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Information Processing view of Electricity Demand Response Systems: A Comparative Study Between India and Australia

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Abstract

Background: In recent years, demand response (DR) has gained increased attention from utilities, regulators, and market aggregators to meet the growing demands of electricity. The key aspect of a successful DR program is the effective processing of data and information to gain critical insights. This study aims to identify information processing needs and capacity that interact to improve energy DR effectiveness. To this end, organizational information processing theory (OIPT) is employed to understand the role of Information Systems (IS) resources in achieving desired DR program performance. This study also investigates how information processing for DR systems differ between developing (India) and developed (Australia) countries.

Method: This work adopts a case study methodology to propose a theoretical framework using OIPT for information processing in DR systems. The study further employs a comparative case data analyses between Australian and Indian DR initiatives.

Results: Our cross case analysis identifies variables of value creation in designing DR programs - pricing structure for demand side participation, renewable integration at supply side, reforms in the regulatory instruments, and emergent technology. This research posits that the degree of information processing capacity mediates the influence of information processing needs on energy DR effectiveness. Further, we develop five propositions on the interaction between task based information processing needs and capacity, and their influence on DR effectiveness.

Conclusions: The study generates insights on the role of IS resources that can help stakeholders in the electricity value chain to take informed and intelligent decisions for improved performance of DR programs.

Keywords: Demand Response, Automatic Metering Infrastructure, Organizational Information Processing Theory, Information Processing Needs and Capacity.

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Introduction

Demand response (DR) programs, enabled by Automatic Metering Infrastructure (AMI), rely on data based decisions to bring a balance between the electricity demand and supply. Information Systems acquire, integrate and analyse data from various sources and provide information about consumer load types to manage peak demand in the distribution sector. Essentially, DR programs act on the information by reducing consumption during peak loads or shifting these peak loads to off-peak hours. Prior studies have identified the parameters affecting DR decisions to shift power demand according to the fluctuating supply side (Watson et al., 2010; Feuerriegel & Neumann, 2014). However, demand-supply uncertainties related to the grid could alter the information processing need for decisions. How do information processing needs and information processing capacity for DR differ between electricity demand-supply of developing (India) and developed (Australia) countries? What are the different types of information processing needs in an electricity value chain driven by the electricity demand-supply uncertainty? How do information processing needs and information processing capacity interact to improve energy demand response effectiveness? There is limited understanding about desired DR systems' need-capacity match to guide strategic and policy decisions particularly for developing nations. Our research seeks to address these guestions in the backdrop of the environmental differences between India and Australia in DR deployment and adoption.

Developing and developed countries differ in electricity distribution and consumption with respect to regulatory environment and stage of implementation of DR which implicate variability in DR maturity between the two categories. In Australia, electricity market is deregulated. Further, technological environment is highly advanced with the large scale deployment of smart meters and smart grid projects, and a significant penetration of DR over the last one decade. DR in this competitive market creates cost-effective programs that allow demand-side resources to compete with supply-side resources while also achieving DR efficiency through sourcing strategies (Shen et al. 2014). In India electricity market is regulated by the government and technology infrastructure is still developing. Although utilities in India recognize DR in their operational planning, distribution utilities are mostly government owned and still evolving. Large scale DR programme implementation requires substantial provisioning of information processing to address market barriers. These limitations along with institutional barriers to bring changes in the regulatory and policy frameworks make India's environment different from Australia (Harish & Kumar, 2014). Furthermore, while DR environmental differences between India and Australia, representing developing and developed nations, are well known, how they differ in the effects such as information needs and processing capacity are not well understood. Prior studies that analyse DR effectiveness based on need-capacity match are limited. In this work, therefore, we develop a theoretical framework to study the concepts linking information processing needs, capacity, and DR effectiveness using Organizational Information Processing Theory (OIPT).

According to OIPT, organizations process information to reduce uncertainty, and the elements of organizational structure vary in their capacity to match its information processing needs in order to attain an acceptable level of performance (Galbraith, 1977; Tushman & Nadler, 1978). Previous studies have shown that the amount of information processing is associated with task characteristics driven by unpredictable external events (Chen & Chou, 2009; Hung & Chen, 2020; Karimi et al. 2004; Khuntia et al. 2016). Organizations are open social systems that process complex information to accomplish internal tasks, coordinate diverse activities, and interpret the external environment. Studies involving the application of OIPT to DR effectiveness are scarce in the extant literature. We draw upon findings from prior research to argue how information exchange (Zhou & Benton Jr., 2007; Zelt et al., 2019) and analytical capabilities (Dubey et al., 2019; Gupta et al, 2019; Kaur et al., 2019; Srinivasan & Swink, 2017; Yu et al., 2020) are essential to achieve desired task performance for organizational advantage (Daft & Lengel, 1984).

A major revamp of the organizational structure in the energy sector is needed to improve the association between infrastructure, information and user behaviour (Nyberg, 2018). As information and communications technology evolved, stakeholders faced various challenges characterized by uncertainties like the enhancement of existing networks to deliver reliable and quality power, integration of distributed energy resources (DER), and improvement of energy analytics providing valuable insights. The technology-driven solutions to these problems necessitate continuous processing of voluminous data, and the information plays a significant role in improving the performance of the DR systems. Information received as output from Business Intelligence and Analytics (BI&A) in DR programs is used by decision-makers to interpret and act on the information to positively influence the consumption behaviour of energy users (IBM, 2012). AMI has the potential to supply data at different frequencies and various levels of granularity (Watson et al., 2010). However, the specific levels of granularity of the electricity consumption data, user behaviour data and grid control data to be captured, transmitted and stored remain underexplored (Alahakoon & Yu, 2016; Jagstaidt et al., 2011).

The purpose of our study is twofold: first to compare DR systems in India and Australia and then to analyse DR need-capacity-effectiveness relationship. In sum, we formulate the specific objectives of our study as: (a) to identify the elements of information processing needs and capacity using exemplars from the DR program initiatives in a developing (India) and a developed (Australia) country, (b) to explore the information processing needs for DR effectiveness driven by the electricity demand-supply uncertainty and (c) to use organizational information processing theory (OIPT) and develop a theoretical framework to understand the fit between information processing needs and information processing capacity that influence energy demand response effectiveness.

The remaining part of this paper is organized as follows. Section 2 discusses the related literature followed by the development of an a priori conceptual framework in Section 3. Section 4 details the qualitative method of analysis and case site description. The analyses and results are discussed in Section 5 followed by Section 6 that provides a comparative case data analysis. Section 7 has the proposed model and propositions. The conclusions of the paper are given in Section 8.

Literature Survey

In this section, we review different studies on the information needs for DR effectiveness and describe the theoretical background of the current research from Information Systems (IS) literature. As demand response systems seek to influence demand side of electricity distribution to address supply side constraints, our study focuses on the demand side studies from IS perceptive.

Information Needs for DR Effectiveness

Information and communication technologies (ICT) enable the communication and coordination of large scale spatially distributed objects (Goebel et al., 2014). In the context of environmental sustainability, Watson et al. (2010) proposed an integrated framework to study information flows in an energy demand-supply system. Feuerriegel and Neumann (2014), following the energy informatics framework, studied the parameters affecting DR decisions to shift power demand according to the fluctuating supply side. ICT in a demand side management system is a major challenge due to interoperability, algorithm stability, network management and information security (Palensky & Dietrich, 2011). Feuerriegel et al. (2016) studied the influence of value and granularity of read-out intervals on ICT cost components in the DR system. Further, Tan et al. (2012) proposed a high-level general framework with functional modules of demand side management decision supporting system.

In addition to energy informatics framework (Watson et al., 2010), scholars have also employed decision science models to study DR system performance. Corbett (2011) employed organizational information processing theory (OIPT) to study the effectiveness of electricity demand management. The author mapped the complexities associated with electricity demand management against the factors affecting information processing requirements. Further, it is shown that DR systems would incur a massive amount of data that demands better information processing capability to meet the challenges of complex energy systems (Corbett, 2013). However, this study explored only the investments in IT support that will improve information processing capabilities in energy demand management. The nuances of DR systems need-capacity match for systems performance remains under explored. Studies addressing DR systems performance from IS perspective are also quite limited.

Information Processing Theory in IS Research

As Organizational Information Processing Theory (OIPT) provides a powerful lens to understand need-capacity match for information processing, we further explore this theory in prior IS research and adopt it as an insightful a priori framework.

According to the OIPT proposed by Galbraith (1973), organizations must process information to complete different internal tasks, coordinate diverse activities and interpret the external unstable environment affecting the systems (Daft & Lengel, 1986). Information processing refers to gathering, interpreting, and synthesizing information in the context of organizational decision making (Tushman & Nadler, 1978). Further, according to OIPT, there should be a match between information processing requirements of an organization and information processing capacity of the organization's structure for the performance of the organization to be effective (Tushman & Nadler, 1978; Venkatraman & Camillus, 1984).

Several researchers have applied OIPT under varying contexts. For instance, information processing theory frameworks in the context of inter-organizational (Bensaou & Venkatraman, 1995; Premkumar et al., 2005) as well as intra-organizational (Cooper & Wolfe, 2005) relationships have been developed and validated. OIPT has also been employed to assess how a firm's information processing requirements and capabilities combine to affect the intention to adopt cloud computing in supply chain management systems (Cegielski et al., 2012; Wu et al., 2013). Others have employed OIPT to explore various strategic management phenomena like strategic alignment (Dutot et al., 2014) and competitive advantage (Smith et al., 1991).

