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Using the Technology-Organization-Environment Framework and Zuboff's Concepts for Understanding Environmental Sustainability and RFID: Two Case Studies

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***Abstract*—**Radio frequency identification (RFID) has been recognized as a key enabler of efficient and effective supply chains. Recently, with increasing concern for environmental sustainability, researchers and practitioners have been exploring the role of RFID in supporting "green supply chains." This qualitative study uses the technology-organization-environment framework of Tornatzky and Fleischer, and Zuboff's concepts of automating-informating-transformating in analyzing two case studies involving RFID use: the recycling of Hewlett Packard inkjet printers and the garbage and recycling program of the City of Grand Rapids, Michigan.

***Keywords*—**Environmental sustainability, green supply chain management, radio frequency identification, technology-organization-environment framework, Zuboff'automate-informate-transformate concepts.

I. Introduction

A recent multi-year study on radio frequency identification (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 [1]. Reported benefits from RFID deployment include reduction in cycle times, reduction in safety stock levels, improvements in changeover times [2], and most significantly, having near real-time information for making key supply chain decisions [3].

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 was 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 [1]. It will take some time, though, before a critical mass of firms use 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. So, therefore, using RFID merely to conform to a customer's mandate like Wal-Mart's will not necessarily bring meaningful results.

As the use of RFID increases through the years, concern for environmental sustainability using technology will be paramount. Sarkis et al. [4] define "green" supply chain management as the integration of environmental concerns into the interorganizational practices of supply chain management, including reverse logistics. Green 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 sustainable or "green" supply chain operations [4]-[6].

This study looks at two case studies featuring the use of RFID to meet environmental sustainability requirements: Hewlett Packard's recycling of its inkjet printers in Brazil and the City of Grand Rapid's (Michigan, USA) garbage collection and recycling program. The main objective of this study is to use Tornatzky and Fleischer's technology-organization-environment framework [7] and Zuboff's concepts of automating, informating, and transformating [8] in understanding the RFID system deployment experiences of both organizations.

II. Literature Review

A. Technology-Organization-Environment Framework

This study will use the technology-organization-environment (TOE) framework introduced by Tornatzky and Fleischer [7] that uses three elements that influence technological adoption --- the environmental context, the organization context, and the technological context.

1. Environmental Context

The environmental context is the arena surrounding a firm, consisting of multiple stakeholders such as industry members, competitors, suppliers, customers, the government, the community, etc. They can influence how a firm interprets the need for innovation, its ability to acquire the resources for pursuing innovation, and its capability for actually deploying

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it. These stakeholders could either support or block technological innovation.

Changing market and competitive conditions prod firms to use various forms of innovation. Government regulation is also another powerful tool for constraining a firm's operational activities, increasing costs of production, and instigating an investigation of technologies that must meet specified mandatory criteria. Finally, dominant customer firms could exert their power to shift their suppliers' production activities and/or business processes to comply with its requirements.

2. Organizational Context

A range of descriptive measures characterize the "organizational context": firm size; the centralization, formalization, and complexity of its managerial structure; the quality of its human resources; and the amount of slack resources available internally; formal and informal linkages within and outside the firm; decision making and internal communication methods; and boundary spanning mechanisms to communicate with the external environment. The concept of the "organic" versus the "mechanistic" organizational system is also relevant here [9]. Frequent lateral communication, decentralization of leadership and control, and active networking both within and outside the firm are hallmarks of the "organic" system. Building interorganizational collaboration mechanisms is fundamental in meeting the needs of electronic coordination linkages enabling supply chain partnerships.

Top executives can energize major organizational changes by: (1) developing and communicating a clear image of the firm's strategy, core values, and role of technology in meeting this strategy; (2) sending consistent signals both within and outside the firm about the value of the innovation; and (3) creating a team responsible for crafting a vision relevant to the innovation [10].

3. Technological Context

Tornatzky and Fleischer [7] presented their "systems design perspective," which is a synthesis of the following approaches: technocentric, sociocentric, conflic/bargaining, systems life cycle, and socio-technical systems.

(1) Understand the Characteristics of the Innovation

The technocentric approach espouses the notion that technological factors dominate the implementation experience, thus, leading to the following consequences: (a) there should be a detailed technical plan for implementation; (b) methods engineering should help in the redesign of business processes and jobs; (c) the innovation should be able to be integrated with the existing technical system; and (d) technical criteria should be used in measuring implementation effectiveness [11]-[13]. The "systems design perspective" used also calls for a technology-organization match. The technology innovation could also influence how different parts of a firm need to coordinate. Implementation of information systems supporting environmental goals extends the level of coordination needed from internal integration to interorganizational integration within the supply chain context.

