RFID USE AT DOW CHEMICAL FOR ENVIRONMENTAL SUSTAINABILITY: INSIGHTS FROM SOCIO-TECHNICAL SYSTEMS THEORY AND AFFORDANCES THEORY

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ABSTRACT

In seeking the environmental sustainability in its outbound logistics operations, Dow Chemicals Company deployed a radio frequency identification (RFID) system to track shipments of its hazardous chemical products (i.e., hazmat shipments). This qualitative case study uses content analysis and the application of the socio-technical systems theory and affordances theory. Applying these two theoretical frameworks results in a better understanding of how information technology (IT) interacts with organizational forces and vice versa in the deployment of an RFID-enabled information system that has environmental sustainability and public safety as one of its top goals.

Keywords: Radio frequency identification (RFID); environmental sustainability; supply chain management; socio-technical systems theory; affordances theory

INTRODUCTION

This study features Dow Chemical Company, a major chemical industry firm, and its use of radio frequency identification (RFID) and complementary technologies for the tracking of shipments of its toxic inhalation hazardous (TIH) products. RFID is a technology that uses electromagnetic energy to allow exchange of information between an RFID reader (i.e., transceiver) and the RFID tag (i.e. transponder) which contains information on the individual product item, case, or pallet it is attached to [1].

The two theoretical frameworks, socio-technical systems theory and affordances theory, were used in analyzing Dow Chemical's RFID-enabled tracking system implementation experience because they focus on the interaction between information systems/information technology components and the organization in producing the desired outcomes in deploying the specific information systems solution adopted by a firm. The socio-technical systems theory provides a simple to use framework for analyzing how components of an organizational system (i.e., task, structure, people, and technology) work together. The affordances theory lens allows researchers to view IT and organizations as entities that exist independently of each other. Yet, IT and organizations can be viewed by researchers as valuable in explaining organization form and function only if it is recognized that they need to be enacted together [36]. So, although IT and organizations each have their own potentials and constraints, theories such as the affordance theory are needed to understand how they are woven together so that "functional" affordances could emerge. The affordance theory lens admits that a technological object has built-in functionalities, but it needs to be recognized as a "social object" as well. And, as a social object, the technological object influences organizational functioning and performance, which, in turn, cannot be viewed apart from worker expertise, jobs, business processes, and structures [36].

LITERATURE REVIEW

The following section highlights the key concepts and theoretical frameworks used in this study.

Green Supply Chain Management

Attaining sustainability has been approached from the perspective of changing supply chain management practices as indicated by the increase in the number of research papers written on the subject [2] [3] [6] [8] [9] [10] [11] [18] [19] [25] [28] [33] [37]. Sustainable supply chains seek to reduce the negative impact of their firm's operations on the physical environment in the course of conducting its supply chain activities with its trading partners like suppliers, contracted manufacturers, logistics service providers, retailers, distributors, etc. Although concern for the environment by itself is not new, the urgency of the disastrous experiences recently spawned by climate change, pollution, global warming, and rapidly depleting natural resources worldwide has spurred a renewed call for green supply chain operations [8] [28]. Sustainability within the context of firms' supply chains involves all important participants that enable the firm to produce its products and/or services.

RFID and Environmental Sustainability Studies

A recent multi-year study on RFID use in the manufacturing sector conducted by two U.S. universities found that between 2005 and 2012, the use of RFID for inventory tracking (i.e., raw materials, work-in-progress, and finished goods) at both the pallet and item levels has grown considerably [29]. It is notable that firms have accepted RFID use in the early stages of the supply chain cycle, notably in the sourcing, manufacturing, and distribution phases. A major driver for this increased use is the declining costs of RFID resources: the average price of an RFID transponder, for instance, decreased from more than US$1.10 in 2005 to less than US$0.40 in 2012 [29]. It will take some time, though, before a critical mass of firms uses RFID for closing the loop of their supply chain, which would involve tasks like handling returns and product recycling. The study also noted that RFID use in and of itself does not bring significant benefits unless it is designed into a firm's coherent integrated supply chain strategy. Much more significant results can be reaped by firms that situate RFID deployment in a more critical position within its supply chain management strategy that encompasses strategy formulation, implementation, and evaluation [17].