Information processing theory in IS literature draws heavily on OIPT. The traditional information processing frameworks (Egelhoff, 1991) assess information processing needs and capabilities based on the structural alignment for transaction processing in an organization. Wang (2003) construed a firm's information processing (IP) capacity as the extent of internal alignment among IS role, centralization, and formalization. Prior studies have also used OIPT to study system implementation and its operational performance in information processing models. The constant evolution of enterprise resource planning (ERP) systems has motivated several IS researchers (Chen & Chou, 2009; Gattiker & Goodhue, 2004; Madapusi & D'Souza, 2012) to develop a systemic approach based on OIPT to explore ERP system implementation and its influence on operational performance. In order to study the organizational benefits from a client/server computing, Anandarajan and Arinze (1998) examined the match between task characteristics and client/server processing architecture to achieve adequate system performance.

Information processing when represented in terms of cognitive theory views organization as systems that learn and make decisions for an organization, while being influenced by the external environment. In this view, environmental conditions serve as the stimulus for

information processing to occur, which in turn influence the socio-psychological determinants of the individual characteristics of organizational members (Wood & Bandura, 1989). In contrast to cognitive theory perspective, in the logistical view of organizational information processing (Egelhoff,1991; Huber, 1982) organizations as systems need to balance the information processing capacity against the information processing requirements inherent in a strategy responding to environment.

In summary, although we identified a few studies analysing DR systems from IS perspective, IS research addressing need-capacity match for DR effectiveness is scanty. In this study we seek to address this gap by identifying diverse and multiple resources - physical, technological and human, as elements of information processing capacity to improve DR effectiveness. Further, addressing nuances of information needs for informed DR decisions we classify task at different levels based on its complexity. Drawing on OIPT, we explore organizational characteristics in terms of the elements of information processing needs and capacity and their influence in improving the efficiency of DR programs. The proposed framework identifies the information processing needs influenced by electricity demand supply uncertainties.

A Priori Conceptual Framework

Following OIPT, we propose a conceptual framework to capture the information processing needs and capacity that impacts the DR program goals. Figure 1 gives a schematic view of the proposed higher level framework.



Previous studies on OIPT suggest organizational effectiveness is affected by the level of uncertainty. Uncertainty is defined as the difference between the information possessed by the organization and the information required for completing a task (Galbraith, 1977). In order to reduce uncertainty, organizational structure and its support systems need to be tailored to provide sufficient data for coordination and controlling activities (Galbraith, 1974; Tushman & Nadler, 1978; Daft & Lengel, 1986). Information processing capacity is the capability of the systems to gather, aggregate, process, exchange, and distribute information to complete an organizational task (Stock & Tatikonda, 2008). Thus an organization has to identify the elements that characterize an increase in information processing needs that demands an increase in its information processing capacity (McCormack & Trkman, 2014). Accordingly, organizations have to design strategies to align information processing needs with its capacity to enhance the performance of a system (Fairbank et al., 2006). Thus, the proposed

framework conceptualises information processing mechanism as an interaction between the information processing needs and capacity that is driven by electricity demand-supply uncertainties, influencing energy demand response effectiveness.

Dimensions of the Framework

In the following sections, we discuss the elements that constitute information processing needs, electricity demand-supply uncertainties and information processing capacity from previous literature.

Electricity Demand-Supply Uncertainties

We identified three types of demand-supply uncertainties that contribute to high levels of information loads. They are environmental uncertainty, source uncertainty, and interorganizational uncertainty.

Environmental uncertainty consists of the external factors affecting the behaviour of a system (Daft & Lengel, 1986). For example, weather patterns have to be recorded to design load forecasting models and take decisions on load curtailment (Feuerriegel et al., 2016). We define source uncertainty as uncertainty formed from different sources of power generation (coal, thermal, wind, solar, ocean, biogas, hydro, etc.). With renewable energy sources integrated into the grid, the complexity of electricity grid management increases with intermittencies of different energy sources like solar and wind power. Another type of uncertainty is inter-organizational uncertainty defined as the nature of the relationships among organizational units (Melville & Ramirez, 2008). Accordingly, inter-organizational uncertainty is expected to increase as the number and complexity of external relationships increases.

Information Processing Needs - Task Characteristics

As information increases, uncertainty decreases (Daft & Lengel, 1986). Information processing requirements are based on each task, their characteristics, external factors that influence the task, and interdependence of the tasks (Tushman & Nadler, 1978). Task complexity is characterized by an increase in information load, information diversity and rate of information change (Campbell, 1988). As the task complexity increases, there are more information processing requirements which affect the performance of the system. We categorize different tasks based on the sources of complexity as energy billing, DR scheduling, pricing decisions, and capacity planning as discussed below.

In order to encourage consumers to participate in energy-saving programs, utility companies offer discounts on monthly bills (Warkentin, 2017). Smart meters generate load profile data that is gathered and aggregated to create monthly energy bills (Albadi & El-Saadany, 2008). DR scheduling algorithms based on consumer segmentation with similar load profiles proved useful to design DR strategies (Albert & Rajagopal, 2013). In an effort to achieve energy efficiency, it is essential to analyze consumers' consumption pattern and track their behavioural attitudes (Abrahamse et al., 2005). Load disaggregation at the appliance level results in more engaged consumer participation (Haq & Jacobsen, 2018). In wholesale DR model, the retailers or distribution network operator communicate price changes in the market to the end-customers, encouraging them to shift or reduce their energy demand (Feuerriegel, 2012). In price depended DR end users can be incentivized or penalized while maintaining their voluntary choice (Eid et al., 2016). In a highly volatile day ahead market, demand shifting mechanisms out-performs the current price-volume bids (Su & Kirschen, 2009) and improve the economic efficiency of the electricity market (Märkle-Huß et al., 2018).

In a prosumer era, where customers play the role of both generators and consumers, it is crucial to differentiate prosumer markets with decision models in electricity market structure

(Parag & Sovacool, 2016). For instance, using peer-to-peer energy trading platforms to incentivize prosumers with distributed energy resources (Morstyn et al., 2018). As renewable penetration increases, capacity planning using demand response with curtailment rules ensures safe operation and grid stability in distributed generation (Xu et al., 2016).

Information Processing Capacity

Organizations adopt different information processing mechanisms to address information processing needs. Information processing mechanisms are the instruments that are deployed by the organizations to create or improve information processing capacity to process more information (Kowalczyk & Buxmann, 2014). We identify four logical elements of information processing capacity – (a) Data acquisition, (b) Semantic information integration, (c) Business intelligence & analytics, and (d) Problem solving & decision making (Author).

Data acquisition capacity measures the system's ability to handle a given volume of data. It is essential to estimate the frequency of inquiry of data among the entities to obtain timely information and avoid information overload. It is also necessary to determine the level of information granularity, processing complex information entities decomposed into different granules that allow stakeholders to focus on the essential facets of the problem (Pedrycz, 2013).

Capturing dynamic data from sensors, integrating with external data from various databases, and logically organizing and optimizing large amounts of data in real time are the objectives of semantic information integration. The quality of information is critical in complex decision-making processes (Mason, 1978). Data quality of an information system is measured in terms of accuracy, relevance, representation and availability of data (Wang & Strong, 1996). Data collected from different database sources have to be pre-processed to filter out flawed and redundant data (Potdar et al., 2018) to ensure data quality.

Organizations collect and store a massive amount of data, but a key to derive value from data is the use of analytics (Watson, 2014). In energy data analytics, business intelligence and analytics provide interactive visualization, online analytical processing (OLAP), predictive analytics and data mining solutions (Chen et al., 2012; Ahmed et al, 2019). In a data-rich DR system, the decisions at different spatial and temporal granularities for curtailment will be guided by advanced data analytics (Simmhan et al., 2013).

As industry digitizes their business, the problem solving & decision making talent pool help predict trends and generate insights from data. This expert group with DR domain experts discover patterns and relationships from facts and use them to provide actionable information that creates value for the organization (Watson, 2014). As the system becomes complex with massive data, distinct information cues must be processed in decision making to match the information needs (Huang et al., 2014).

Energy DR Effectiveness

DR programs ensure the grid stability at real time by balancing the demand and supply despite the uncertainties in the future market. Time-varying pricing plans encourage customers to take control of their electricity prices and their consumption. Incentive-based programs for load management provide grid stability and thus enhance its reliability. Electricity DR system performance is determined by the success of different DR strategies that are implemented.

Research Methodology

The purpose of our research is to understand the information processing needs and capacity of DR systems and their influence on DR program outcomes. Using the theoretical lens of OIPT, this work seeks to propose a model that characterize relevant constructs and their interrelations based on the data obtained from case studies. Our research aims to explain the contextual conditions that influence information processing in electricity DR systems. We chose case study methodology for our research as the concepts related to information processing in the metering infrastructure of electricity demand-supply systems are still evolving. It further enriched our a priori conceptual framework by providing data sources to identify its specific constituents and their interactions (Yin, 2013).