(2) Develop Measures of Implementation Effectiveness

A wholistic approach to measuring implementation effectiveness would include metrics that are relevant to the technocentric, systems development life cycle, sociocentric, and conflict/bargaining approaches.

(3) Plan and Pace Implementation

Pacing technology implementation refers to the speed at which changes are unfolded, which could range anywhere from gradual to radical [14].

(4) Design or Redesign the Organization

The sociocentric approach focuses on making the organization more flexible, humanistic, and open to changes brought about by the innovation [7], [15], [16].

(5) Modify Human Resources Policies

Human resource policies involving employee selection, compensation, appraisal, and training --- all of which have important implications for innovation implementation have to be modified to fit the innovation [17], [18].

(6) Design or Redesign Jobs

The design and/or redesign of jobs are needed to ensure that the affected workers and the work system required by the innovation are linked [7].

(7) Install the Innovation and Integrate with the Existing System

The systems design approach prescribes the following: (a) incorporating end user needs into the requirements definition phase; (b) designing the new system so that it can integrate with the larger IT system that encompasses the firm; and (c) ensuring the provision of resources for reliable system maintenance and providing for both incremental and radical system changes if called for.

Only steps 1, 2, 3, and 7 will be covered in this study as the data that was available and gathered addresses only these steps.

Green Information Systems and Information Technology Support for Sustainability

Environmental management systems (EMSs) would need some form of IS to capture, collect, store, and analyze data and subsequently distribute information in the form of reports for various stakeholders. Chen et al. [19, pp. 2-3] define green information system (IS) as "...the design and implementation of information systems that contribute to sustainable business processes." A green IS could be used to:

* Reduce transportation costs with a fleet management system and dynamic routing of vehicles to avoid traffic congestion
* Support team work and meetings when employees are distributed throughout the world, and thus reduce the impact of air travel
* Track environmental information (such as toxicity, energy

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used, water used, etc.) about the creation of products, their components, and the fulfillment of services

* Monitor a firm's operational emissions and waste products
* Provides information to consumers so they can make green choices in their purchases.

Using automation in establishing information baselines on inputs (energy, water, materials, etc.) and outputs (waste, greenhouse gas (GHG) emissions, etc.), a green IS can strongly support an EMS in monitoring, evaluating, improving, and communicating an organization's environmental performance [20].

The different elements of a green IS (i.e., hardware, software, procedures, data, networking, people) have a critical contribution to the EMS that oversees the improvement of the natural environment and addressing climate change [20], [21]. Support for meeting the Global Reporting Initiative (GRI) standard, an internationally recognized sustainability reporting framework used for firms in all industries, would be a good example of the how a green IS application can enable the high report generation requirements of an EMS [22].

Use of TOE Framework in Previous Studies

The TOE framework has been a helpful tool in understanding how firms adopt technological innovations as indicated by the following studies. Lin [23] used TOE to explain the factors involved in the adoption of radio frequency identification (RFID) in the logistics industry in Taiwan. Zhu et al. [24] used TOE in deriving a technology diffusion perspective on e-business adoption in 10 countries. Hackney et al. [25] used TOE in analyzing the adoption of Web services in five U.K. firms using the case study approach. In 2005, Sharma and Citurs [26] used some elements of TOE in their model as antecedent conditions to explain the adoption of RFID in 16 firms. In 2001, Kuan and Chau [27] investigated the factors of electronic data interchange (EDI) adoption among 575 small Hong Kong firms using TOE. In 2000, Ryan et al. [28] used some TOE elements to explain the adoption of knowledge management technologies using data obtained from the U.S., Mexico, and Japan.

B. Zuboff's Automate/Informate/Transformate Concepts

This study uses the concepts introduced by Zuboff on the impacts of information technologies on the organization: automate, informate, and transformate [8]. "Automate" refers to the use of IT to replace the use of human assets in undertaking business processes, tasks, or work activities in order to gain operational efficiencies. "Informate" refers to the use of IT to generate timely and relevant data which can be used by organizational workers and their external trading partners such as customer and suppliers in making important decisions and in carrying out work processes and tasks more effectively. "Transformate" refers to the use of IT to help firms restructure or reconstitute their business models, processes, practices, assets, capabilities, and relationships in order to create new products, services, or business processes, reposition itself in the marketplace, or enter an entirely new market segment.

III. Research Methodology

This study uses the case study approach in aligning the concepts and guidelines prescribed by the TOE framework and Zuboff's three concepts to the RFID systems of HP and the City of Grand Rapids in their pursuit of environmental sustainability. The case study approach is an appropriate methodology in testing the application of a conceptual framework to a real firm.

