastructure visibility. Facility Site Management Systems automate the operation of building lighting and Cooling and Thermal Management Systems automate the process of air distribution based on thermal dynamics. Similarly, many of the DCIS support informatisation by informing up decision makers about important performance measurements such as Management Accessibility Support Systems, or informing down technical team about critical changes in the health of systems such as Physical Computing Management Systems. A few DCISs such as Virtual Computing Management Systems and Energy Management Systems have transformational effect as they significantly change the way Data Centre business functions are being conducted and energy is used. This implies that Data Centres provide a setting to explore Watson et al's (2010) Energy Informatics framework.

As to the *management level*, the DCIS serve the unique requirements of different management levels. For instance, Applications Service-Level-Management Systems facilitate business alliance and building external linkages with stakeholders. Management Accessibility Support Systems offer tactical level advantages through an oversight management of Data Centre operations. Operational level managers are served by systems such as Physical Computing Management System. However, the type of Data Centre, whether it is corporate or co-located, determines the management level being served. In corporate Data Centres, DCIS constitute to an IT infrastructure advantages. For instance, systems such Physical Computing Management System and Virtual Computing Management Systems allow the management of heterogonous hardware and software for increasing the system's availability, optimising resource usage and improving processing performance. This might not be the case in co-located Data Centre where the IT infrastructure is typically owned and managed by external clients. Further, a co-located Data Centre represents an independent organisation on its own right, whereas a corporate Data Centre constitutes an IT department (or a unit within the IT Department). Thus, the analysis suggests that it is essential to extend the three management levels by adding a fourth attribute of "Technical Level". This extension is supported by Gable et al. (2003) study of enterprise systems success where they suggest the inclusion of technical level as a separate management level. The advantages of DCIS to technical level staff include, but not restricted to, failures diagnosing, hardware status checking, visual modelling, and help desk functions support (e.g. Workflow Management Systems).

With respect to the *IS Portfolio view of* DCIS, Cooling and Thermal Management Systems can reduce Data Centre operation cost by improving the efficiency of energy use and reducing the labour force. Virtual Computing Management Systems improve the productivity of Data Centres through consolidation and virtualisation of IT infrastructure. Management Accessibility Support systems provide informational value by enhancing the visibility and reporting of platform performance. Workflow Management Systems offer transactional value through automating the job scheduling execution processes. The analysis, however, suggests that in addition to strategic, infrastructure, informational and transactional value, environmental value need to be included to reflect the value of some DCIS to Data Centres. We define the Environmental value as the contribution of DCIS to improve a Data Centre's environmental footprint. Given Data Centres' energy consumption and carbon emissions, it is important to address the energy efficiency of Data Centres in order to ensure that the associated impacts, such as strain on infrastructure and financial and environmental costs are mitigated (EPA 2007; Karanasios et al. 2010; Alaraifi et al. 2011). Our results indicate that some of DCIS such as Cooling and Thermal Management Systems and Energy Management Systems allow the reduction of energy consumption and the calculation of carbon footprint. When IS are used to improve the environmental footprint of Data Centres, it can bring environmental value, and thus support the inclusion of environmental value as a fifth value attribute to the *IT Portfolio* dimension.

As regards the *Value Chain* view, the Data Centre type defines what constitutes primary and secondary Data Centre value chain activity. In corporate Data Centres, where Data Centre is within the IT department of an organisation, any DCIS that help to manage the activity of a Data Centre can be considered as an information system that support secondary activity. However this is not the case for co-located Data Centres whose main business is provision of Data Centre hosting service. Another important aspect to apply the value chain is by looking at the functions of Data Centres. Typically Data Centres consist of four broad functional areas; facility site operations, cooling operations, power operations and computing operations (Alaraifi et al. 2011). Given that Data Centres' main purpose is to provide information processing to institutions' needs, ICT equipment represents a core infrastructure or primary activity. Other equipments that provide power, cooling, security and other services to the ICT equipment can be regarded as facility infrastructure or secondary activities. In the case of co-located Data Centres, computing operations is owned and managed by the clients and hence are not a part of their value chain. In general, DCIS are used to control the operations of facility equipments (Facility Site Management Systems), consolidation of different platforms (Management Accessibility Support systems), management of the inbound power to the facility and outbound power to the equipment (Energy Management Systems), processing and management of inbound and outbound data (Data Management Systems), and service-level-management (Applications Service Level Management Systems). This implies that one can study the value of DCIS using the *Value Chain* model. Such a study needs to control for the type of Data Centre.

