Information Systems: Transforming the Future

24th Australasian Conference on Information Systems, 4-6 December 2013, Melbourne

Proudly sponsored by

[Logos of sponsors: Nab, RMIT University, Citrix, GS1 Australia, ACS, ACS Foundation, ACPHIS, AAIS]
Overcoming integration challenges in organisations with operational technology

Anastasia Kuusk
School of Information Technology & Mathematical Sciences
University of South Australia
Adelaide, Australia
Email: anastasia.kuusk@unisa.edu.au

Professor Andy Koronios
School of Information Technology & Mathematical Sciences
University of South Australia
Adelaide, Australia
Email: andy.koronios@unisa.edu.au

Dr Jing Gao
School of Information Technology & Mathematical Sciences
University of South Australia
Adelaide, Australia
Email: jing.gao@unisa.edu.au

Abstract
Competitive advantage is traditionally an outcome of leveraging people, processes and technologies. Today organisations have several technologies with disparate information. Information integration may assist organisations to remain competitive. Organisations that have technology which manage or control assets have particular integration challenges compared to organisations with corporate business areas. This is because organisations do not view technology managing infrastructure assets in the same way as managing functions such as finance, retail and human resources. The paper defines a current, asset management based taxonomy for organisations integrating Operational and Information Technology. It identifies a number of challenges, such as the commitment to information integration, organisation-wide governance and architectural approaches as well as the aligning of operational open standards with existing information technology standards. Furthermore it highlights opportunities for further research in the area.

Keywords
Integration, Operational Technology, Information Technology, Engineering Asset Management

INTRODUCTION
Organisations have traditionally strived for competitive advantage by leveraging corporate information systems (Leavitt, 1965; Rockart, 1979). As organisations expand corporate information systems also expand and multiply organically and often chaotically, implemented by different organisational functions to support new functions in the lines of business and facilitate strategic decisions. As organisations expand, so does the disparateness of information. Twenty years ago Drucker (1995) identified that “knowledge has become the key economic resource and the dominant and perhaps even the only source of competitive advantage” (p. 271). Leavitt, Rockart and Drucker proposed competitive advantage was based on optimising people, processes and technology, and that competitive advantage is also dependent upon a holistic organisational wide view of information. An organisational wide view of information requires integration of staff, standards and technology integration. As with other organisations, engineering asset management organisations require fully integrated systems in order to maximise their use of information and knowledge assets and thus gain competitive advantage (Too, 2010).

The process of integrating information systems is compounded in organisations that utilise technologies that manage or control engineering and infrastructure assets. Examples of such organisations include power, water, sewerage, telecommunications, utilities, process plants and other infrastructure such as ports, transportation systems and large built structures. Information systems supporting these types of organisations include technologies such as Condition Monitoring Systems (CMS), Supervisory Control and Data Acquisition (SCADA), energy management systems, and sensor monitoring systems such as temperature and emission control systems. The governance and management of these asset control and management technologies and systems have been traditionally overlooked in most engineering and infrastructure type organisations. In those organisations such technologies, collectively known as Operational Technology (OT), are often managed and controlled in an ad hoc manner by engineering personnel. Unlike traditional information systems such as
finance, human resources and retail which are managed by Information Technology (IT) personnel and are the responsibility of the IT Director or Chief Information Officer (CIO), Operational Technologies are excluded from such governance.

This paper examines this significant disconnect between Information Technology and Operational Technology. It defines key terms and identifies the challenges to achieving ‘from device to the boardroom’ integration as a requirement for effective decision making in asset management organisations. The research is part of a larger research project and reports on the first phase of the research.

**REVIEW OF LITERATURE**

The remainder of the paper will define key terms, provide a literature review of the area, outline the methodology used in this research and finally will report key findings, contributions, limitations and future research.

The term information technology (IT) has an established definition and refers to application of computers and telecommunication equipment to acquire, process, store, retrieve, manipulate, use and disseminate information (International Standards Organisation, 2008; Daintith, 2009). Components include hardware, software, electronics, semiconductors, internet technologies, telecommunications equipment and computer services (Chandler and Munday, 2012). Types of systems include Financial Management (FMS) Electronic Document Records Management (EDRMS), Billing, Enterprise Resource Planning (ERP), Customer Relationship Management systems, email and a plethora of other information systems and applications. Information Technology is differentiated from another class of technologies termed Operational Technology (OT). Although OT was coined as far back as the 1970’s (Kariel, 1970), it is more recently popularised by Gartner (Steenstrup, 2008). Operational Technology is defined as hardware and software that detects changes, monitors or controls assets or processes. Such technologies generate real time asset data with embedded software. Operational technology controls or manages functions such as monitoring the condition of machinery, the operation of transportation systems, the control of (often remotely) power stations, oil rigs, automated process plants and other large engineering assets (Kariel, 1970; Steenstrup, 2008).