Primary data was gathered from the transcripts of the presentations given by representatives of HP and the City of Grand Rapids at the RFID Journal Live! Annual conferences in 2012 and 2013. Secondary data using articles and published case studies on the two organizations were used as well. All of these materials were content analyzed using key concepts embodied in the TOE framework and Zuboff's concepts. The following are accepted definitions of the content analysis method:

"Content analysis is any research technique for making inferences by systematically and objectively identifying specified characteristics within text." [29, p. 5]

"Content analysis is a research technique for making replicable and valid inferences from data to their context." [30, p. 21]

"Content analysis is a research method that uses a set of procedures to make valid inferences from text." [31, p. 9]. In this study, the concepts used for conducting content analysis were derived from the TOE framework and Zuboff's concepts. These form the "context" of the content analysis method as applied to the RFID projects of HP and City of Grand Rapids.

> "A context is always someone's construction, the conceptual environment of a text, the situation in which it plays a role. In a content analysis, the context explains what the analyst does with the texts; it could be considered the analyst's best hypothesis for how the texts came to be, what they mean, what they can tell or do. In the course of a content analysis, the context embraces all the knowledge that the analyst applies to given texts, whether in the form of scientific theories, plausibly argued propositions, empirical evidence, grounded intuitions, or knowledge of reading habits…. The context specifies the world in which texts can be related to the analyst's research questions." [32, p. 33].

TOE concepts were used in analyzing the secondary materials within the context provided by the different theoretical frameworks or "prior theory." "Analytical constructs operationalize what the content analyst knows about the context, specifically the network of correlations that are assumed to explain how available text are connected to the possible answers to the analyst's questions and the conditions under which these correlations could change….analytical constructs ensure that an analysis of given texts models the texts' context of use…" [32, p. 34].

The following key conceptual elements of the content analysis method as stipulated by Krippendorf [32] were used in this study: (1) body of text selected for the analysis; (2)

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research question that needed to be addressed; (3) a context of analysis within which interpretations will be made; (4) analytical constructs that operationalize what the analyst knows about the context; and (5) inferences that will be arrived at to address the research question.

IV. Research Findings

A. Hewlett Packard Brazil Recycling Project

1. Environment

The key business driver that motivated the recycling phase of HP's RFID implementation was the mounting pressure for compliance with government regulations for environmental sustainability [33]. This is also the basis of increasing competitiveness within the electronics industry as sustainability has spawned product and service innovations.

2. Organization

HP exhibited the following attributes of an organic organizational system in exploring and eventually implementing RFID: frequent lateral communication, decentralization of leadership and control, active networking within and outside the firm. Hallmarks of this system also include top management support communicating a clear image of the firm's strategy, core values, and the role of technology in meeting this strategy. Top management relies on cross-functional teams to craft a vision for the innovation and communicates consistent messages about the value of the innovation.

HP started its exploration of the use of RFID in its global supply chain as early as 2002, even before complying with Wal-Mart's mandate to its suppliers to tag cases and pallets in 2004. In 2004, then HP CEO Carly Fiorina said this: "RFID has huge potential to automate the supply, significantly reducing manual intervention and eliminating inefficiencies from the process." [34]. Since then, HP's senior leadership exhibited total support by approving the pursuit of RFID research in its HP Labs, creating RFID Centers of Excellence, testing RFID in the HP global supply chain, and participating in EPCGlobal's RFID standards initiatives [35].

HP undertook dynamic networking of both its internal and external resources to learn how to deploy RFID. HP extensively used its internal consulting services, research laboratories, hardware, and software resources in testing RFID [36]. The firm also collaborated intensely with RFID specialty vendors in evaluating RFID tags and readers as it struggled to select the appropriate set of equipment for its working environment and figuring out how to deal with electromagnetic and other forces interfering with the radio frequency signals [36]. In HP's RFID deployment in Brazil in 2006, HP relied on an implementation team consisting of a project manager, engineers, technicians, IT staff members, and representatives from HP and Flextronics, the manufacturer HP contracted with for printer assembly [37]. This implementation team was overseen by HP's CORE Team, which consisted of members from HP's worldwide departments --- research and development, supply chain, consulting, procurement, and legal.