We further employed cross-case analyses for generalization of the concepts in two different contexts – Australian and Indian. Eisenhardt (1989) recommends cross-case analyses to look beyond initial impressions and examine evidence through multiple lenses. Cross-case analyses enable researchers to generalize patterns and render deeper insights from the case site data. Following this principle, we used cross-case analyses to identify the value creation variables that capture the similarities and differences of DR at an organization level. The electricity systems in Australia are highly advanced in metering technologies with a large-scale installation of smart meters. Contrastingly, India is still in the early stage of adoption, aiming for a fast rollout of smart metering infrastructure and its efficient integration into the existing electricity system. DR programs have been successfully implemented in Australia during 2017 & 2018 as pilot studies and are maturing with new products and services. In comparison, DR is in its nascent stage in India. It is against this backdrop that we chose a comparative case study. Furthermore, mechanisms explaining the socio-technical phenomenon in one setting may provide plausible propositions that may be validated in other similar contexts (Avgerou et al., 2019). Therefore, we did a comparative case study analyses between Australian and Indian electricity DR initiatives. The unit of analyses for the comparative study is DR systems at country level.

We employed both the principles of deduction and induction for theory building. We deduced an a priori framework which gave our field study a direction in the early stage of our research. Here an a priori specification of important constructs from extant literature helped us to start with a broad understanding of the phenomena. Subsequently, we validated the observed phenomena by following the methodological principles of retroduction (Wynn & Williams, 2012) in giving plausible explanation of information processing mechanisms in the context of DR systems. According to Lee & Baskerville (2003) findings from case studies can contribute to theory building by helping to capture the constituent components of the observed phenomena and generalize reflections of observations in conceptual terms that generated the phenomena in the specific context. Following Yin (2013) we used purposive sampling to suit our research objectives and included various stakeholders involved in the electricity value chain across multiple organizations. We interviewed respondents from different public and private distribution companies who have implemented DR systems as pilots, government regulatory bodies who are decision-makers, and firms who provide software as a service for DR processes.

Data Sources and Data Collection

We chose key informants who were experts in the implementation of AMI deployment having more than five years of experience in the Indian (Case site 1) and Australian (Case site 2) power industry. We predominantly used interview mode of data collection. For the purpose of data triangulation, we also referred other sources of evidence provided by the informants in the form of documents such as AEMO operational & market challenges, Australian Renewable Energy Agency (ARENA) DR customer insights reports; and other reports on DR pilot programs available through online resources suggested by the organizations.

We started our expert interviews in India (Table 1, SI No: 1-11). The process of identifying the respondents, getting their consent for interviews and conducting the actual interviews took eight months (March 2017 to October 2017). Most of the interviews (8 out of 11) were done in person, and the rest were telephonic interviews. All the interviews were recorded except three of them which were documented manually. At the case site 2, we conducted 13 interviews (Table 1, SI No: 12-24) with the key informants for three months (August 2018 to Oct 2018). At this case site, all the interviews were recorded where 7 out of 13 were conducted in person and 6 were telephonic interviews. At both case sites, the interviews lasted about 50-60 minutes. The characteristics of our sample and the roles of the respondents are given in Table 1. The data corpus consisted of 43,520 words from 11 interviews in case site 1 and 67,988

Table 1 - Case Sites and Participant Profile						
SI No	Participant Role	Organization Type	Country	Years of Experience	Labels	
1	Head of Operations	Private Distribution Company	India	15	KI-1	
2	General Manager (Analytics Expert)	Private Distribution Company	India	11	KI-2	
3	Additional Vice President	Private Distribution Company	India	23	KI-3	
4	Assistant Engineer (Reforms Project Management Cell)	Public Distribution Company	India	26	KI-4	
5	Executive Engineer	Public Distribution Company	India	10	KI-5	
6	General Manager (Smart Grid Project)	Public Distribution Company	India	27	KI-6	
7	Deputy Technical Lead	Solution Provider Company (Meter Data Management)	India	8	KI-7	
8	Director (Business Development)	Solution Provider Company	India	11	KI-8	
9	Deputy Director (Power Systems)	State Electricity Regulatory Commission	India	30	KI-9	
10	Joint Director (Engineering Unit)	State Electricity Regulatory Commission	India	36	KI-10	
11	Chief Engineer (Reform and Restructuring)	Ministry of Power Government of India	India	34	KI-11	
12	Head of System Management	Australian Energy Market Operator	Australia	30	KI-12	
13	Demand Response Manager	Wholesale Electricity Retailer	Australia	9	KI-13	
14	Program Director Retail Strategy	Public Electricity Enterprise	Australia	14	KI-14	
15	Data Science Lead	Public Electricity Enterprise	Australia	20	KI-15	
16	Chief Technology Officer	Public Electricity Enterprise	Australia	12	KI-16	
17	Economist, Policy	Public Electricity Enterprise	Australia	7	KI-17	
18	Senior Policy Advisor	Public Electricity Enterprise	Australia	9	KI-18	
19	Energy Solutions Manager	Public Electricity Enterprise	Australia	21	KI-19	
20	Distributed Energy & Innovation Manager	Private Energy Provider	Australia	17	KI-20	
21	Senior Demand Management Engineer	Private Energy Provider	Australia	18	KI-21	

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

Tab	Table 1 - Case Sites and Participant Profile					
22	Product Manager (Electricity Markets)	Private Energy Provider	Australia	6	KI-22	
23	Associate Director	Energy Consumers Australia	Australia	17	KI-23	
24	General Manager	Energy Solution Provider Company	Australia	17	KI-24	

words from 13 interviews in case site 2, resulting in a sample with rich and experiential data (Cresswell & Poth 2017; Yin, 2013; Morse, 2000) to explain the phenomenon under study.

DR systems are at its inceptive stage with multi-faceted phenomena within an organizational context. Hence, it is important to investigate the phenomena through various stakeholders' viewpoint (Klein & Myers, 1999). Based on the theoretical framework, a semi-structured questionnaire (Appendix A) was used with ten questions covering the context, roles of the stakeholders and the information processing needs and capacity in demand response systems. Semi-structured interviews allow to gather rich descriptive data and uncover insights from the perspective of participants (Ryan & Bernard, 2000). We started our interviews typically with open-ended questions across the stakeholders to elicit more elaborate questions. However, further interview questions were guided based on the interactions, reflective thoughts and the response of the experts and the initial questionnaire was thus updated. The interview data was fully transcribed into text, and a summary report of the interviews was sent back to the experts to ensure validity and seek further comments on the insights.

Data Analysis Procedure

We followed a two-fold approach while coding the case study data. Initially, we performed reflective data analysis manually to send the summary reports to the experts after the interview. Then, we used computer-assisted qualitative data analysis software Nvivo 11 to encode and categorize the concepts that emerged from the data. However, the initial dimensions drawn from literature served as seeds to map to the emergent concepts from the data (Miles & Huberman, 1984). Both the case site data were analysed individually so that we could check if both the case sites generated the same concepts. These concepts were then grouped into the dimensions of task characteristics, information processing capacity, demand supply uncertainties, and energy demand response effectiveness. We followed the coding procedure given by Strauss and Corbin (2008) to code our case study data. The initial coding using the inductive approach resulted in 27 themes. In order to ensure the reliability of the concepts, another researcher read and coded the case study data independently. The two coders compared the coding generated from the case study data and mutually agreed on the final coding comprising 14 themes. Table 2 represents the details of case study data references mapped to each coded theme using Nvivo.

Case Sites

We covered two different countries, India and Australia, for our case study. While Australia is far ahead in terms of smart metering deployment, India's smart metering technologies is in its initial phases of implementation. Further, the Australian Government with Australian Electricity Market Operator (AEMO) conducted different types of DR trials across the country in the previous years (2017 & 2018). In India, DR systems are fast gaining traction; our study helped us to understand how they were implementing and integrating DR systems into AMI. Since both nations differ in their electricity value chain structure, their challenges and barriers in the AMI deployment also differed.

Case Site 1 – India

Electricity is one of the key enablers for achieving socio-economic development of India. The national electricity plan by Central Electricity Authority (CEA) shows the projected growth rate of energy demand to increase by 7.44% with a peak demand of 226 GW by 2022 (National Electricity Plan, 2018). Indian electricity generation is the world's fifth largest capacity with 302 GW of installed capacity as on December 2016. Even with such rapid growth in the generation side, there is a 3% peak load deficit that is now managed by load shedding in the distribution (SCADA) integrated with the availability based tariff (ABT) structure ensures the stability of the electricity grids and maintains grid discipline at the generation and transmission networks. On the other hand, distribution sector development has been stagnant for the last 30 years with regulators and the utilities bringing no significant changes or technological innovation to this vital link in the electricity value chain. In a developing country like India, the growth of distribution sector is very critical because they provide the interface between the utilities and consumers to meet the energy demand.