Operational Technologies are implemented and managed by engineering personnel, and are thus also governed by engineering standards and governance regimes. The main differences between OT and IT are highlighted in Table 1 shown below and represent people, process and technology challenges for information integration.

<table>
<thead>
<tr>
<th>Element (Pe=People, Pr=Process, Te=Technology)</th>
<th>Information Technology (often managed by IT branch)</th>
<th>Operational Technology (often managed by engineering branch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget (Pr)</td>
<td>Dedicated for Branch</td>
<td>Embedded within another branches budget</td>
</tr>
<tr>
<td>Staff (Pe)</td>
<td>Dedicated IT focus – network analyst, engineer, systems administrator</td>
<td>Dual role – Engineering and IT maintenance focus</td>
</tr>
<tr>
<td>Staff focus (Pe)</td>
<td>Security</td>
<td>Reliability</td>
</tr>
<tr>
<td>Objective (Pr)</td>
<td>Strategy/decision</td>
<td>Asset performance</td>
</tr>
<tr>
<td>Systems standards focus (Pr)</td>
<td>Control information</td>
<td>Control asset</td>
</tr>
<tr>
<td>Examples (Te)</td>
<td>Customer information, asset management and billing systems</td>
<td>SCADA or real time data tracking systems</td>
</tr>
<tr>
<td>Information type</td>
<td>Information non real time</td>
<td>Data real time</td>
</tr>
<tr>
<td>Networks (Te)</td>
<td>Consolidated</td>
<td>Own network beyond firewall</td>
</tr>
<tr>
<td>Uptime (Pr)</td>
<td>Down for patching/backups</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Adapted from Steenstrup (2010)*

Recent years, through the dramatic increase in Internet technologies, have seen the corresponding increase of Internet Protocol (IP) enablement of not only corporate information systems but also engineering technologies, systems and even individual components such as motors, sensors and actuators. Today power stations, engineering process plants, mining rigs and other engineering assets can be controlled, often, remotely, through the Internet using IP protocols. Such systems have traditionally been ‘closed systems’ with their own vendor specific communication protocols. It is therefore becoming much easier for operational technologies, to be
integrated with corporate information systems; so too are the challenges of governance and security becoming more critical. Vendors have in the past dominated in providing proprietary Operational Technologies to compliment corporate information system platforms (Lin et al., 2007; Waddington, 2008; Koronios et al., 2009, Thomas, 2009; Haider, 2010; Steenstrup, 2010; Institute of Public Works Engineering Australia, 2011; Strenstrup, 2011; Berst, 2011; Steenstrup, 2012).

As more and more of asset management organisations move away from government ownership and they themselves become more ‘corporate’, a need exists for the provision of complimentary information technology to assist organisations to achieve integration with ‘the business’. Some industry researchers (Zimmerman, 2007; Steenstrup, 2008) have suggested that the level of integration may follow a particular maturation path. Terms suggested to indicate the stages along the maturation path include ‘convergence’, ‘alignment’ and ‘integration’ of people, processes and technology. They thus suggest that full integration of corporate information technology can be achieved through the passage from convergence to alignment and then integration of people, processes and technology.

Furthermore, taxonomies have been devised by practitioners and academic researchers. Examples include Teo and King’s (1997) information systems strategic planning, Steenstrup’s (2008) converge, align and integrate, Zimmerman’s (2007) parallel and Hoque et. al’s (2005) Build Transform Maximise (BTM) taxonomies. The taxonomies describe similar stages, albeit not consistently. For example, convergence is defined by Steenstrup (2010) as integration of platform, programming language and standards as activities undertaken by the vendor. Villars and Perry (2011) define it as the percent of data centre storage, memory, server nodes, network Input/Output virtualisation, and virtual operating system images that can be deployed from a pooled collection. Both definitions are technically hardware and networks based.

Whilst Zimmerman’s taxonomy is based also on asset organisations, people and process compared to technical elements are highlighted. Convergence at the technical level is occurring with asset intensive industry vendors such as Ventyx and MDM Porta offering converged hardware and software solutions that are increasingly based on IT chips, routers and communication protocols (Jaffe, et. al, 2011; Romero, 2011; Berst, 2011; Rhodes, 2011). Such a technically oriented definition was not shared with earlier authors. Hoque et. al (2005) defines it as business and technology activities intertwining and leadership teams interchangeable. This is similar to Teo and King’s (1997) classification of full integration.