3. Technology

a) Understand the Characteristics of the Innovation

HP as a firm has been conducting RFID experiments and pilot projects under the supervision of its R&D labs and centers of excellence since 2004. The HP Brazil RFID project for recycling was supported by HP's internal expertise represented by its HP Lab and Brazil Center of Excellence [35], [37].

b) Develop Measures of Implementation Effectiveness

HP Brazil successfully recycled 100,000 tons of inkjet printers and captured 28,000 RFID tag readings to be used for business intelligence analysis within the period July 2011 to October 2012 [33]. New inkjet printers that were subsequently manufactured contained up to 40 percent recycled raw materials captured from this lot. Information from returned inkjet printers, which were manufactured within the period 2009 to 2012 covering 20 stock keeping units, was captured and analyzed for subsequent decision making.

c) Plan and Pace Implementation

HP's deployment of RFID for recycling initiated in 2011 builds on the RFID infrastructure previously put in place in HP Brazil in 2006 for item-level tagging to increase efficiencies in HP's supply chain management, manufacturing, and distribution processes [37]. In Sao Paolo, Brazil, HP outsources printer assembly to Flextronics, a $15 billion contract manufacturer, and logistics operations to DHL.

The initial RFID infrastructure put in place in 2006 consisted of the following elements [37]. About 100 RFID Sirit interrogators installed in the manufacturing lines, packing lines, inventory portals, storage areas, in-warranty repair lines, and the outbound door. The same devices were installed in DHL's receiving and outbound doors and pallet preparation area. The RFID tag is attached to the bottom of the printer's chassis at the time of assembly. The embedded tag information includes the Electronic Product Code (EPC) number, the unit's serial number, part information, and product DNA information. Initially, HP used Philips EPC Generation 1 ultra high frequency (UHF) tags and then switched to Gen 2 UHF tags operating at 950 megahertz.

HP used OATSystems' OAT Foundation Suite 5.1 which provided the RFID data management platform and middleware needed for the RFID deployment. HP integrated the RFID data generated by this platform with its SAP enterprise resource planning system (ERP) and with Flextronic's Baan ERP application. Both Flextronics and DHL store RFID data generated from the tags in their respective databases, which when queried are capable of sending query responses to HP. The increased volumes of data generated after the full production deployment of the system was handled by T3Ci, an RFID analytics and reporting firm, which consolidated the data and applied business intelligence capabilities to it [37].

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d) Install the Innovation and Integrate with Existing System

When HP closed the loop in its supply chain by applying RFID for recycling its inkjet printers in July 2011, HP Brazil designated drop-off centers for used printer cartridges, which were collected and placed in pallets for processing in the Oxil recycling facility [33], [38]. The tags on the used printers were read by Mercury5 RFID readers from ThingMagic. The advantage of these readers is that they have an IP52 rating, thus, providing dust ingress protection and water resistance in rugged environments such as the Oxil Recycling facility, which was basically dusty and dirty, with no humidity controls. To protect them in the dirty facility, HP secured the readers in steel-enclosed cases and reinforced the readers' antennas to protect them from the dust. Recycling facility personnel are also trained to make minor antenna adjustments if called for.

After depalletizing, the printers are transferred to a disassembly line where laborers manually separate parts by type of material --- plastic, metal, paper, and electronic components.

For its recycling operations, HP used the SmartWaste solution. This application captured additional printer information on recyclable materials used in the printers such as acrylonitrile butadiene styrene (ABS) and high-impact polystyrene (HIP) plastics, from the tags and forwarded this to a database [38]. A special data collection software application was written to transfer RFID tag information using the Internet via a wired connection to HP Brazil's business intelligence software which is integrated with its manufacturing product database. The business intelligence software generates decision making information for the environmental business strategic team members who can now view screen dashboards that highlight things like the amount of recycled materials such as ABS, HIPS, and metals recovered and the number of products recycled monthly. This information, in turn, helps in forecasting how much recycled material can be used for future printer production. Brand new HP inkjet printers currently being manufactured can contain as much as 40 percent recycled raw materials [33].

Zuboff's Concepts

1) Automate:

In the original RFID deployment in 2006, RFID interrogators in the Flextronics assembly plant recorded tag information and tracked the printers in the assembly line [37]. The printers were, then, transferred to inventory transition points marked by portals that had installed interrogators that tracked the movement of the printers to and from the holding areas. When the printers were packed, the EPC tags were recommissioned and assigned a new stock-keeping unit number. The interrogators used in the packing lines recorded the SKU unit and packing information and tracked them. Interrogators were also installed in outbound portals which read the tags on packed printers ready for outbound delivery, and captured shipping information was transferred to the distribution center thereafter. More or less the same procedure takes place in the distribution center. Interrogators installed at the inbound doors of the distribution center record tag data as pallets of printers enter the staging area where they are printers are prepared for final delivery. On the way out to shipping, tags on the printers are read by interrogators posted on the outbound doors of the distribution center.