In terms of the *Products-utility*, DCIS have specifiable capabilities that allow the substitution of labour force through automating wide-range of daily activities (e.g. Facility Site Management Systems), enhancement of productivity and performance through workload distribution and capacity planning systems (e.g. Physical Computing Management System), enhancement of information processing through new ways of communications such as failure diagnosing and job handling (e.g. Workflow Management Systems), and alteration of social relations among organisations through changing the business processes communication within Data Centres (e.g. Applications Service-level-Management Systems). The analysis further suggests that, DCIS, in addition to offering tools for labour substitution, enhancing productivity, information processing, and changing social relations, can also be used as tools for enhancing the Data Centre sustainability and for improving the Data Centre governance.

One of the specifiable capabilities of DCIS for sustainability is their ability to reduce the energy consumption through efficient utilisation of resource, provide information that can improve the energy efficiency of systems (e.g. Energy Management Systems), enhance the lifecycle of hardware and hence reducing the e-waste (.g. Physical Computing Management System), and reduce the overall environmental impact of Data Centres. This implies that DCIS are effective tool for supporting the environmental sustainability. This is consistent with the finding of Molla (2009:756) who, after analysing the Green IT literature, argued that in addition to Orlikowski and Iacono's four manifestations of the tool view, IT is taking a fifth dimension as a tool for improving energy efficiency and reducing CO_2 emissions. Another capability of DCIS is their ability to support the economic sustainability by reducing the overall operation cost of Data Centres, enhancing the organisations effort to conserve energy and reducing the corporate compliance cost. This implies that DCIS indirectly contribute to organisations long-term economic performance through maximising shareholder's returns. Furthermore, DCIS support social sustainability by allowing organisations to respond to the demands of stakeholders (e.g. governments, external clients). They also facilitate the adaptation to greener social practices (e.g. reducing the environmental footprint). As technological innovations, DCIS improve the lifecycles of Data Centre operations that can bring long-term advantages to the society and harmonise the present and future relationships of Data Centre owners and stakeholders.

Furthermore, DCIS have the ability to enhance the Data Centre governance with respect to the accountability and responsibility of energy efficiency and operations transparency. Systems such as Infrastructures Performance Monitoring and Energy Monitoring improve the visibility and provide detailed measurement about important activities such as energy efficiency, operations efficiency, and cost of Data Centre operations. Thus, we suggest the inclusion of two additional attributes to the products-utility dimension; tool for enhancing sustainability and tool for improving governance. Based on the above discussion, a revised DCIS Classification Framework is presented in Table 6.