Alignment is defined by Hoque (2005) as the state when technology supports and enables rather than constrains business strategies. Teo and King (1997) agree but refer to the step as sequential integration. Steenstrup (2010) defines alignment as occurring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems. Luftman (2000) provides further qualification of this step with five stages of initial, committed, established, improved and optimized.

The discussion above highlights the emerging issues with the disconnect between Operational Technologies and Information Technology and the need for additional research to identify the activities and challenges in achieving information integration in engineering asset management organisations. The issues extend to reaching consensus on terminology and the taxonomies to describe the fiend as well as to identify the steps for full integration to be achieved. Once a taxonomy baseline is defined, applicable to the operational technology environment of asset management organisations, further challenges of information integration can be addressed. A summary of example taxonomy differences appear in Table 2 below.

**Table 2. Convergence, alignment and integration taxonomies**

<table>
<thead>
<tr>
<th>Industry based</th>
<th>Academic based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converge (OT and IT share same client, server, network tiers IT and IP based activities often undertaken by vendor)</td>
<td>Parallel Path (doing things more consistently between the groups, common understanding and respect)</td>
</tr>
<tr>
<td>Align (occurring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems)</td>
<td>Complimentary Path (IT and controls separate entities with different approaches, mindsets and methodologies, but are moving closer together, better defined responsibilities)</td>
</tr>
<tr>
<td>Integrate (an outcome of the alignment pending the impact)</td>
<td>Converged Path (Controls engineering and IT groups have Convergence (business and technology)</td>
</tr>
</tbody>
</table>

24th Australasian Conference on Information Systems Overcoming technology integration challenges 4-6 Dec 2013, Melbourne

Kuusk, Koronios & Gao
A number of issues with the taxonomies identified in Table 2 will now be discussed. The convergence and alignment steps of the Steenstrup (2010) taxonomy are technically orientated and have not been empirically validated compared to Hoque (2005) and Teo and King’s (1997) taxonomies. Hoque, Teo and King’s taxonomies for information technology have been applied to integrating IT systems from a corporate information perspective, compared to an OT perspective. The Zimmerman (2007) and Steenstrup taxonomies provide organisational technology perspective of asset intensive organisations often overlooked in earlier literature such as Hoque. Each of the taxonomies, whilst providing documented stages of convergence, alignment and integration lack context such as who should be involved, when and how organisations should move between the stages.

Such people, process and technology elements indicate other issues that need investigation for practical application of the taxonomies. Moving between the maturity stages requires personnel from corporate and operational areas of organisations to identify roles in the integration process. Organisational and cultural issues also need investigation as the integration of OT and IT can provide a source of conflict in organisations when it comes to oversight and governance of the systems. This is because engineering personnel being reluctant to surrender control over what were traditionally in their domain.

Current literature does not provide guidance and often has opposing points of view as to whether the IT function or Engineering should be responsible for the governance and management of OT (Steenstrup 2008; Schneider, 2006; Kern, 2009). Identification of roles is further exacerbated by the number of information, security and computer governance frameworks, standards and principles that organisations may use to converge, align and integrate OT and IT. Examples include COBIT (embodied in International Standard 38500), NERC CIP security guidelines for the utility industry (International Electrotechnical Commission, 2007; Kassakin, 2011), MIKE 2.0 (Hillard, 2010) and Information Data Governance (IBM, 2007; Thomas, 2009). Furthermore, relevant engineering asset management standards exist and include PAS 55, ISA 95 and several industry players such as Rockwell Automation and Ventyx publish white papers covering roles, challenges and outcomes of information integration.

The literature also highlights the challenge of identifying the critical success factors for integrating information. Daniel (1961) initially identified critical success factors (CSF’s) for organisational competitiveness. Rockart (1971) popularised Daniel’s model with the identification of CSF’s within contexts, indicating that contexts such as engineering asset management have three to six key areas that determine an organisation’s business success. Little literature is evident on the identification and application of CSF’s to the asset management context for system integration. Mendoza et. al (2006) identifies system integration success requires configuration, data model standardisation, outsourcing management, justified change, senior management support, manage project scope, security strategy and communication but does not identify application to the asset management context. Others such as Yeoh et. al (2009), Parekh (2007) and Haider (2011) and Too (2010) highlight success factors for EAM organisations. The factors, such as interoperability, cross sharing of IT and engineering skills, enterprise wide care and information governance are not applied to the integration of technologies.