2) Informate:

At HP Brazil, captured RFID tag has been very important in the firm's decision making processes [37]. At the manufacturing site, captured RFID information was used to ensure that only approved products were forwarded to the packing area. Furthermore, HP used the RFID data to identify points in the assembly workflow where work was taking longer than it should --- very specific data on the date, time, and number of products impacted by inefficient business processes are pinpointed. With this information, HP is able to check the production line equipment, the quality of parts being used, and other factors in the activities involved that contribute to variations in the dwell time and the time it takes for a printer to move from the beginning to the end of the manufacturing process. The distribution center used the RFID information to validate that the right printers were delivered to the appropriate country. And for purposes of repair under warranty, serial numbers were used to check effective dates of coverage.

In terms of its recycling goals, HP captured 28,000 RFID tag readings covering about 100,000 tons of inkjet printers collected for recycling, covering about 20 different stock keeping units for inkjet printers manufactured from 2009 to 2012 [39]. From this information, HP collected data on the amount of recyclable raw materials it could use for future production forecasts.

HP learned an important lesson with this experience that has to do with developing ways for its research and development department to create formulas for separating and reusing different types of plastics in its inkjet printers [37]. These formulas would, then, have to be programmed into some kind of software application that will effectively separate different plastic raw materials and create a stream for those that can be reused and separated from plastic streams that need to be disposed of (because they are past their effective product life). There is a limit to the number of times certain plastics can be recycled and reused in new inkjet printers. "The issue, technically speaking, is there is a challenge in terms of material, its constitution and the preservation of engineering properties of a particular plastic," Pandini said [38].

3) Transformate:

With the closed loop RFID implementation, HP graduated from the "cradle-to-grave" to the "cradle-to-cradle" production mode, the preferred modality for environmental sustainability. Braungart et al. [40] discuss the need to transition from the earlier model of production based on "cradle-to-grave" material flows going through industrial systems where the production and consumption processes

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transform resources into waste and the earth into a "graveyard." With the "cradle-to-cradle" model, on the other hand, the raw materials used are considered either "technical" or "biological" nutrients. Technical nutrients are non-toxic, non-harmful synthetic materials that do not harm the environment and that can be used over and over without losing product integrity or quality. Biological nutrients are organic materials, which after used in a product, need to be disposed of into the natural environment and allowed to decompose into the soil, thus, feed small life forms without harming the environment. The case of HP involves the recycling of technical nutrients in the form of recyclable plastics and other components.

B. City of Grand Rapids RFID-Enabled Refuse and Recycling Program

1. Environment

Governments at any level --- city, state, or federal --- are usually the sources of regulations to control certain corporate business operations. Such regulations are one of the more powerful influences in the environmental context to alter firm behaviors. In this particular case study, it is the city government itself that is spearheading the environmental sustainability initiative and thus, is expected to be proactive in its adoption of this initiative.

2. Organization

The city government of Grand Rapids exhibited certain attributes of an organic organizational system that supported its RFID-enabled recycling system. There was strong top down support for environmental sustainability and a consistency in pursuit of this city government level initiative as manifested by different Grand Rapids institutions. As a result, the city has won a number of awards in different environmental sustainability fronts as expressed by James Hurt, Director of Public Services, City of Grand Rapids:

"….Grand Rapids was identified as number one in Leeds certified buildings per capita per mid-sized cities in 2010. Grand Rapids is one of the top 20 green power purchasers in 2008-2009. Grand Rapids was awarded for excellence in its recycling program by the Michigan Recycling Coalition in 2012. Grand Rapids has the first platinum multi-family facility in Michigan. Grand Rapids has the first Leed [certified] public art museum. It has the first Leed certified YMCA. It has the first Leed certified public transit station [and] first Leed municipal building. And in addition, Mayor George Heartwell was announced as the national large city top winner in a 2012 mayor's climate protection award as sponsored by the U.S. Conference of Mayors. The International City County Management Association identifies sustainable communities as a core responsibility for local government.…Grand Rapids is holding sustainability as a core value in its intention about being a green city…." [41].

Other organic organizational system attributes that facilitated the city's success were the use of lateral communications across the city government units, active networking, and building collaboration mechanisms. Mike Lewis, business unit leader of Xtreme RFID, one of the vendors involved in the RFID project, attributed the success of the RFID system to the collaboration of city government units in operations, customer services, finance, and the garbage truck drivers. Representatives from these offices met weekly to regroup, discuss the project, and plan for the future steps to take. Lewis expressed this as well: "The mayor and the city manager were involved….A lot of departments within the city had input into scoping out the service and selecting it." [41].