Socio-Technical Systems Theory

Building on Leavitt's [20] socio-technical model, the socio-technical systems (STS) theory as articulated by Bostrom and Heinen [5] provides a framework for analyzing how components of an organizational system (i.e., task, structure, people, and technology) relate to an information system. Leavitt [20] identified task, structure, people, and technology as important dimensions of organizations as work systems.

The technology dimension of the Leavitt model consists of elements of an information system as an integrated set of software using information technology to transmit, process, and store information.

The simplicity and elegance of the STS model have been recognized and the framework has been frequently used for studying IS-enabled organizational change [4] [23] [27]. Two subsystems constitute the overarching STS system: (1) the tasks and technologies that make up the technical subsystem transform inputs into outputs; and (2) individuals in a work unit, their relationships, reward systems, and authority and work structures make up the social subsystem. This STS framework has been useful in studying

organizational change and in capturing the rich context of factors and interactions involved in deploying information systems in meeting organizational goals. A major missing piece in using the STS theoretical framework, though, is the articulation of how the critical structural, technological, people, and task-based dimensions interact in the process of changing the organization. Thus, this case study's analysis transitions to the use of the "affordances theory" [13] [14] [15] and very specifically, the concept of "functional affordances" [24].

Affordances Theory

In understanding the deployment of information technology in organizations, the "affordances" theory has been espoused by a number of academics [12] [16] [22] [24] [26] [35].

Gibson [14, 15] first offered the concept of "affordance" in the field of ecological psychology and used it to define the range of possibilities and constraints for action that a material object presents to an actor. Material properties of information systems allow "possibilities for goal-oriented action" or "functional affordances" of that form of technology [24]. Chemero [7] suggests, though, that affordances have to be perceived by the end user before they can be enacted or actualized. Leonardi [21] dovetails this idea by suggesting that the end user's ability to perceive the action possibilities proffered by functional affordances depends on the relationships between the form of information system and the end user within the context in which the information system is used.
Features of different forms of information technology can be used by human agents or ignored by them, depending on the end purposes they have in mind [30]. Thus, both intended and unintended consequences of information technology are realized through functionalities of material artifacts that "afford" those consequences.

RESEARCH METHOD

This study uses the case study approach and content analysis in aligning the concepts prescribed by the two theoretical frameworks to the sensor-based systems of Dow Chemical. The case study is an appropriate methodology for understanding complex social phenomena especially for purposes of exploring, describing, and explaining such phenomena [34] and in testing the application of a conceptual framework to a real firm. The primary data used was based on the transcription of the conference presentation talk of key executives from Dow Chemical at the RFID Journal Live! 10th Annual Conference and Exhibition, on April 3-5, 2012, Orlando, Florida USA, and the Conference "RFID in Energy" produced by the RFID Journal, September 20, 2011, Houston, Texas, USA. The primary speaker on behalf of Dow Chemical for both conferences was Craig Castro, Auto-ID Technology Leader, Dow Chemical. In addition, secondary data sources from academic and trade articles were content analyzed using key concepts in the model. Content analysis was applied to both primary and secondary data.

STUDY FINDINGS

The following are the study findings for Dow Chemical applying the two theoretical frameworks: socio-technical systems theory and affordances theory.

Application of Socio-Technical Systems Theory and Affordances Theory

The concept of "functional affordances" allows us to analyze how end users both within Dow Chemical and those working with external allied agencies interpret the material properties of an RFID-enabled IT infrastructure system to track, monitor, and manage hazardous materials shipments in transit and during storage (Tables 1 and 2).