As a summary, the key issues and gaps from the literature review include;

1. Taxonomy - Establishing a maturation path to integration that has a consistent definition, empirically validated and for the asset management context.
2. People challenges – Is engineering, IT, vendors and or the organisation responsible and for what parts of the taxonomy and what role do differences in perceptions about security and reliability play
3. Process challenges – Are existing, empirically validated critical success factors applicable to the OT and IT integration context and which standards should be applied
4. Technical challenges – Consolidation of hardware, network, application, information and data tiers

RESEARCH DESIGN

Myers (2009) distinguishes between qualitative and quantitative research methods. Quantitative methods such as laboratory experiments were designed to study natural phenomena, whereas qualitative methods such as observation, interviewing, questioniing and reviewing documentation were designed to study social and cultural
phenomena. When and whom in an organisation should converge, align or integrate operational and information technologies is not a natural but a social phenomenon. The current research is of a qualitative nature because it explores the extent information integration is being applied in the social context of practice (Chua and Garrett, 2009) of engineering asset management.

The aim of this research is to understand the social context of engineering asset management organisations integrating information for competitive advantage. The specific aim of the research is twofold:

1. Firstly to identify a current, asset management, practitioner based taxonomy clarifying the maturation stages, if they indeed exist, of information integration;
2. Secondly to identify the people, process and technology challenges of information integration in engineering asset management organisations.

The Delphi qualitative research method was chosen to meet the research aims as it facilitates, through consensus of expert practitioner, understanding of information integration in an asset management context. Chua and Garrett (2009), Myers (1997) and Kaplan and Maxwell (1994) identify the need to choose research methods which allow the study of the social context of practice. Mintzberg (1979) and Eisnerhardt (1989) highlight the choice of methods should lead to data validity and theory building. Delphi research method has been used, as in the current study, for technical forecasting (Dalkey, 1959; Gordon and Helmer, 1964; Cornish, 1977) in the information systems domain for the past thirty years (Pare et. al., 2013). The method provides for subjective individual judgements, meeting time and cost efficiencies, a way of efficiently structuring group dialogue and bringing together different organisational functions such as IT and Engineering in a non-competitive environment (Sitt-Ghodes and Crews, 2004; Powell, 2003; Turoff, 1970).

Three survey rounds covering key Delphi components of brainstorming, selection and ranking phases as a means for consensus-building using a series of questionnaires to collect data from a panel of geographically dispersed participants (Pare et. al, 2013) were undertaken. In the first round thirty participants from twenty seven Australian consulting, utility, mining, councils, IT solutions, planning and development government agencies and engineering manufacturers agreed to respond to open ended questions relating to convergence, alignment and integration of operational and information technology in organisations with engineering asset management functions.

Theoretical sampling of practitioners as opposed to statistical sampling was used in the study to facilitate validity and reliability through replication as defined by Yin (2009), model building and applicability of theory (Eisenhardt,1989; Benbasat, et al., 1987). Practitioners were drawn from asset intensive organisations that have professional information, engineer and IT staff and hardware or software that detect or cause a change through the direct monitoring and or control of physical devices, processes and events (such as Asset Management Systems, SCADA, telemetrics and geological monitoring (GIS systems) convergence, integration and alignment OT and IT and if information governance facilitated these activities. Table 3 Below summarises the cohort of practitioners consistently responding to three rounds of questionnaire’s.

<table>
<thead>
<tr>
<th>Organisation Type</th>
<th>Job title</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Asset Owner</td>
<td>Northern Territory</td>
</tr>
<tr>
<td></td>
<td>Business Manager</td>
<td>New South Wales</td>
</tr>
<tr>
<td></td>
<td>Information Technologist</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Business Manager</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Asset Manager</td>
<td>New South Wales</td>
</tr>
<tr>
<td>Contractors</td>
<td>Project Manager</td>
<td>Northern Territory</td>
</tr>
<tr>
<td></td>
<td>Asset Advisor</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Information Manager</td>
<td>Northern Territory</td>
</tr>
<tr>
<td></td>
<td>Legal Advisor</td>
<td>New South Wales</td>
</tr>
<tr>
<td></td>
<td>Information Technology Advisor</td>
<td>Victoria</td>
</tr>
<tr>
<td></td>
<td>Asset Owner</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Researcher</td>
<td>Victoria</td>
</tr>
<tr>
<td></td>
<td>Asset Engineer</td>
<td>Victoria</td>
</tr>
<tr>
<td></td>
<td>Business Analyst</td>
<td>Brazil</td>
</tr>
<tr>
<td>Machinery provider</td>
<td>Chief Information Officer</td>
<td>Northern Territory</td>
</tr>
<tr>
<td>Software/hardware provider</td>
<td>Managing Director</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Technologist</td>
<td>Queensland</td>
</tr>
<tr>
<td></td>
<td>Systems Engineer</td>
<td>Queensland</td>
</tr>
<tr>
<td>University</td>
<td>Academic</td>
<td>Queensland</td>
</tr>
</tbody>
</table>
Fifteen responses (50%) to the first questionnaire were received over four weeks in October and November 2012. Thirteen responses were received via email, and two were elicited via telephone calls, and one by social media. Other respondents indicated that they were not familiar the convergence of operational technology and information technology to adequately respond. Responses were thematically analysed and provided rankings of key terms for use in round two and three questionnaires. A Likert scale was added to the questionnaire to facilitate identification of consensus. Twelve individuals of the fifteen participating in Delphi questionnaire for round one responded (80%) to questions covering when organizations should converge, align and integrate OT and IT, whom should be responsible, why organisations should undertake such activities and if information governance could facilitate convergence, alignment and integration activities in organisations with engineering asset management functions. Responses were received over three weeks in November and December 2012. Eleven responses were received via email and one via telephone.