3. Technology

The following is a discussion of the different steps involved in the technology context.

a) Understand the Characteristics of the Innovation

The city of Grand Rapids implemented the RFID project in phases which facilitated its understanding of the innovation they were introducing to the city residents. The full details of the three phases are explained in step 3 of this discussion. The city government's total commitment to environmental sustainability had the mandate of its top management, resulting in an investment of $2.4 million. The city's project team collaborated closely with the different vendors involved in designing the implementing the RFID system: XTreme RFID, CaptureIt, AMCS, and Cascade Cart Solutions, to ensure the availability of all tangible and intangible resources needed for understanding and coping with the physical and technical challenges of deploying RFID in garbage collection and recycling.

b) Develop Measures of Implementation Effectiveness

The city of Grand Rapids has monitored and tracked the progress of the RFID project and developed measures of its implementation effectiveness. Hurt clearly indicated the different measures of effectiveness that the city has been able to achieve since the RFID project's inception: "….the use of RFID technology has allowed the city to experience significant increases in recycling material collected in the short few years. We're up 8 percent in terms of tonnage collected for recycling, while refuse tonnage continues to fall some 13 percent, thereby diverting less waste into the waste stream. This is truly a green system that is reducing our environmental impact. In four years, total refuse tonnage collected decreased 4,000 tons, while during the same period, recycling tonnage increased by an equivalent amount. This means an additional 4,000 tons of material is spared from incineration [thus, saving the city incinerator fees] and recycled and reused in other consumable products --- a great testimony to the city's emphasis on sustainability.

Nearly a million plastic refuse bags are no longer going to the incinerator to be burned or placed in a landfill. In keeping with the city's sustainability goals, the smart carts are manufactured using 40% recycled materials. Finally, the program changes have allowed for near paperless billing and communications with our customers as they can use online means for billing and customer account information. This has eliminated over 40,000 paper invoices generated each year. In all accounts, transitioning to an RFID enabled refuse and

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recycling system has been a very successful venture for the city of Grand Rapids." [41].

Lewis of the vendor XTreme RFID, in turn, expressed this: "We have signups every day….Part of our overall goal is to reduce the amount of plastics being burned. We're not burning a million bags a year anymore." [43] Hurt expects the $2.4 million spent for the RFID project to pay for itself within a five-year period.

c) Plan and Pace Implementation

The City of Grand Rapids rolled out its recycling program in phases. Prior to phase 1, however, the city introduced the single stream recycling with RFID-enabled carts starting August 2010. This short period considered the "pilot" phase before the onset of phase 1 when rewards for resident recycling efforts were formally administered.

The introduction of the single stream recycling with RFID-enabled carts in August 2010 was a step up from the system used for 40 years wherein residents prepaid for garbage collection using 32-gallon plastic bags they purchased for $2.50 each from local designated stores. This was a costly and labor-intensive program to support in terms of administration and distributing the bags to authorized stores in the city [43]. But worse yet, this system was contributing largely to environmental pollution by sending more plastic bags to landfills and releasing heavy metals into the atmosphere by burning these bags in incinerators.

Phase 1: Rewards for Recycling

The City of Grand Rapids set up the following RFID infrastructure in 2010 to start phase 1 of its implementation of the recycling project. In phase 1, the RFID-enabled system was used to introduce the innovative program, "myGRIcitypoints," which rewards residents for the total points earned based on the total weight of the recycled garbage collected [43]. These points are eligible to be exchanged for special products or services offered by local businesses. So, a resident, for instance, could exchange the points for a free sticky bun at a local bakery or a cup of coffee from a café. Points can also be used to earn the privilege to "name a beer" at a brewery or points could be donated to a local park. Parks are allowed to collect points so that if it garners, say, 1 million donated points, the city government will award it with $50,000 for park improvements [43]. As of June 2013, 47,000 households were using SmartCars for recycling.

The RFID infrastructure for recycling garbage consists of on-board truck hardware and software; CapturItMyRoute office software; RFID components; global positioning system (GPS) transmitters; personal digital assistants (PDAs); and Cascade SmartCart and Xtreme RFID tag [41].

The Cascade SmartCarts are made from recycled materials and ultrahigh frequency (UHF) Gen 2 EPC Snap-In RFID tags from XTreme RFID, a Cascade subsidiary [43]. These tags with a ten-year life snap securely in place below the garbage can lid. UPM ShortDipole ultra-high frequency inlays from UPM RFID power these UHF Gen 2 tags, which are hardy when it comes to extreme temperatures and weather conditions [42].

Mechanical platforms are installed in the trucks that these have automated the lifting and emptying of the garbage bins. An RFID reader and antenna from the AMCS Group are also installed in the trucks and are supported by a truck systems developed in collaboration with AMCS [43].