Table 1: Conceptual analysis of the multiple functional affordances resulting from the tracking/monitoring of hazardous material shipments at Dow Chemical

(1) Material Properties of Information Systems

+ *Tracking Features:*

+ Cylinders of hazmat shipments have both bar-coded labels and Savi 433 megahertz active tags, which report the tank's internal temperature, the presence of a leak, shocks, and whether or not the tank's dome is open.
+ Dow workers gain access to this information from data transmissions via satellite to the Savi SmartChain application.
+ This software also sends alerts to workers when exception conditions occur requiring action.
+ RFID readers installed in the railway tracks communicate with the SmartChain software so that when the railcars pass by, the software can match information transmitted by the active Savi tags on the railcar tanks against programmed routes and destinations.
+ The nearest Orbcomm 29 low earth orbit (LEO) satellite captures data from transponders on their unique identification number, location, and condition.
+ Savi Technology's SmartChain Asset Management software receives and interprets data received from the nearest satellite for Dow workers.
+ Salco's Fullview software also works with data from the satellites by enabling changes in transponder programming like requests for reporting sensor status or altering the schedule for transmitting reports.
+ Savi's SmartChain software connects a firm's accounting and ERP systems, manual processes, and other systems while generating real-time information on shipments, supplies, equipment, and materials.

+ Use Context/STRUCTURE

+Dow Chemical's Corporate Environmental Advisory Council was created in 1992 and later renamed Sustainability External Advisory Council (SEAC) in 2008. This body champions environmental sustainability initiatives at Dow. In 2005, Dow announced a general call for RFID project proposals from all its business units, resulting in the submission of 450 ideas from about 100 business leaders from different businesses and firm units. Dow uses the Six Sigma method in the implementation of its RFID-related projects. The Dow Expertise Center sets up standards and oversees the IT and RFID projects. Dow used its Technical Advisory Board in determining the final ten RFID projects that would receive the firm's full support. Representatives from SAP, Cisco, Intel, Accenture, and other vendors are in this board.

+ Use Context/PEOPLE

-**Dow rail & truck drivers:** need to know how to read and interpret info on the FSN Web-based real-time locating reports that provide real-time visibility into hazmat materials in transit or storage & location of responsible personnel; truck drivers need to wear the RFID-enabled personnel badges for identification. **-Dow supervisors overseeing hazmat shipments:** anticipate real-time message alerts to warn them of changes with the hazmat chemicals in storage or transit or changes in ambient conditions affecting these chemicals. **-Intermodal transport workers** have access to the RFID system-generated information to help monitor/track Dow shipments as they travel.
-Workers in various stations --- factories, warehouses, receiving centers, border custom control, etc., will have access to the RFID information to help monitor/track the shipments as they travel.
-Personnel in allied agencies such as: railroad personnel in non-Dow property, Customs Clearance & Control Offices, ChemTrec, and Transportation Security Administration (TSA) can user the Dow-generated RFID tracking information to ensure the safety of the workers & general public. **-Dow Chemical's ultimate customers** expecting the hazmat shipments can be better assured of the safe & timely arrival of these hazmat shipments. **-Members of the public in the local communities** where the railroads & trucks will be passing through will be better assured of the preventive measures potentially being undertaken to prevent accidents/incidents when hazmat shipments are travelling through their communities.

+ Use Context/TASK

Affordances:

+ ***hazardous material tracking affordance***, if realized, will help Dow gain real-time visibility into the movements of its hazmat shipments throughout its global supply chain.
+ *inter-agency information sharing for public safety affordance*, if realized, will help Dow Chemical and external agencies like Chemtrec and TSA prevent or mitigate the disastrous consequences of an environmental incident due to faulty shipping of hazmat inventories.
+ ***negotiating bargaining power affordance*** for Dow Chemical in dealing with its suppliers, if realized, will enable Dow Chemical to optimize the value of the RFID tracking system information in negotiating for better prices when dealing with intermodal logistics services providers.
+ ***reduction of power of & overall control of rogue supply chain activities like diversion & theft affordance***, if realized, will enable Dow Chemical to identify and trace hazmat shipments within the influence and access of counterfeiters & thefts & resolve the situation.
+ *operational efficiencies in logistics activities (cost reduction and savings in time) affordance*, if realized, will allow Dow to cut the time involved in its outbound shipments and save costs as well.
+ ***asset tracking affordance***, if realized, will enable Dow to track & locate important assets like ISO tanks & containers & better manage their leases and audit billing asset providers.
+ ***equipment maintenance management affordance***, if realized, will enable Dow to detect the need to provide maintenance services for its logistics equipment in advance & avoid expensive costs associated with total equipment repair & replacement.
+ ***workmen safety/emergency response affordance***, if realized, will enable Dow to track employees as well and be immediately informed if an accident has taken place.
+ ***securing the physical plants & offices of Dow afforda***nce, if realized, will enable Dow to detect the presence of persons in restricted areas in their plants & office compounds.