Table 2 - Coding Themes & Reference Details						
Item	Code	Dimensions	Number of Sources		Number of Coding	
NO:			(Respo	ndents)	References	
			India	Australia	India	Australia
			(11)	(13)		
1	Energy Billing		5	4	14	10
2	DR Scheduling	Information	6	8	98	68
3	Pricing Decision	Processing	6	8	24	51
4	Capacity Planning	Needs	6	6	25	14
5	Environmental Uncertainty	Electricity	4	5	7	7
6	Source Uncertainty	Demand- Supply	3	3	3	4
7	Inter- organizational Uncertainty	Uncertainties	4	8	8	22
8	Data Acquisition		6	10	63	67
9	Semantic Information Integration	Information	6	4	26	9
10	Business Intelligence & Analytics	Processing Capacity	6	8	56	88
11	Problem Solving & Decision Making		5	3	17	9
12	Consumption Savings	Energy DR	4	3	11	5
13	Cost Savings	Effectiveness	4	5	18	9
14	CO ₂ Emissions		2	3	5	7

Case Site 2 – Australia

Australia's diverse and abundant availability of high-quality energy resources is a key contributor to the country's economic prosperity. According to the Bureau of Resources and Energy Economics (2014), the gross Australian electricity generation is projected to grow by nearly 30%, with the share of renewables in the electricity generation mix to increase by 22% reaching 88.5 GW by 2027. Likewise, Australia also projects a steady population growth

leading to new electricity connections to increase by 27% in the coming decade. The residential energy sector shows the maximum usage of power due to appliance penetration per house (National Electricity Forecasting Report, 2016), estimated to increase by another 35%. Recent modernization in the transmission and distribution network to meet the growing demand gave a price shock in the electricity bill of Australian consumers. As the country shifts towards integration of fluctuating renewables output to the grid, there is an oversupply of generation capacity in the wholesale market. The continued falling costs of solar photovoltaic (PV) panels have enabled the consumers to use on-site generation to overcome the sustained high retail prices. In order to achieve reliability targets and meet renewable supply gaps, storage technologies have been developed to harness the renewable energy for managing the peak demand. Since 1990, the Australian Government has bought changes to the regulatory measures to increase energy efficiency and generate choices for consumers. These new business models have become the key focus of the power development strategies in Australia. Table 3 highlights the inherent structural and operational differences between the case sites.

Table 3 – Inherent Structural and Operational Differences between Case Sites				
Features	Case Site 1 - India	Case Site 2 - Australia		
Structural differences in the value chain	Traditional framework with distribution and retail under one geographic monopoly	Transmission and distribution managed together, and energy retailer is separate with competition in the retail energy markets		
Utility structure	Power utility is a stand-alone structure under the current system	Single utility structure with retailers providing single window service for electricity, gas, and water		
Energy market operations	No retail competition	Energy market retail competition		
Business model value levers	Loss reduction by energy auditing	Consumer choice through demand participation		
AMI Initiatives	Outage management and power quality, Renewable integration	Demand side management, Automated DR, Renewable integration, Energy storage technologies		

Analyses and Results

We identified specific concepts on DR effectiveness from prior studies (as explained in Section 3) and detailed the constructs of the model using the codes that emerged from the qualitative analysis of case study data. Our findings provided support for all the dimensions and the elements that constitute the proposed conceptual framework. The elements of information processing needs, electricity demand-supply uncertainties and information processing capacity developed from the previous literature were mapped to the themes evolved from the data corpus (Table 2). Three specific elements of energy DR effectiveness construct emerged from our case study data (Table 2 – Item No: 12,13,14).

Electricity Demand-Supply Uncertainties

We explored the types of electricity demand-supply system related uncertainties of the electricity value chain. While wind and solar PV currently dominate the growth of renewable electricity production, capturing the freely available but varying amount of wind and solar

irradiance is still a challenge in grid integration. The following statement indicate that DR systems must be integrated with the weather information systems.

Unlike our conventional generation, 10000 MW of renewable energy will vary with seasonal conditions and climate, and the real-time data will be much more helpful in handling future renewable energy grids.(KI-5)

Resolving the intermittency problem will require real-time processing of vast streams of demand-supply data to match the needs of the network capacity of electricity systems. The complexity will increase in the future with individual households playing the role of prosumers.

Secondly, solar energy or wind energy both have no capacity factor associated with them, so you still need the capacity to be supplied from conventional plants; you cannot depend on wind to provide quick demand support that is uncertain.(KI-8)

The distribution systems face a huge challenge in providing the right mix of highly intermittent and variable generation of DER sources. As the solar energy penetration increases in the power system, the demand curve depicts the "duck curve" representing over-generation of solar energy in the early afternoons and a severe ramp up in the early evenings (AEMO, 2017).

In an electricity value chain, the stakeholders have to communicate, coordinate and collaborate among different organizational entities to take a collective decision in optimizing the energy resources usage. For instance, the decision rights on the energy costs and pricing for the energy mix will be guided by the policy regulations influenced by the governing bodies and the regulatory commissions. The generators, distributors, retailers, governing bodies and market operators have to jointly collaborate in framing regulatory frameworks.

The frameworks of regulation that governs these markets are very rigid and not changing with the pace of change that we see in the industry.(KI-12)

Information Processing Needs - Task Characteristics

Our study shows that the nature of the task plays a vital role in determining the solution for the desired outcome. Table 4 summarizes the information processing needs in the energy DR system. The following statement illustrates that the organization is using data for various tasks.

The data is used for different purposes; some of the data is used for billing; some are used for analytic purposes. We do electric shock monitoring and outage detection [SIC]. We also do archetype modelling to model customer profiles. (KI-15)

Information Processing Capacity

We notice that different types of uncertainty create different information processing needs, and organizations should deploy information processing mechanisms to match these needs. As information processing needs arise, relevant information processing mechanisms should be employed to augment the processing capacity of the organization to improve energy DR effectiveness.

Table 5 provides information processing capacity mapped to the case study data. The component "regulation & policy implementation" of the construct "problem solving and decision making" emerged from the case study data. The recent annual report of Synergy (2018) notes that it is imperative to bring sustainable reforms to guide investments in the electricity system. The energy sector needs a coordinated and collaborative direction to include decisions from the state level and national level to develop policy frameworks in the multi-stakeholder

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

competitive electricity value chain (Friedrichsen et al., 2014) that benefit consumers and the market.

Table 4 - Information Processing Needs					
Tasks Classification	Nature of Tasks	Case Site Data			
Energy Billing	 Assembling smart meter data 	The billing errors can be avoided using the smart meters and the consumption data automatically get saved in the computers.(KI-4)			
	 Aggregation of load consumption history 	f We do bill shock calculation. The computer predicts based on your historic behaviour; what you're likely electricity bill is going to be.(KI-15)			
Demand Response Scheduling	 Demographics and Socio- economic factors 	In Pondicherry, the peaks hours are morning and evening. But in Delhi and Mumbai, the night peak hours start from 10 PM to 12 or 1 AM. So demographic parameters and social attitudes also affect.(KI-4)			
	Customer segmentation	We segment based on the shape of the load profile. Are they evening user or daytime user? Are they a twin peak or a flat user? we had seven such groups. (KI-15)			
	 Demand shaping 				
Pricing Decisions	 Prosumer markets 	Now all the states have revised their renewable power policies. For solar, the price from the field has come down drastically. (KI- 5)			
	 Forecasting future spot prices 	What probably would be useful in the future is the concept of the instantaneous market price. (KI-15)			
Capacity Planning	Operational planning of distribution & transmission	The peak is increasing every year only by 5%, so do I have to install a power plant for this? DR is a wise decision because the peak is not there every time. (KI-6)			
	systems	Currently, we have about one gigawatt of generation from renewables. Unless we have capacity firming by storage or			
	Renewable energy integration	create flexibility in distribution, these investments will not be attracting, the return to those investors will not be as expected. (KI-12)			

Energy Demand Response Effectiveness

DR programs ensure the prompt response of consumers to dynamic pricing. Consumption of less energy in response to high prices will reduce the cost of total electricity production and thus bring down the wholesale purchase costs in the electricity markets. The electricity consumers will financially benefit from cost savings, regulating their demand needs in response to price-based or incentive-based programs. The following quotes highlight consumption savings and cost saving as performance indicators.

How much you have reduced in terms of Megawatt and how much power you didn't have to buy this costly during peak demand. (KI-9)

If distributors are getting their load forecasts wrong [SIC]*, impacts their capital revenue cap.* (KI-18)

Sangeeth L R et al.: Information Processing view of Electricity Demand Response Syste

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

Table 5 - DR	Table 5 - DR Information Processing Capacity					
Information Processing Capacity	Information processing mechanism	Case Site Data				
Data acquisition	 Frequency of data capture 	We have load data which comes once in 15 minutes, (sic) and events log reported in a day, and asynchronous events like tamper data or a power outage every 2 mins; daily billing and monthly billing aggregated a month.(KI-7)				
	Data granularity	The issues faced during the design of the baseline algorithm were in finding the right set of data; the days and times of a day to call the DR events [SIC]. Therefore, high-resolution data is always of interest as it will give more insights and will help the distributors to run effective DR programs.(KI-20)				
Semantic information integration	 Data quality 	The third challenge is availability of accurate data. You need to have accurate plot-wise data; absence of accurate data brings delay in implementation of DR.(KI-8)				
Business Intelligence & Analytics	Techniques Tools Algorithms	We are converting data to information using analytics tools. The information is used for various purposes like forecasting, detecting thefts & tampering events.(KI-2) We look at 15-minute intervals energy data in a day. We plot the daily median of each month for every customer. We use				
	• Algonanins	clustering to group those patterns and identify a common set of clusters called archetypes.(KI-15)				
Problem Solving & Decision Making	 Domain Experts Regulation & Policy 	We need domain experts to deal with the consumers psychologically; what kind of rule we need for demand shifting; how to call a DR.(KI-3)				
	Implementation	Yes, the policy needs to be liberalized. It is essential to get experts in this area to make regulations for modelling tariff charges of distribution systems.(KI-8)				

Further, United States Department of Energy (2006) reports demand response in long term and short term resource planning will eventually bring financial benefits to utilities by driving down prices for wholesale electricity purchases. In the long run, this price reduction will be reflected in the consumers' cost saving.