All respondents of the Delphi cycles 1 and 2 were invited to respond to the cycle 3 questionnaire. Comprehensive feedback of the group consensus was given to all participants of the Delphi study after each cycle. Non responding participants were followed up by telephone in January 2013. Of the sixteen invited to respond, 10 responded (62.5% down from 80% in cycle two). Four changes were made by respondents between rounds one and two did not alter consensus rankings from cycle two. An almost 20% drop in responses between cycles indicated there would be little benefit from undertaking subsequent cycles particularly where the same depth of concept description means overselling is a risk to busy experts (Linstone and Turoff, 2002; Goodman, 1970).

Several statistical measures were used to measure consensus of practitioners as there is no one agreed set of statistics to indicate consensus (Hasson, Keeney and Mckenna, 2000). The mean (average answer on the Likert scale) was calculated to identify group response to indicated if organisations should always or never undertake a task. Measures of central tendency such as correlation coefficients, percentages, mean, median, and Inter Quartile Range (IQR) have been used to identify consensus in Delphi studies (Dalkey, 1969 and Linstone and Turoff, 2002; Santos, Araújo and Correia, 2012; Raskin, 1994; Rayens and Hahn, 2000; Von Der Gracht, 2008). Percentages were not used in the current research as the previous literature did not indicate consistency of the point range, ranging anywhere from 15% change in mean score between rounds to between 51% - 100% (Stitt-Gohdes and Crews, 2004; Hasson, Keeney, McKenna, 2000; Green et al (1999); Sumsion, 1998; Loughlin and Moore, 1979 and Mckenna, 1994).

A standard deviation closest to 0 was calculated to indicate consensus polarisation by the practitioners. The Interval Quartile (or interquartile) Range (IQR) was also calculated. The Interval Interquartile Quartile Range (IQR) was calculated as this has been used to indicate consensus in original Delphi studies (Dalkey, 1969; Linstone and Turoff, 2002) and recent studies in IT contexts. An IQR of less than 1 with closer to 0 representing higher consensus. Consensus levels were identified as Strong, Medium, Low or No consensus based on a combination of the three statistics as in Table 3 below.

<table>
<thead>
<tr>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Interquartile Range</th>
<th>Number of responses</th>
<th>Likert scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>$\sigma$</td>
<td>IQR</td>
<td>$N$</td>
<td>$1 = Never$</td>
</tr>
<tr>
<td>Strong consensus = above 8</td>
<td>Strong consensus = less than 2</td>
<td>Strong consensus = less than 1</td>
<td>More than half responding</td>
<td>$3 = Sometimes$</td>
</tr>
<tr>
<td>$5 = Always$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The people, process and technology elements were chosen to group results for presentation and discussion as the balanced elements required for organisations to be effective (Leavitt, 1965; Rockart, 1979) and account for current theories of integrated asset management (Too, 2010; Brown et. al., 2011). The research was also based on the most current taxonomy covering the majority of the organisational effectiveness elements applicable to the asset management context. Steenstrup’s taxonomy terminology of convergence, alignment and integration was used as the basis to confirm practitioner understanding of what are, roles, when and why organisations...
move through the maturation stages, culminating in integration. The results provide empirical validation for Steenstrup’s (2008) taxonomy and existing integration critical success factor identification, whilst providing new insights, particularly at the pre convergence stage, to enable detailed application of taxonomy by researchers and practitioners in the asset management context.

**FINDINGS**

The overarching aim of the research was to identify a current, asset management, engineering and information technology practitioner based taxonomy clarifying the maturation stages of information integration and to identify the challenges of achieving such integration. This could be used as a basis for identifying the critical success factors for achieving integration and to build a framework for doing so; these are intended activities of the next stage of this research.