The concept of "functional affordances" in this case study allows us to accomplish the following: (1) identify what relevant functional affordances there are that apply to both internal Dow Chemical end users/workers and personnel in allied agencies; (2) understand how these end users who subscribe to emerging action goals related to tracking, monitoring, and managing hazardous materials within their respective establishments interpret the material properties of an RFID-enabled IT infrastructure system; and (3) understand the nature of the structure and tasks that end users are working with.

Table 2: Organizational-Level Affordance: monitoring & tracking hazardous material inventory shipment & storage

1) **Dow Chemical RFID-Enabled Tracking Solution (material properties of information systems):**

-[See (1) in Table 1.]

2) **Characteristics of Actors**

-Using a web-based data center, Dow workers can gain 24 by 7 visibility of the conditions and locations of critical hazmat shipments worldwide.
-Dow workers can check on rail cars remotely and have them report their positions and status. Undesirable events like if a rail car has been opened and is not positioned in a defined secure facility, would trigger an alert.
-Dow workers can track the firm's intermodal containers and obtain readings from a list of chokepoints. This data allows these workers to minimize idle or sidelined cargo.
-Dow supervisors in charge of hazmat shipments can answer questions like: "Is every shipment on time?" "Has any item been misrouted?" "Which orders have been fulfilled, as indicated by the physical arrival of shipments?" And, "What output or delivery can we commit to?" This is possible because of Savi SmartChain's capability to link with Dow's ERP system.

3) **Example of immediate concrete outcomes from data**

Dow Chemical has made estimated measures of savings achieved as a result of the RFID-enabled hazmat tracking system:
+ Current safety performance of 99.97 percent incident-free shipments of hazardous materials
+ More than 20 percent cost reductions in excess inventory and container fleet requirements
+ 100 percent reduction in theft/loss/pilferage
+ Up to 90 percent reduction in transit time for shipments
+ 25-50 percent improvements in on-time deliveries
+ 50 percent reduction in response time to identify in-transit problems.

4) **Goal-directed actions needed to actualize an affordance**

+ Dow Chemical workers in the railcars and trucks would:
-need to know how to respond to respond to real-time alerts via phone/text message and real-time web-based reporting of any exceptions --- like discovery of a tampered ISO tank or open tank or container, sensing of temperature, humidity, and shock thresholds that have been exceeded, etc. –

-- for corrective actions by appropriate staff members.
+ Professionals/end users involved in the appropriate allied security, safety, health, and environment agencies will need to know how to receive and respond to alerts sent by the Omnitrol edge appliance used by Dow Chemical to capture and store all transit and condition data to provide real-time visibility of the hazmat inventory in transit.
+ Workers in each station such as factories, warehouses, receiving centers, and border custom control need to know how to use and interact with a real-time locating system (RTLS) that communicates with a monitor communicator and interpret its alerts and messages. This RTLS is linked to a central monitoring system center through TCP/IP.

5) Applicable goals and organizational context

Dow Chemical seeks the following goals with its RFID-enabled system:
-supply chain security in protecting its primarily hazardous materials shipments worldwide
-ability to track and monitor its hazmat material shipments worldwide
-local protection of human health and the environment
-protection of its workers and prevention of accidents usually resulting in worker disability
-collaborate with Chemtrec and the Transportation Security Administration (TSA) and local railroad workers in seeking the protection of human health and the environment use the information generated by the RFID-enabled system to facilitate maintenance and repairs of expensive assets involved in storage and shipping
-use RFID information to negotiate better terms with supply chain trading partners such as intermodal carriers
-use RFID information to prevent or resolve problems arising from the activities of rogue members of its supply chain --- such as thieves who divert shipments, vandals, counterfeiters, terrorists, etc.
-use RFID information to streamline outbound logistics operations and thus, cut costs.