When the garbage bins are tipped, the reader and antenna capture the identification number of the RFID tag which is attached to the Cascade SmartCart. This ID number is associated with a customer's account. Tag information is, then, transmitted to a global positioning system (GPS)-enabled computer from CapturIt, mounted on the truck's dashboard. Then, using mobile communications, the same information is sent to the city's back-office application called MyRoute office software also from CapturIt [41]. When a customer's garbage is picked up, the software installed in the truck captures tag data which records the time of pick up, GPS coordinates, and the weight of the garbage collected. The information captured by the truck software generates a detailed history of ownership, location, and cart repairs, thus leading to an efficient asset management system for the city's 77,000 carts in use on the streets. Software on the truck also enables unassisted lifting of the SmartCarts --- thus, automating the lifting and emptying of the carts. SmartCarts with a negative account balance and those not assigned to a customer are still placed on the list but are not emptied [43]. The information generated by the system on the truck is securely integrated with the Grand Rapids billing system and Interactive Voice Response capability [44].

Phase 2: Upgrading Trash Collection

In April 2011, the real impact of the RFID-enabled system was observed in this phase when the city changed its business model for charging residents for garbage collection services and migrated from a static flat monthly charge for garbage collection to a system where residents are charged based on the actual weight of their refuse. This new business model incentivizes residents to lower the weight of garbage sent to the landfill and to increase the accumulation of recyclable refuse.

In 2012, the city purchased new garbage trucks and operated two types of trucks [43]. The semi-automated ones required the drivers to wheel the SmartCarts to the tiper, operate the lever, and dump the trash. The fully automated ones have an arm that grabs the SmartCar and dumps the container itself.

Using the same RFID infrastructure system described in phase 1, this is how the system works. Residents have to put money in advance in their accounts either by phone or through the Internet. They usually get email reminders from the city when their balances reach low points. Every week the trucks go out to collect the trash and residents pay only for what they throw out. Garbage trucks charge three fees --- $2, $4, or $6 depending on the size of the garbage cart used, indicating the volume of garbage to be collected. A 32-gallon cart costs $2 per tip, but a pack of ten 32-gallon bags for city waste disposal

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cost $25. Residents are not charged if they choose to not put out their garbage cart. The city used different promotional campaigns to encourage residents to shift to the pay-as-you-throw system --- community meetings, emails, media releases, billboards, radio shows, demonstrations, etc.

The software on the truck controls the trucks' pickup efforts in that it will not service customers who have not put funds in their customer accounts. Mark Harvey, national sales director of CapturIt said, "…If a driver inadvertently attempts to empty a cart on the stop list, the reader will capture the tag's ID number and the onboard software will prevent the truck from completing the lift." [43].

Phase 3: Composting

The next step up would be designing a system so that the city can collect organics and green waste and enable composting food scraps and yard waste with RFID-enabled carts. Hurt expressed the ultimate goal for the city: "Zero waste stream—putting nothing in the trash—that's a goal….I'd love to see only 10 percent of what we throw away go in the incinerator." [43].

d) Install the Innovation and Integrate with Existing System

The RFID system that was designed was the first of its kind used in the city of Grand Rapids but was evolved in different stages. The installation of the RFID system is fully discussed in step 3, plan and pace implementation of the innovation. The RFID system was integrated with the city's existing billing and interactive voice response systems.

Zuboff's Concepts

1) Automate:

The RFID system automated the process of lifting and emptying the SmartCarts. Prior to the use of this RFID system, garbage truck drivers had to manually lift and tip the garbage bins themselves. Other business processes that were automated include tracking the recycling and garbage pickups for residents, tracking the level of funds still available in the customer accounts, sending email alerts to residents when the funds in their accounts were at low levels.

2) Informate:

The RFID system has tremendous informating benefits for the city of Grand Rapids. Detailed and accurate information about a wide range of activities is now available for decision making purposes. Summary data highlighting geographic areas in the city with high and low recycling rates help the city government understand recycling practices and trends. The points gathered from recycling automatically feeds the "myGRIcitypoints" program that incentivizes residents to maintain and increase their recycling efforts via the rewards redeemable from local businesses [43].

Hurt, shared more details illustrating the "informating" benefits of the RFID system:

"Extreme RFID tags allow for signing a refuse recycling cart and its related data to a specific location and customer. This provides for a detailed history of ownership, location, cart repairs, allowing for the monitoring the city's cart asset during its useful life. At present, we have approximately 77,000 carts on the street. We're able to generate specific participation rates for recycling for refuse customers, something we were not able to do with the refuse bags. We are able to determine landfill and incinerator diversions of tonnage. We're able to measure route efficiencies and allow operational decisions to be made quickly. Lastly, it maximizes operating revenues from refuse and recycling collections.