A summary of the key taxonomy, people, process and technology challenges identified by practitioner consensus and current literature appear in Table 4 below.

Table 4. Delphi study findings of OT and IT integration challenges for asset management organisations

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Issue</th>
<th>Literature</th>
<th>Delphi consensus findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxonomy</td>
<td>Consistent definition</td>
<td>Asset Management context</td>
<td>One size not fit all ((\times 4, \sigma .77, IQR -1)); Asset management context pathway; Converge to align when; Hardware consistent but applications disparate ((\times 4.09, \sigma .7, IQR -0.5)); business needs accounted for ((\times 4.36, \sigma .81, IQR -1); costs ((\times 4.45, \sigma .82, IQR -1) )</td>
</tr>
<tr>
<td></td>
<td>Current taxonomy applicability to asset management context</td>
<td>Zimmerman (2007), Steenstrup (2008-2013)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Empirical validity of Current taxonomies</td>
<td>Corporate information context</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hoque (2005), Tao and King (1997)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>People, Process and technology elements for efficient organisations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leavitt (1965), Rockart (1979)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gap = Empirically validated definition for asset management context</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering or IT responsible</td>
<td>Managed separately</td>
<td>a. Combined ((\times 4.73, \sigma .47, IQR -5))</td>
</tr>
<tr>
<td>People</td>
<td>Vendor or organisation responsible</td>
<td>Jaffe et al (2010)</td>
<td>b. Vendors converge, organisations align and integrate (66%, ((\times 1.58, \sigma .92))</td>
</tr>
<tr>
<td></td>
<td>Reliability or Security importance</td>
<td>Steenstrup (2008), Barber (2012); Schneider (2006), Kern (2009)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Security v reliability</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Griffith (201), Barwick (2013), Chaudary, (2012), Beggs (2012)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gap = integration</td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>Critical Success Factors applicable to asset management context such as costs, training, management support, standards, planning, project governance</td>
<td>Identifying CSF’s for context</td>
<td>High consensus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daniel (1961), Rockart (1979)</td>
<td>Agreed enterprise level architecture ((\times 3.91, \sigma .54, IQR 0))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSF’s for managing system integration - Configuration, data model standardisation, outsourcing management, justified change, senior management support. Manage project scope, security strategy, communication Mendoza et. al. (2008)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CSF’s for asset management OT/IT context Standards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PAS 55, ISA 95, COBIT/ISO38500, ISO15489, NERCCIP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>System implementations in EAM orgs Yeoh, et al. (2009), Interoperability of IT and Engineering platforms and standards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medium consensus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strategic vision ((\times 4.27, \sigma .47, IQR -5)); research, plan and execute ((\times 4.45, \sigma .69, IQR -1); open data and communication standards ((\times 4.18, \sigma .6, IQR -5)); manage as a project ((\times 4.18, \sigma .75, IQR -1); mutual collaboration ((\times 4.09, \sigma .71, IQR -1); Input from all ((\times 4.27, \sigma .9, IQR -1); ease of use ((\times 3.55, \sigma .82, IQR -1); engineering and IT role to catalyse business</td>
<td></td>
</tr>
</tbody>
</table>
The key taxonomy, people, process and technology challenges identified by practitioner consensus are identified below according to the elements for competitive advantage identified by management theorists such as Teo and King (1997), Hoque (2005), Rockart (1979) and Leavitt (1965). The order of presentation is:

1. **Taxonomy -** Establishing a maturation path to integration that has a consistent definition, empirically validated and for the asset management context
2. **People challenges –** Is engineering, IT, vendors and or the organisation responsible and for what parts of the taxonomy and what role do differences in perceptions about security and reliability play
3. **Process challenges –** Are existing, empirically validated critical success factors applicable to the OT and IT integration context and which standards should be applied
4. **Technical challenges –** Consolidation of hardware, network, application, information and data tiers

### Taxonomy challenges

<table>
<thead>
<tr>
<th>Technology</th>
<th>Integration of OT and IT such as data and information, networks, communications, hardware, software tiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why</td>
<td>a. Why High Efficient exchange of data; efficient management of information ((\bar{x} = 4.55, \sigma = 0.52, IQR = 1)) increased reliability ((\bar{x} = 4.36, \sigma = 0.67, IQR = 1))</td>
</tr>
<tr>
<td>How</td>
<td>b. How High Information governance facilitate enterprise level technology change coordination ((\bar{x} = 4.18, \sigma = 0.75, IQR = 1))</td>
</tr>
<tr>
<td>Gap</td>
<td>Gap = Empirically validated why &amp; how OT &amp; IT integration occurs in asset management practice</td>
</tr>
</tbody>
</table>