The following exemplified quotes show measuring the performance of DR systems in terms of CO2 emissions is also essential to mitigate the climatic change globally.

CO2 reduction is a good sellable indicator, say, 70 MW is saved that is converted to a decrease in CO2 emission.(KI-3)

The Power Shift program was an initiative to help low-income households to reduce their energy usage to save money; and also towards emission reduction.(KI-23)

A study by Stern et al. (2016) demonstrates how DR programs can reduce more than one per cent of carbon dioxide (CO2) emissions. According to the Pacific Northwest National Laboratory (2010) report, the "Shift and Save" program in California stated an estimated reduction in the carbon footprint to be between 10% - 20% for each participant enrolled in the DR program. Environmental taxes supplemented by regulations of emissions invite consumers to engage in DR programs. In order to meet the Paris Agreement target of 28% reduction in emission, the Australian government is investing in renewable-based

technologies (Australian Government, 2015). In India, integrating the renewable sources like solar and wind to the grid is estimated to serve 22% of India's power demand and result in cost-savings through national and regional coordination of scheduling and dispatching power supply (Greening the grid, 2017). Based on our empirical results, we determine the elements of energy DR program outcomes by linking its information processing with performance measured in terms of consumption savings, cost savings, and CO2 emissions as given in Table 6.

Cross Case Analyses

Having identified constructs related to information processing needs, information processing capacity and effectiveness of DR programs, we now analyse our data and abstract our findings at national level DR systems. In particular, we extract value creation variables from our data and use those variables to compare DR systems in Australia and India.

Table 6 - Demand Response Effectiveness			
DR Performance Indicators	Case Site Data		
Consumption Savings	Since the consumer will know how much he is consuming every day, he can monitor his bill and control his usage of electricity in the house. So there is self-conservation of energy. (KI-4)		
	How much consumer have participated against total, how much load is reduced. For example, baseline demand of any consumer is 10 MW and he has reduced 1 MW then 10% efficiency is achieved. (KI-3)		
Cost Savings	The distribution company can manage the remote automatically; say at 10:00 PM the set point will be different and 4:00 AM the morning set point will be different. This is a huge value to the customer cost reduction, and a value addition to the customer. Thus, technology will add value from both sides and will change the scenario of DSM completely. (KI-8)		
	The number one selling point is how much can they save by lowering their energy costs. (KI-22)		
CO ₂ Emissions	In future, value comes from the decarbonization. As you reduce the demand you need not build new conventional plants. Secondly, if you have solar or wind energy you can switch off conventional plants, although, due to its uncertainty they cannot provide quick demand support. (KI-8)		

DR Value Creation in India and Australia

Electricity systems are undergoing a gradual change from centralized generation to widespread adoption of distributed energy resources (DER). This transformation disrupts the traditional business models across all the stakeholders in electricity value chain. Demand response program is an initiative aimed at securing the grid reliability to manage electricity supply during extreme peaks. Such programs work on the simple principle of strategically levelling the demand curve to remove the stress on the electricity grids. The large commercial businesses, industries and households are given incentives in exchange of shifting electricity usage to off peak hours or limiting their energy usage during peak times to reduce the strain

on the grid and prevent blackouts. However, it is important to realize that the design and successful implementation of such programs depend on regional specificities. In this context, four national level concepts emerged from the analysis of our case data for cross-case analysis - pricing structure for demand side participation, renewable integration at supply side, reforms in the regulatory instruments, and emergent technology. Table 7 enlists the similarities and differences between the two case sites.

Table 7 - Value	Creation Variables in	n Electricity Demand-Supply Systems
Variable	Items	Case Site Data
Pricing Structure for Demand Side Participation	 Australia Consumers' access to the wholesale electricity prices Market reform initiatives Incentives for DR program participation Cost-reflective Pricing 	Customers intend to reduce the risk they hedge in a couple of different ways; they can hedge through financial instruments using futures market products things like swaps, caps and Asians. However, if they can hedge physically, they can also reduce that risk to significant price increase. And one of those methods under the physical hedge is demand response. (KI-13) I guess we've got a problem at the moment is that we haven't been able to set pricing, there's probably no retail process set by the government; we try and influence what they are but ultimately that's the government's decision process. I think it would be a good outcome if we could at least shift pricing that is in terms of retail tasks to an independent regulator and that might be ERA (Economic Regulation Authority) or might be some other body. (KI-18) I think we need to explore having reflective pricing so that we can manage demand especially the new peaks that may form in the network; so that it becomes more reliable. (KI-22)
	India • Cost-reflective Pricing	With dynamic tariffing consumers by themselves will reduce, if they know that the frequency is low or if they are getting the message that this is peak now and they will be charged high. With dynamic pricing they will automatically curtail the loads. But we are not matured now for frequency based pricing. (KI-6) There is no demand response pricing mechanism designed. There is no clarity on how much the consumers have to be incentivized or de-incentivized concerning DR program outcomes. (KI-9)
Renewable Integration at Supply Side	 Australia Energy storage technology Subsidy schemes and Feed-in-tariff policies Carbon Policies 	Government sponsored battery storage programs, we use about 400 inverters all turning on together as a response to a load shortage and we've done that in a couple of different scenarios. One, a nice sunny day and a similar sort of trial at night time. On a nice sunny day, the batteries were already charged and the household wasn't using much of the power, so they were exporting a lot of it to the grid. Again, when we spontaneously discharged the batteries in that mode, we found that we got about 25% of the capacity we expected. And when we did the same sort of trial at night when there was no solar generation, we basically got close to 100% of the battery outputs. (KI-19) The disincentive that has existed here for promoting solar generation, it's been really good. This is a great success so far, but we need to think what is the impact it can have on the system and how we can then come up with the right

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

		policies to satisfy the environmental objectives also. The policies must be to bring in consumers participation like an incentive that satisfy affordability, system security and reliability and also meeting the objectives of lowering emissions. (KI-12)
	India Tradable renewable energy certificates 	We are supposed to adhere to renewable energy obligations that 3% of our power procurement should be met from renewable energy so if we don't have renewable energy sources, we will have to buy renewable energy certificates. So we are encouraging people to put up rooftop. (KI-4)
	State level policy for renewable source integration	Different states have different policies. Distribution companies will purchase certificate from renewable power producer. Earlier price was more, during power shortages utilities used to pay 8-9 Rs/ 12 Rs per unit as per the renewable power obligation. Now all the states have revised and as everyone is going for solar the price from the field has come down drastically. (KI-5)
Reforms in the Regulatory Instruments	Australia Cost-reflective pricing 	The government has to come up with policies with respect to the cost reflective structure and that's driven by the costs, a lot of that cost is largely about the cost of setting up generation, there is some costs through the network. (KI-14)
	 Price-quantity- reliability based regulatory framework 	Design regulatory frameworks that encourages all the shareholders to invest in energy grid efficient systems, incentives to shift to DER leading to lower transaction costs across the network, reward based DR strategies to shift the energy consumption increase during the peak periods to off-peak periods. (KI-14)
		The regulatory framework of electricity markets assumes that all load is fixed. Whereas in distribution the market can be cleared on price quantity and reliability. There is lot of degree of tolerance in distribution loads to various reliability and if we can unbundle this we can create a market that distinguishes between a load that needs 100% reliability. and between your load that needs 60%, 30% reliability. For example, your pool pump which really doesn't need to be turned on at a specific time, your hot water system in future we will have PVs, electric vehicles etc. So the objective of what we need to do is to create that flexibility of different types of loads in the distribution systems. Therefore, I'm saying in distribution networks you can create markets that clear on different reliabilities, and the technology coupled with data science can create a lot of possibilities there. (KI- 12)
	India Incentives for consumer participation 	Regulatory on other hand should have encouraging regulation supporting DR initiatives. So you need to create an encouraging environment rather than creating a very tough environment in the form of regulations. (KI-8)
Emergent Technology	Australia Product based solutions 	We offer particular products to help the customers manage the price risk and respond to those increase in the wholesale market price. We do that through a message service and we also do that through hardware which is connected to the customer side that is connected via the

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

 Baseline learning algorithms 	cloud 4g mobile network to our proprietary software called KWatch that help a customer manage their load and their exposure to high price period. (KI-13)
Virtual power plantEdge computing	We've built an internal software solution that analyze the smart meter data and run that through a base learning algorithm to determine the level of performance in an event. And then an automated SMS will go back to the customers in a customized message to say how they performed during the event. (KI-20)
	I don't think we have a definitive answer still on what is the best baseline, we actually tested multiple sets of learning approaches and use the one which we found is giving us better correlation or better accuracy prediction on a control group of customers. (KI-20)
	And the other one is that managing all of that sort of technical challenges, one of the ideas is managing a virtual power plant. So instead of looking it as a big monolithic generator, it is viewed as how do you orchestrate the delivery of the right amount of energy to the right place at the right time that delivers an optimum outcome? (KI-15)
	So solar is a sort of a blessing and a curse, in the sense, it's volatile, okay. But by the same token, battery, is the buffer to that. So if we can bank the excess energy, and we can manage it, a lot of the technology comes down to our ability to manage that solar and be able to predict how to manage it more into the future. So the ability to do that processing, that prediction, that forecasting, getting final level detail right at the edge is important as well. (KI-15)
India Baseline learning algorithms 	When we are going for bigger kind of DR then we need all this analytic tools to find the baseline and find out how much capacity he has saved, shifted or he has increased. As such the data is used by our analytic department for tamper analysis or meter defects analysis, other parameters like demand variation, consumption variation, abnormalities is done for high load consumers on a daily basis and monthly-wise for medium load consumers. (KI- 3)