Program benefits cross over businesses, residents, and the environment. On the business side, data has become much more visible as we have gained greater understanding of customers, our collection routes, and our collection equipment. This program is an incentive volume-based pricing model; in other words, we have the aligned the costs of service with refuse fees charged to customers. A reduction of system costs [has] been experienced in the form of developing an accurate database of customers [and] minimizing the costs of [communicating] with residents. We've eliminated approximately a million dollars of non-value added costs to operate a refuse bag program, and route optimization has led to removal of four collection trucks from our fleet." [41].

3) Transformate:

Perhaps, the most significant contribution of the RFID system project is its "transformating" effect on the city of Grand Rapids. The city was able to change the business model behind its refuse collection services in a way that encourages recycling and soon, composting waste as well. With the new business model, increased recycling and composting would result in lower garbage collection fees for city residents. Hurt articulated this important change for the city residents: "On the resident side, our customer side, the technology has allowed us to give control of refuse and recycling services back to the customer in the form of web-based account management system and online billing. Residents are only charged for the services when they present their smart cart out to the curb for collection as opposed to a static monthly charge. Customers have the responsibility for their own environmental impact. The less refuse material generated, the lower their costs. In contrast, the more they recycle, the more MycityGRI points are earned stimulating our local economy." [41].

V. Conclusions

The TOE framework has been a useful tool in explaining the RFID system deployments at HP and the City of Grand Rapids for environmental sustainability --- one in the private and the other in the public sector. Each deployment has its own unique impact in its particular sector of society. There is clear evidence of the automating, informating, and transformating benefits of RFID in the two organizations.

In the private sector, it behooves firms to undertake environmental sustainability initiatives and mount green supply chain management programs to meet societal demands to conserve natural resources and reduce GHG emissions. HP's RFID system typifies the "closed loop" strategy, which covers product recovery and recycling and the "cradle-to-

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cradle" product development approach. Most firms that have deployed RFID systems in the manufacturing sector have used the technology mainly for inventory tracking and therefore, are still a long way from achieving the benefits of the closed loop strategy pursued by firms like HP who are ahead of the sustainability curve.

HP has undertaken the preliminary steps towards the "cradle-to-cradle" approach to manufacturing its printers. HP admits that its current process of salvaging printer raw materials that can be recycled still needs to be improved in order to more specifically identify and target those materials that can still be reused within the prescribed limits for each ingredient. Its R&D staff is still working on formulas for separating and identifying recyclable printer materials and the number of iterations of reuse still feasible. A more advanced approach to recycling would be to be more selective of the raw materials used so as to approach the goals of "zero waste."

Recycling, if undertaken, by the original product manufacturer reduces the need for exporting used e-waste that usually leads to informal recycling in developing countries. End-of-life electronics is often exported to developing countries where recycling is undertaken under very unsafe conditions in worker families' backyards [44]. Despite the call for bans on trade in end-of-life toxic goods by nongovernmental organizations, social activists, and other societal stakeholders, reuse and recycling of e-waste are sources of employment and revenue in developing countries. Informal, dirty, and unsafe backyard recycling processes could emit toxins that were not present in an original computer, for example. Even if this computer was built with no toxic raw materials in it, an informal recycling process could still produce dangerous emissions of chemicals like dioxins, furans, acids, and cyanide [44]. Thus, efforts of firms like HP to undertake its own recycling within premises under its supervision and control (whether or not they own these premises) will contribute to the decrease in incidence of informal recycling in any part of the world.

The RFID system deployment at the City of Grand Rapids highlights the lesson of using the power of city government in inducing community-level behavior modification and rewarding favorable changes residents' behaviors with respect to garbage disposal and recycling. Transformating the city's business model for garbage collection service fees is an important lesson in creativity by exercising simple solutions linking garbage collection revenue generation and local business development using the "myGRIcitypoints" rewards program that enabled its residents to exchange points earned through recycling with products or services offered by local businesses.

What the city has been able to achieve using a fairly uncomplicated deployment of RFID for this one necessary community service could be considered just one piece of a puzzle for a "smart city" solution. Vendors like IBM are now providing an integrated technological platform that can support a city that can be transformed into an "intelligent" and "smart" city using Internet enabled sensors and pervasive computing information technologies. RFID, along with sensors and global positioning systems, can be used, for instance, in reducing greenhouse gas emissions in transportation systems that are better planned and monitored, which can "sense" and "track" congested routes and divert traffic flows during peak times. A city like Grand Rapids can integrate its already existing garbage collection and recycling RFID system with other aspects of city government services using the same smart city platform.

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