The research set out to establish a maturation path to integration that has a consistent definition, empirically validated and for the asset management context. Compared to previous taxonomies the current research identified pre convergence or first stage tasks of business analysis, documenting convergence strategy, alignment of open and communication standards, mutual collaboration between IT and Engineering using project management techniques and documenting critical success factors. Respondents confirmed Steenstrup’s identification that convergence occurs when technical components used are the same for OT and IT. Such technical elements are not evident in the other taxonomies.
The current research identifies that asset management organisations should converge when there is consensus between business and IT functions to work collaboratively and move from converging to aligning OT and IT when hardware is consistent but applications are disparate, when business needs are accounted for and when IT structures are aligned. At this point Steenstrup’s taxonomy identifies synchronised standards and architecture plans, which in the current research were indicated by practitioners as occurring prior to the convergence stage. The other taxonomies focus on the collaborative people elements at this stage.

Respondents to the current study agreed that organisations should move from alignment to integration when market competitiveness and data use requires it, providing guidance to organisation when to strive for integration. The Steenstrup taxonomy does not indicate characterisation of the ultimate information integration goal, indicating organisations should manage firewalls, bandwidth, impacts on performance, integrity and reliability, and, as with the other taxonomies focuses on collaborative elements of OT and IT staff. The current research fills this gap by indicating integration is characterised by agreed enterprise level architecture, standardised platforms, efficient exchange of data, efficient management of information, increased reliability, decreased costs and collaboration between Engineering and IT.

These findings provide a significant contribution for systems integration knowledge in the asset management context by empirically confirming for researchers and practitioners with definitions, activities and roles at stages along the path to integration whilst empirically confirming where on the continuum asset organisations are currently at and how and when to move to actualising information integration for competitive advantage.

The research results have provided a unique contribution of knowledge. Thus being a current, asset management, OT and IT integration contextual, empirically validated maturation taxonomy. The empirically validated results indicate asset management organisations planning to integrate OT and IT for competitive advantage should:

1. Plan for convergence when external factors such as a corporate vision and consolidated industry standards are in place. Organisations should prepare by analysing business needs and objectives, planning and research options available and developing a convergence strategy. At this point vendors may sell l a vision of convergence to organisation.

2. Move to convergence when there is consensus between business and IT. Convergence is established when vendors provide hardware which is IP addressable and has the same chips and routers as provided in other parts of the organisation and engineering, information management & IT provide input into application development.

3. Move from convergence to alignment when the hardware is in place but applications and information are disparate. Alignment is characterised by an architecture aligned by IT & Engineering with advice provided by vendors.

4. Move from alignment to integration when market competition and need for cost savings arise. The integration stage is characterised by enterprise wide data exchange.

A summary of how the theoretical contribution contributes to existing taxonomy body of knowledge is provided in Table 5 below.

<table>
<thead>
<tr>
<th>New asset infrastructure OT and IT consolidation taxonomy</th>
<th>Existing IT and OT consolidation taxonomies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre convergence (Business analysis, convergence strategy, open and communication standards, mutual IT &amp; engineering collaboration)</td>
<td>Elements not identified</td>
</tr>
</tbody>
</table>
Convergence (Consistent hardware provided by vendor; IT & engineering consensus and input into application development)

Converge (OT and IT share same client, server, network tiers IT and IP based activities often undertaken by vendor)

Alignment (technology supports, enables and not constrains business strategies)

Sequential integration (business goals considered, formulate IS strategy to perform business strategy)

Alignment (Architecture aligned by IT and Engineering; Hardware in place but applications disparate)

Align (occurring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems)

Synchronisation (IS expert resources, support business strategy)

Reciprocal integration (IS expert resources, support business strategy)

Integration (Efficient exchange of information and data; driven by market competition and cost savings)

Integrate (an outcome of the alignment pending the impact of communications such as bandwidth reduction and firewall conflicts on performance, integrity and reliability of the two technologies)

Convergence (business and technology activities intertwining and leadership teams interchangeable)

Full integration (joint development of strategies, senior management involvement, critical to success of business)

**People challenges**

The research set out to establish what roles and responsibilities engineering, IT, vendors and organisation play in achieving integration. Respondents indicated that vendors provide converged hardware, organisations align and integrate with the assistance of vendors. Results indicated integration should be the combined task of IT and Engineering, possibly IT and not by Engineering personnel on their own. The results also indicate that with a combined approach to integration discrepancy between engineer and information technology risk tolerances and perceptions of security and reliability may impede the two areas working together. The literature review identified security as a reason for integrating, whilst this was not highly rated in the current study as reliability was identified as a higher ranking element. Such cultural risk tolerances and perceptions need further study for application to the asset management context.