Pricing Structure for Demand Side Participation

We identified four items related to this variable in Australia - consumers' access to the wholesale electricity prices, market reform initiatives, incentives for DR program participation, and cost-reflective pricing. One of the drivers for implementing DR strategies in Australia is an increase in the electricity prices in the wholesale market in response to the fluctuating demand and supply. The wholesale DR model endows the consumers with the benefit of lower prices. The electricity market in Australia has a diverse structure. Therefore, market integration in Australia is a big challenge as different operators are governed by different policies. While in India, the power market has been dominated by publicly-owned vertically integrated utilities. This single entity under state control structure has led to high losses due to non-collection of bill payments, low investments leading to low growth prospects in the utility sector. Our analysis shows that experts in both the countries recommend a cost-reflective pricing. As the electricity markets are liberalized and consumers are exposed to rising electricity prices, dynamic pricing options are a promising mechanism to encourage peak load management and demand reduction.

Renewable Integration at Supply Side

As the cost of renewables declines, the corresponding increase in the usage of DER leads to alternate market opportunities. The distribution systems face a huge challenge in providing the right mix of highly intermittent and diverse DER sources. Since the price elasticity of demand for electricity is high in Australia, the domestic government adopted different subsidy schemes and feed-in tariff policies following which the amount of solar power production by households and business entities increased. Therefore, in the context of Australia, three items were identified with reference to the variable renewable integration at supply side - energy storage technology, subsidy schemes and feed-in-tariff policies, and carbon policies. In India, distributed renewable energy and storage are gaining momentum at residential, commercial and industrial levels. State level policy instruments, like Renewable Purchase Obligations (RPOs) regulate renewable energy trading. The latter is carried out by purchasing tradable renewable energy certificates. Therefore, tradable renewable energy certificates and state level policy for renewable source integration, were identified as items for this variable with reference to India.

Reforms in the Regulatory Instruments

We determined two items related to this variable in the context of Australia - cost-reflective pricing and price-quantity-reliability based regulatory framework. As part of new tariff reforms, the electricity distributors propose to develop a "cost-reflective" pricing that considers the true cost of supplying electricity by removing the reliance on state government subsidies. The cost reflective tariffs lead to sharper price signals that encourage the stakeholders to use the network efficiently thereby delivering savings to the consumers in a longer run. The current energy market model is based on the price-quantity pair, but the future energy market clearing price can be multi-dimensional with contributions from price, quantity, time and reliable loads. Energy markets are looking forward to use analytic techniques and BI tools in developing a multi-dimensional pricing framework. In rapidly growing economy like India, with increasing power demand, there is an increase in tariff rates that allows utilities to earn returns on their investments. Whenever there is a spike in the consumption pattern, DR program initiatives with regulatory interventions can reduce demand by incentivizing users. Therefore, incentives for consumer participation was identified as the item corresponding to the variable reforms in regulatory instruments, in the context of India.

Emergent Technology

Emergent technology items identified for Australia were - product based solutions, baseline learning algorithms, virtual power plant, and edge computing. Our analysis shows that both Australia and India focused on developing baseline learning algorithms in their DR pilot programs. The DR programs in Australia provide creative solutions through technologies ranging from voltage control, smart connected thermostats to control heating and cooling, automatic curtailment devices like Wattwatchers, and monitoring and controlling by KWatch intelligent controllers. With the information dissemination the energy users are able to rapidly adjust their energy usage and adapt to changes in the electricity system. There are different factors affecting day to day energy usage of households. DR trials assisted in refining the baseline inaccuracies by continuously monitoring deviations from baseline energy usage in achieving the targeted contracted capacity. With the growing adoption of DER, cloud based virtual power plants provide energy management systems through centrally managed software. In India, Meter Data Management System (MDMS) is used as a platform in helping the utilities to increase their collection efficiency and improving the energy awareness of consumers through online dashboards. The data-driven management of electric energy systems needs to be further explored enabling the utilities and third parties to develop additional applications that use grid data intelligence in decision making.

Emergent Theoretical Model & Propositions

We present our proposed model (Figure 2) based on the analysis of the case study data, OIPT framework and related literature. In the subsequent section, we posit a set of propositions related to the fit between information processing needs and capacity and its influence on the effectiveness of DR systems.



Fit as Mediation

According to Venkatraman(1989b) there exists six different perspectives of fit-based relationships; these are, fit as (a) moderation, (b) mediation, (c) matching, (d) covariation, (e) profile deviation, and (f) gestalts. Following this framework, we conceptualize fit as mediation in our study. In this conceptualization of fit, "...mediation perspective specifies the existence of a significant intervening mechanism (e.g., organizational structure) between an antecedent variable (e.g., strategy) and the consequent variable (e.g., performance)" (Venkatraman, 1989b, p.428). The existing OIPT literature also suggests that there exists a fit between the information processing needs and capacity that improves the performance of a system (Tushman & Nadler, 1978). Drawing on the mediation processing capacity) between an independent variable (i.e., information processing needs) and the dependent variable (i.e., DR effectiveness). Our conceptualization of fit as mediation in relation to OIPT is also consistent with the operationalization of fit in OIPT adopted in prior research (Bergeron et al., 1999; Croteau & Bergeron, 2001; Yu et al., 2020).

We further model electricity demand-supply uncertainty as the antecedent for the development of information processing needs (Figure 2). Effectiveness of DR programs are dependent on the level of coordination, formalization and specialization of various DR tasks. Different interdependent task units in DR system must be able to coordinate activities and deal with problem solving to achieve desired outcome of task performance. Therefore it is important to facilitate the collection, gathering, and processing of information of both external and internal sources of uncertainty (Tushman & Nadler, 1978). For instance, a simple routine task like energy billing with a minimal amount of intra-unit interdependence can be pre-planned, and requires primarily communication support for information exchange. While, a complex DR task like capacity planning associated with greater uncertainty demands higher levels of coordination, control and communication mechanisms. These, in turn, require the rationalization of the decision-making process in DR programs by way of augmenting their information processing capacity. In particular, the fit between information processing needs and information processing capacity plays a vital role in the success of DR programs. The proposed model suggests information processing needs, contingent on the complexity of tasks, can be transformed into DR success by the continuous improvement in the information processing capacity.

Mediating Role of Information Processing Capacity

In the utility industry, the information processing mechanisms at different levels catering to the uncertainty in the information processing needs influence the efficiency of DR programs. For instance, different task characteristics require different levels of information processing capacity, which points to the congruence between information processing needs and capacity that impacts the energy DR effectiveness. Therefore, following OIPT, the multi-stakeholders across the electricity value chain would strive for capacity-increasing mechanisms to meet adequate information needs. For instance, currently, the electric power grid supports intelligence through a centrally controlled SCADA system for outage management. However, the concept of self-healing electricity grid systems provide innovative efforts to foresee the possibility of distributing intelligence at the substation for each of the processing components at the circuit level to make the system resilient to dynamic perturbations, reducing the operating costs.

From data and information perspective, it's much more of a requirement [to] push processing and data management out to the edge [SIC]. We have to work out on what data you contextualize and start to aggregate; whether it is to make simple decisions like billing or complex decisions on how to make 100,000 houses generator across a city to route about in a network to provide generation [SIC].(KI-16)

Organizations must have mechanisms to learn and interpret from external and internal events (Daft & Lengel, 1986). Uncertainty at a low level in an organization can be absorbed and solved using routine programs set by the organization. Simple rules in the billing system ensures timely collection of bill payments improving the collection efficiency and increasing revenue for distribution companies. With smart metering infrastructure, the distribution companies can monitor the usage in the grid for energy thefts and thus save commercial losses. Subsequently, the process of energy auditing is made simpler, outage time is reduced, tampering is scaled down and man power is utilized for other emergency related tasks arising in the grid. When the information processing capacity is less than what is required to perform a task, performance standard will not be met, the task will not be completed on time, or the task will be completed at a higher than the desired cost (Stock & Tatikonda, 2008).

According to OIPT, when uncertainty increases the decision making is referred to the higher levels of hierarchical authority structure in the organization. Adequate planning and goal setting reduces overload on the management structure. For instance, the peak time demand in the electricity grid is typically for 2-3 hours a day with double the amount of usage compared to normal hours. With predictive analytics in place, DR programs could manage peak load through appropriate capacity planning. This would improve the operating efficiency of the system by optimal usage of power averaged over load curve for the day. This avoids an emergency situation where a higher authority has to intervene and take a call for power curtailment or generation of power from more conventional power resources. Therefore, the decisions can be made at lower levels and minimize information processing load on the hierarchical structure in the organization. This is also consistent with prior studies which have reported that information systems reduce cost of coordination (Shin, 1997).