Dimension	Description	Attribute
DCIS Role	Focuses on the role played by DCIS	• DCIS automate the operation of building lighting, air distribution, processing workload and infrastructure visibility, • DCIS informate up decision makers about performance measurements and informate down technical team about critical systems changes, • DCIS transform the way Data Centre business functions are being conducted and energy is used and accounted for.
DCIS Manageme nt Level	Focuses on the management level the DCIS support	• DCIS for strategic level managers facilitate business alliance and building external linkages with stakeholders, • DCIS for tactical level managers facilitate oversight management of Data Centre operations, • DCIS for operational level managers increase the platform's availability, optimise resource usage and improve processing performance, • DCIS for Technical level managers support failures diagnosing, hardware status checking, visual modelling, and help desk functions support.
DCIS Portfolio	Focuses on the value of the DCIS	• DCIS Environmental value includes the reduction of energy consumption and carbon emission, the calculation of carbon footprint, and the improvement of overall footprint, • DCIS Strategic value includes the reduction of operation cost, • DCIS Infrastructure value includes the improvement of productivity of Data Centre operation and efficiency of IT resource usage, • DCIS Informational value includes the enhancement in the visibility and reporting of platform performance, • DCIS Transactional value includes the automation of job scheduling and execution processes.
DCIS Value Chain	Focuses on Data Centre functions that the DCIS support	• DCIS for ICT infrastructure support include consolidation of different platforms, management of computation resources, processing and management of inbound and outbound data, and service-level-management, • DCIS for facility infrastructure support include the control the operations of facility equipments, management of cooling systems, and management of the inbound power to the facility and outbound power to the equipment.
DCIS Utility	Focuses on the specific capabilities of the DCIS and on their desirable outcome.	• DCIS as tools for sustainability: through efficient utilisation of resource improve the energy efficiency of systems, reduce energy-source related emission, enhance the lifecycle of hardware, reduce the overall corporate compliance and operation cost and harmonise relation with various stakeholders. • DCIS as tools for Data Centre governance through the improve of visibility and provide detailed measurement about important activities such as energy efficiency, operations efficiency, and cost of Data Centre operations, • DCIS as tools for labour substitution through automating wide-range of daily activities, • DCIS as tools for enhancing productivity through workload distribution and capacity planning systems, • DCIS as tools for information processing, through new ways of communications such as failure diagnosing and job handling, • DCIS as tools for changing social relations through changing the business processes communication within Data Centres.

Table 6. A Revised DCIS Classification Framework.

6 CONCLUSION

This paper explained the characteristics of DCIS. The literature depicts various characteristics of IS with different dimension and value attributes. Based on the literature review, we developed a preliminary IS characteristics based classification framework. We used data collected from both case studies and practitioner literature to identify 19 DCIS. Using the open coding method, we categorise the 19 systems into nine distinct groups. We analysed each group by applying the preliminary classification framework. While the preliminary classification framework applied to most of the categories and systems, we were also able to identify areas where extensions are necessary. In particular, our results extends the preliminary IS classification framework by adding "Technical Level" as a fourth attribute to the three management levels dimension, "Environmental Value" as a fifth attribute to the IT Portfolio dimension, and "Tool for Enhancing sustainability" and "Tool for Improving Governance" as additional two attributes to the Products-Utility dimension. The result led us to develop a revised DCIS classification framework.

The study provides one of the first studies in the use of IS within the Data Centre environment. The results highlight some of the important applications of DCIS. This shows that DCIS are used for management accessibility support, facility site management, cooling and thermal management, energy management, physical computing management, virtual computing management, data management, workflow management and applications service level management. This finding provides more clarity about the role of information systems for Data Centre Automation and Data Centre sustainability. In particular, we highlight examples where DCIS are and can be used in the area of Data Centres sustainability in general and eco-sustainability of Data Centres in particular.

The study contributes to the IS research by proposing a DCIS characteristics based classification framework. Researchers can use this framework to investigate both the antecedents to and the value of different DCIS for Data Centres automation and the overall sustainability of Data Centres. The study also contributes to Data Centre industry by providing IS characteristics classification that can help the Data Centre managers to understand the different dimensions and value attributes of DCIS. This classification would also be valuable for the developers of DCIS that can help them to develop and deliver systems and focus more on the value attributes of DCIS.

In conclusion, from both the literature review and case studies, the following observations can be made. First, there is a general lack of academic research in the area of Data Centres and in the IS specific to Data Centres specifically. Therefore, this paper calls for more academic research into the area. Second, although IS classification in IS literature provide basis for classifying the dimension and value attributes of DCIS, our findings reveal that DCIS provides additional value attributes that are not covered by previous IS classifications. In particular, the results suggest the inclusion of technical level as an additional management level; environmental value as an addition to IS portfolio and eco-sustainability and governance as additions to IS utility. Third, the type of Data Centre, be it corporate or co-located can influence both the dimensions and value attributes of DCIS.

Lastly, this study has some limitations that need to be considered. First, the empirical investigation focused only on Data Centres within Australia. In addition the number of cases is relatively small. Furthermore, the practitioner literature is derived from single source. Thus the findings can only be considered as a preliminary and require a more in depth study before any conclusion can be made.

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