**Process challenges**

Several empirically validated critical success factors related to people, process and technology integration are provided in existing literature. The research set out to identify the applicability of such critical success factors to OT and IT integration in asset management. Factors identified in the existing literature, such as manage as a project, training, ease of use and agree on standards prior to embarking upon integration activity were confirmed in the current study. The results also contribute further critical success factors to those commonly identified in information systems literature, indicating specificity for the asset management context. Management support was not identified as a factor, whilst agreed enterprise level architecture ranking as medium to high factors differentiating previously identified critical success factors to those applicable to the asset management context.

Several engineering, IT and information governance standards have been identified in the literature. Analysis of respondent results indicated medium consensus for standardised platforms, and in responses to a separate questions, consensus qualified this to be open data and communication standards. Further research may further define standards used in system integration activities by asset management organisations.

**Technical challenges**

The research set out to establish challenges for consolidation of hardware, network, application, information and data tiers when integrating OT and IT. In relation to hardware, consensus of practitioners indicated organisations move to alignment when hardware is consistent but applications are disparate and indicating moving to the maturation point of integration when technology tiers are aligned and data use requires integration. This validates the need for integration information to achieve competitive advantage. Medium consensus was identified for achieving a single platform from integration.

A significant contribution of the results is validating the applicability of information integration to the competitive advantage goal of asset management organisations. Efficient exchange of data and management of
information was the highest ranked consensus item of any responses across the survey questions and is increasingly important as asset managers move to predominantly public from private ownership and therefore different governance frameworks and competitive challenges.

The significance of the findings are discussed in the next section.

DISCUSSION

Engineering asset organisations with substantial Operational Technology supporting their operations face challenges when striving for competitive advantage in an environment of increased competition. For many such organisations competition is quite foreign as they have been in many cases government monopolies. The organisations may be supported in their quest for competitive advantage from information integration by applying the preliminary framework identified by practitioner responses in the current research. The research findings contribute unique and empirically validated insights into OT and IT integration in the asset management context. Such unique insights are explored, albeit briefly below by comparing the existing literature to the findings. The discussion covers the main challenge areas of taxonomy, people, process and technology.

The research set out to establish a maturation path to integration that has a consistent definition, empirically validated as it may apply to engineering asset management context. Results in this study suggest that the time to move from converging to aligning activities is when a number of disparate systems exist within these organisations. Furthermore, it suggests that organisations should move from alignment to integration after an whole-of organisation enterprise architecture activity has been completed. From the governance perspective explicit roles and responsibilities need to be further clarified. In particular the professional and cultural risk definitions and tolerances that engineers and information technology personnel bring to the integrated project team table need further investigation as an impediment to achieving integration and therefore competitive advantage.

A number of critical success factors were confirmed, dismissed or added as applicable to IT/OT governance in engineering asset management organisations. Notable contributions of the research include an additional pre convergence stage to existing taxonomies, top level management commitment not being a significant factor whilst confirming information integration for competitive advantage in the asset management context, a commitment to open data and communication standards, agreed vision and architecture at the outset as particularly relevant to the asset management context.

LIMITATIONS AND FUTURE RESEARCH

Whilst progress has been made in the development of a taxonomy for organisations with operational and information technology, further validation is required. A number of challenges have been identified in closing the gap between Operational Technology and Information Technology governance. Work still remains in identifying the steps for achieving this less from the technology standpoint and more from the organisational, cultural and people issues within engineering asset management organisations. The Delphi study poses some methodological limitations in terms of validity and generalisability. Further research using in-depth case studies of multiple engineering asset management organisations will provide additional insights to refine the current research findings.

CONCLUSION

This paper defines a current, asset management based taxonomy for organisations integrating Operational Technology and Information Technology. It has identified a number of challenges, such as the commitment to information integration, organisation-wide governance and architectural approaches as well as the aligning of operational technology open standards with existing information technology standards. Furthermore it highlights opportunities for further research in the area.

REFERENCES


Leavitt, H. 1965. Applied Organizational Change in Industry. Pittsburgh:


ACKNOWLEDGEMENTS

The authors acknowledge the support of the CRC for Integrated Engineering Asset Management (CIEAM) in conducting this research project.

COPYRIGHT

Anastasia Kuusk, Andy Koronios & Jing Gao © 2013. The authors assign to ACIS and educational and non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the article is used in full and this copyright statement is reproduced. The authors also grant a non-exclusive licence to ACIS to publish this document in full in the Conference Papers and Proceedings. Those documents may be published on the World Wide Web, CD-ROM, in printed form, and on mirror sites on the World Wide Web. Any other usage is prohibited without the express permission of the authors.