Increase in uncertainty calls for higher levels of coordination among various vertical information processing systems attached to the hierarchical structure. Currently, a critical problem in the utility industry is integrating renewable energy into electric grids. With varying seasonal conditions, leading to intermittent renewable energy penetration, estimation from real time data using analytical tools could provide more useful insights on balancing electricity demand and supply. This requires coordination among heterogenous sources to absorb all the seasonal variability for different scenarios to improve the prediction system with more granular data. The decision making expertise in the electricity value chain also demands coordination among different stakeholders. High levels of coordination between regulators and distribution companies are required to i) implement policy changes with respect to the increase in tariff rates, ii) offer incentives to consumers for variable pricing schemes, and iii) approve renewable purchase certificates for the net export of renewable energy sources. Thus, when information processing needs are high, adequate coordination among information systems and use of lateral relations through liaison roles enhance the information processing capacity. Thus, the higher the task complexity, the greater is the amount of information that must be processed among decision-makers to achieve a given level of performance (Galbraith, 1974). In other words, the information processing needs based on the task complexity demands more information processing capacity, which in turn improves the performance of DR systems. Therefore, based on the evidence that emerged from our qualitative analysis and support from prior literature, we posit the mediating role of information processing capacity through the following proposition:

P 1: The degree of information processing capacity mediates the influence of task based information processing needs on the energy demand response effectiveness.

Lower Order Effects

Having posited the second order effect of information processing need-capacity-DR effectiveness relationship, we now analyse our data at lower levels of the constituents of information processing needs and capacity and argue our propositions in more detail.

Energy Billing

A routine task like monthly energy billing uses disaggregated load profile data from smart meters that are assembled and stored in the load history database of meter data management systems. The information processing capacity should provide technical level support to the sensors and sensitized objects required for data aggregation. We observe from our data that energy billing is the first step towards the energy management initiative as it helps in tracking the trends in utility consumption and identifies the facilities that cost you the most (Table 8, A).

Efficient billing process could reduce the billing cycle time, resulting in improved revenue and cash flows for the utilities. This also helps in reducing the errors in comparison to manual billing (Table 8, B). Thus, DR creates a valuable revenue stream that can be reinvested in energy management initiatives to deliver greater savings. Providing projected bills to the customers will create awareness about their consumption and keep the consumers more informed. The utility bills expose their energy saving percentage during the DR event participation. This self-motivates the participants and gradually make them aware of energy savings. It also serves as the key source of information for decision makers to understand consumption behavior. Thus,

P 1(a): Data acquisition and semantic information integration mediates the influence of energy billing information processing needs on the energy demand response effectiveness.

Pacific Asia Journal of the Association for Information Systems, Vol. 12, Iss. 4 [], Art. 2

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

Table 8 - Energy billing – Capacity-DR effectiveness			
Billing-Capacity	Case data		
A , Energy Billing - Data Acquisition	See for reading I can get it monthly, what is the purpose of getting it every 15 minutes. Reading is only for billing consumption of users. So it doesn't make sense to save data every 15 minutes. (KI-4)		
	They tracked the energy usage at activity levels. They tracked usage and then gave feedback mid-month through bills, that says this is how much it will cost if you keep using at that level. (KI-23)		
B. Energy Billing - Semantic Information Integration	Thirdly, one person has to go to the consumers' home to get the reading for the billing. So then we will have billing errors. These errors can be avoided using the smart meters as there will be no human interface and the consumption data automatically get saved in the computers. (KI-4)		

DR Scheduling

The diffusion of smart meters provide a novel communication platform to connect with consumers better. It is important for the utilities to have good information processing support to integrate heterogenous data sources and evaluate information to identify the best DR strategies for their consumers. According to the respondents, consumer segmentation is a very important feature of the DR program. Our analysis show that there are different types of customers with different usage patterns and it is very evident that customer segmentation and customer targeting will help the utilities towards DR initiatives. Consumers are segmented based on their energy usage load profiles, and utilities identify consumers who have greater potential for shifting loads (Table 9, E). Presently, DR recommendations are done manually by collecting and analysing the data from the historical records. Instead, the disaggregated data from the smart meters can be employed to categorize consumer segments and track their behavioural attitudes towards DR programs. For example, the load profile data captured every 15 minutes provides activities of occupants and their consumption patterns (Table 9, C).

Demand response programs require customer participation by changing their normal consumption patterns in response to price changes to bring measurable reduction in their total energy usage and cost. Further, real-time monitoring and information evaluation using data mining techniques help in load prediction and providing effective feedback to customers to achieve the desired load curtailment. Baseline models provide real time visibility to the utilities in finding operational energy metrics to measure the reduction in energy usage and avoid generation costs to reduce the risk exposure to market price during system emergencies. Therefore,

P 1(b): Data acquisition, semantic information integration, and business intelligence & analytics mediates the influence of demand response scheduling information processing needs on the energy demand response effectiveness

Sangeeth L R et al.: Information Processing view of Electricity Demand Response Syste

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

Table 9 - DR scheduling – Capacity-DR effectiveness			
Scheduling-Capacity	Case data		
C. DR Scheduling - Data Acquisition	On using 15 minutes interval, will give 4 slots of information and hence more information to make better decisions. This will also help the utilities to better understand customer participation in the DR programs. (KI-1)		
	If you add more granular data, say, one minute or five minutes, then you can do the load disaggregation. So if we have their one-minute data or five-minute data, we can do is say what kind of load they are using[SIC] and can give more actionable tips customized based on their load usage. (KI-21)		
D. DR Scheduling - Semantic Information Integration	We conducted DR for 1 hr duration, we took the pattern for the last 10 days suitable to that particular industry and then we calculated if the person has reduced the load or not. Some said they have participated in DR but that was not reflected in the data. So we did analyze it and saw that they have reduced it but they have increased it somewhere else. It didn't save energy so we didn't incentive them also. (KI-3)		
	When we're looking to manage DR, we need to really understand data at a hyper-local level what weather is doing, we need to understand almost to the street level, maybe even down to a house level, having cloud cover, or if you've got high solar penetration in one area can destroy all of our stability across the grid if we're not careful. (KI-15)		
E. DR Scheduling - Business Intelligence and Analytics	This segmentation has been designed on the load survey data from the meter that we have taken from the individual consumers. We are analyzing this for last 3 months and we run the algorithm that we designed which shows these many consumers in this particular consumption pattern will be grouped in one particular segment. (KI-7)		
	So we integrated the level of analysis we saw that those people who were tracking their live feed saved more than those who did not track. (KI-21)		

Pricing Decisions

Technology enabled platforms can capture savings opportunities by generating timely data and predicting the future costs. One of the key challenges faced by the distribution companies is optimization of power purchase cost. The distribution companies are tied up for more than the requisite capacities in long term power purchase contracts for a considerable duration. The highly priced long term contracts continue to overburden the distribution company financials. Thus, in competitive energy markets, buying energy is very time consuming and a complex process as it has to be procured at the best possible price. Using DR systems, the distribution network operators and retailers communicate to the end customers about the price changes in the market along with their energy usage information. Here, the consumers are informed and encouraged to adjust their energy demand, thus, mitigating price volatility and eventually reducing the overall cost of electricity production. With the bi-directional flow of power in distributed energy resources, distributed renewable energy and storage are gaining momentum and can be appealing at residential, commercial and industrial levels. In the decentralized electricity grid, the pricing decision models for prosumer adoption is more complex as it envisages information processing capacity to differentiate the prosumer markets based on the types of services and the variety of information thereof (Table 10, F).

Pacific Asia Journal of the Association for Information Systems, Vol. 12, Iss. 4 [], Art. 2

Information Processing View of Electricity Demand Response Systems / Sangeeth L R et al.

Table 10 – Pricing decisions – Capacity-DR effectiveness		
Pricing-Capacity	Case data	
F. Pricing Decisions – Semantic Information Integration	Consumption pattern history and other parameters are used to decide the tariff. Based on tariff demand is going to change [SIC]. (KI-5)	
	There are ways we can take on customers; flexible load if they don't have the capacity to be flexible we can financially hedge to them. We can use products in the futures market to help them avoid energy usage because they aren't able to financially hedge. (KI-13)	
G. Pricing Decisions – Business Intelligence and Analytics	We did some predictive analysis during the peak to calculate how much we have to take from outside may be in Unscheduled Interchange. (Sic) how much we have saved based on how much PPA's we have saved. What kind of UI power? (KI-3)	
	If you're able to provide a pricing plan that says we want to maintain voltage and frequency on the network, then you're gateway device needs to have a lot of processing and data analysis is required to work on how to best do that with loads. In turn, if you really heavily incentivize someone to move loads, things like doing your washing, you can automate your washing machine to run overnight. And data needs to be done at the edge rather than send it all back centrally to figure it out and then send signals. (KI-15)	
H. Pricing Decisions – Data Acquisition, Problem Solving & Decision Making	There are no prediction techniques or a granular exercise at an individual level to take a decision by the distribution companies in buying power. But when smart meters are installed the distribution company can track and correctly predict the demand for the long term and decide the power purchase agreement cost. (KI- 11)	
	If there's significant maintenance on the interconnector site between Victoria and South Australia. We know that South Australia is going to have high prices, then we will try and warn customers when we're confident that we think there's going to be an event, and then we'll continue to notify them and updating them after that event. (KI-22)	

Most decisions relevant to energy consumption are taken in the context of limited or asymmetric information about energy service costs by the stakeholders in the electricity value chain. Therefore, pricing decisions are crucial for making effective forecasting and initiating demand response programs. In DR systems, it is important to predict and model how consumers shift their loads from high-priced peak hours to low-priced off peak hours to reduce their energy cost. The utilities must design pricing mechanisms which encourage consumers to participate in the DR initiatives. Such pricing mechanisms should account for attractive returns to the utilities with the objective to maximize the social welfare. Time varying price signals sent to consumers will motivate them to modify their consumption profiles. Price depended DR is a method by which end users can be incentivized or penalized, while maintaining their voluntary choice. Overall, pricing decision is a task that requires system to combine and coordinate information exchange for decision making (Table 10, G., H). Hence, we propose,

P 1(c): Data acquisition, semantic information integration, business intelligence & analytics, and problem solving & decision making mediates the influence of pricing decisions information processing needs on the energy demand response effectiveness.