Strong et al. [31] extended the affordances theory by articulating affordances in an organizational context and specifying the "actualization" of functional affordances. Strong et al. [31] distinguish between affordances as potentials for action and their actualization and developing the concept of "organizational affordances." An "organizational affordance" is one that calls for potential collective actions of its members in the effort to achieve organizational –level immediate outcomes, which should, in turn, support organizational level goals [31]. The "function" of an "organizational affordance" is expected to be the same across different individuals and different organizational levels.

IT-related affordances are defined by Markus and Silver [24, p. 622] as "… the possibilities for goal-oriented action afforded to specified user groups by technical objects…." These IT-related affordances are also called "functional affordance" in the context of this study. Zammuto et al. [36] call attention to affordances that arise from the interaction of organizational systems and different forms of information technology. Technology is not viewed as being "static" --- rather, it evolves through time, especially when implemented and used by individuals in an organizational context and "interpret" it during its use.

The authors define actualization of affordances as "…the actions taken by actors as they take advantage of one or more affordances through their use of the technology to achieve immediate concrete outcomes in support of organizational goals…." [31, p. 70].

An immediate concrete outcome is a specific expected outcome from the "actualization" of an affordance. The concrete outcomes discussed in item (3) of Table 2 are viewed as useful for realizing overarching

organizational goals, which in the case of Dow Chemical would fall under the umbrella of "effective tracking/monitoring/management of hazardous chemical shipments." These immediate concrete outcomes also serve as an "intermediary" between "actualization" outcomes and a firm's organizational goals [31]. Whether or not Dow Chemical achieves its desired organizational level outcomes depends on the consistency, extent, and alignment of the collective actions of all the end users involved in the process of preparing, shipping, storing, and delivering the hazardous material shipments from point to point in Dow's supply chains worldwide. Strong et al. [31] further explain that an "affordance" is defined by a set of characteristics related to the nature of an immediate outcome. However, an organization's members may actualize a functional affordance is a variety of ways appropriate to their particular organizational setting.

Yet, despite the multiplicity of negative possibilities that could derail Dow's best efforts to track and protect its hazmat shipments, Dow has achieved notable successful outcomes with their RFID-enabled system: (1) better experience with hazmat inventory control in transit and storage, and ultimate order fulfillment; (2) better regulatory compliance; (3) improved ability to manage risks involved with the shipments; (4) reached 99.97 percent incident-free shipments of highly hazardous materials; (5) cutting back response times in identifying and resolving logistics problems; and (6) reduction in the incidence of product theft. This is described using the concept of the "immediate concrete outcome" in Table 2 illustrate how successful end users have reached certain organizational goals.

CONCLUSIONS

This study features the contextualization of our knowledge around the use and effects of information systems in firms within the specific context of Dow Chemical's hazmat shipment tracking system enabled by RFID. This qualititative analysis has woven functional affordances into the relationships among the subsystems of the socio-technical work systems. This case study's data is based primarily on transcripts of talks given by Craig Castro, Dow Chemical's Auto-ID Technology Leader in both the 2011 and 2012 conferences produced by RFID Journal. This research project identifies the appropriation mediators needed in the use of the information systems in order to realize the built-in affordances of these systems [33]. These mediators consist of structure, action goals, user characteristics, and task characteristics required within the context of hazmat shipment tracking. Understanding and awareness of the affordances provided by the RFID-enabled information systems for Dow Chemical could be useful not only theoretically in terms of analyzing how technical and social subsystems interact and broadening the base of application of the two theoretical frameworks used here. There is a practical benefit as well in terms of gaining insight into creating explicit criteria in selecting hardware and software components from technology vendors, or, more specifically, RFID and sensor vendors, in order to ensure the realization of desired functional affordances.

REFERENCES

References available upon request.