Capacity Planning

Capacity planning is associated with very high levels of information requirement and information diversity that requires a thorough understanding of the problem domain to design a solution scheme. The interviewees unanimously identified capacity planning as a DR task to match the demand and supply side needs. Using DR to maintain capacity requirements, reduces the need for investment in expensive power plants and this could result in substantial cost savings. In short term planning, DR helps in adjusting the load to the network capacity constraints in order to stay within technical limitations and avoid the system collapse. Business intelligence and analytics tools can be used to extracts insights from the raw data to achieve smart energy management. For instance, the impact of high reactive power implies poor power factor that results in more line dissipation and low transmission frequency. This information is very crucial to the grid operators in capacity planning (Table 11,I).

Table 11 – Capacity planning – Capacity-DR effectiveness		
Planning-Capacity	Case Site Data	
I. Capacity Planning - Data acquisition	Secondly, every 15 minutes we will get the readings- current, voltage, power factor. The voltage level is monitored and later it is analyzed to see where there is low voltage, how much current is being used. Currently, what we are planning is different from the actual usage. With live monitoring, we can see what is actually getting consumed and hence the outage can be reduced, as we can plan accordingly. (KI-4)	
	We've done phase identification, that shows the amount of load per phase. This is for identifying the phase imbalance at hosting capacity, which is our ability to host more renewable energy. At a very fine level of detail, we collect a vast amount of data, when you're right at the edge. (KI-15)	
J. Capacity Planning - Semantic Information Integration	That is not like our conventional generation so 10000 Megawatt available means it will not be same always it will vary with seasonal conditions and climate. The real-time data will be much more helpful even in the handling of renewable energies. (KI-5)	
	We do have weather inputs in the SCADA, just temperature and we are moving towards having our weather integration so that we can actually forecast demand at real time. (KI-19)	
K. Capacity Planning - Business Intelligence and Analytics	I think predictive analysis will show how we should position ourselves or which direction we should go as we build the insights in shaping this industry. And the future markets are more prescriptive rather than predictive. (KI-12)	
L. Capacity Planning - Problem Solving and Decision Making	The distribution companies have to call DR events during the peak. If the consumers are not willing to participate, the distribution companies have to inform the generation units to meet the excess demand or take a decision to buy power from the unscheduled interchange exchange to meet the need. (KI-10)	
	Since the introduction of rooftop PV'S, we haven't proposed a solution to these challenges in a timely manner. The renewable energy is intermittent, this variable nature of intermittent generation will make us invest or over invest. Let's say in 2030 or 2040, how we are going to dispatch and what is the right mix of generation will be to supply? (KI-12)	

Power contracts are influenced by the peak usage and can levy heavy penalties when exceeding upon the agreed peak. This is a major concern to the distribution companies while they schedule the power. Although the peak is only for few days in a year, it will put

considerable amount of stress on the grid increasing the risk of black outs. Electricity demand reaches its highest point when there is huge usage of air conditioners during summers and heaters during winters. With peak load management programs, consumers are aware of their energy usage and can lower energy significantly (Table 11, L). Better information and decision-making during times of peak demand could significantly reduce sudden peaks and risk of power outages. Thus, capacity planning with demand response will help in reducing power outages during contingencies and guarantees power quality.

With the increase in the deployment of distributed generation at the supply side, it is hard to predict demand due to its variability based on the renewable sources and the climatic conditions. Uncertainty in the demand and supply information will require the decision makers to evaluate and integrate diverse sources of information in making a prediction about the likelihood of some future event. The operational and forecasting models developed for demand planning have to ensure harmonics of all the components of this complex system (Table 11, J, K). In distributed energy environment, it becomes difficult to process real time data in a centralized system. Therefore, from a data and information perspective, enabling technologies in the edge computing paradigm provides consumers with faster, efficient, and secure responses. Thus, it can be stated,

P 1(d): Data acquisition, semantic information integration, business intelligence & analytics, and problem solving & decision making mediates the influence of capacity planning information processing needs on the energy demand response effectiveness.

Conclusion

This research contributes to the body of knowledge in information systems related to DR systems in energy domain. Our work contributes to both theory while also deriving insights for practicing managers in the energy domain.

Contributions to Theory

The recent technological innovation and transformations urge the need for Information Systems expertise to collaborate with power engineers to realize the electricity grid's potential benefits. This paper contributes to the IS literature by examining the role of IS resources in DR systems. We investigated the association between task complexities and information processing capacity and its effect on DR performance. By doing this, we extended OIPT to energy domain to explain how matching task with information processing capacity leads to desired DR program outcomes.

DR systems still being at their immaturity and conceptual level, this research is an early attempt to capture the information processing needs and capacity in electricity demand response systems using case study methodology. We identified the dimensions of information processing inherent to the DR systems in the utility domain, and posits their interaction effects of these elements in constructing decision rules to improve DR efficiency. It is further supported by case study data in explaining the mediating role of information processing capacity aligned with the task characteristics to enhance the performance of DR programs.

This study also drew upon a rich set of data collected from two diverse countries, India and Australia and compared DR systems country-wide. Following an retroductive approach we first identified four national level variables from our interview data collected from India and Australia. Further, based on these four variables that emerged from our study, we made a country level comparison of DR systems.

Contributions to Practice

Considering that DR is a potential area wherein a lot of experimentation and knowledge are needed, our model will help utility organizations to develop strategies, particularly in the early stages of implementation of DR programs. By investigating DR systems in two different sociotechnical contexts, the study directed attention towards the contrasts and similarities between implementation processes, serving as potential explanations of divergent interpretations of DR program outcomes. The present framework serves to provide guidance to the utility and policy makers in developing business models to leverage the data and extract relevant information. Our cross-case analysis captures variables of value creation - pricing structure for demand side participation, renewable integration at supply side, reforms in the regulatory instruments, and emergent technology - that can be used by the stakeholders while designing DR programs. Our detailed propositions identified from the case study data indicate that different stakeholders in the electricity value chain have to adopt different information processing mechanisms aligned with their needs to develop an effective DR system. Our study results reveal that technology-enabled platforms drive energy consumers to participate in DR programs and enhance their awareness of energy conservation. Thus, stakeholders can develop products expanding its usability and services (like the opt-in/opt-out choice of programs to the consumers) to engage and convert passive energy consumers to participate actively in the decision making of their consumption patterns.

Limitations and Future Directions

Besides the contribution of this study to an emergent IS research area, some limitations must be highlighted. Firstly, our study is limited to experts of organizations from two case sites – India and Australia. As a result, the findings cannot be generalized or extrapolated globally due to their distinct socio-economic attributes, structural differences in political culture, diverse energy sources' mix, and policy asymmetry in energy market design causing variability in consumption trends. Secondly, DR programs in India and Australia are at the pilot level, and hence, our sample of experts is small. Thirdly, considering the different types of stakeholders, our key respondents represented in the study is not proportional across the value chain. For instance, though we have captured the reforms that need to be brought at the policy and regulation side from other stakeholders in the digital value chain, we were not able to get the views directly from the regulators in Australia.

As electricity grids evolve, a large number of utilities under different regulatory schemes and structures will execute DR programs. Thus, future work will include empirical studies to validate the proposed research framework to confirm the findings and derive additional insights. Although our study has identified the relationships among concepts as propositions, further research could focus on converting these propositions to the testable hypothesis and follow a quantitative approach for statistical generalization.

Consumers being the main stakeholders in DR programs, it is essential to include human dimensions of energy consumption (Kempton et al., 1992; Stenner et al., 2017). Decision making in smart energy consumers can be studied through the lens of behavioural economic theories like prospect theory (Kahneman, 2011) that explains individuals using personal heuristics based on the potential value of gains and losses to make their decisions. Therefore, the proposed model can be enhanced by incorporating behavioural and psychological aspects of the consumers in delivering significant energy savings.

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Appendix A: Questionnaire for Interviews

- 1. Have you been involved in the implementation of AMI? Share your experience.
- 2. Have you been associated with DR implementation strategies? If so, what are some of the key challenges you faced during the implementation and how did you overcome them?
- 3. Do you use any energy analytic techniques or business intelligence in decision making? Please elaborate on this.
- 4. Based on your experience, does providing more information to the customers about their energy usage and market conditions result in more energy efficient behaviour?
- 5. What is the role of regulators in the power sector transformation driven by technological advances in AMI?
- 6. How does the implementation of smart meters affect cost savings?
- 7. How are pricing decisions arrived at?
- 8. What are the different policy changes you would recommend?

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