EXPLORING ADOPTION, IMPLEMENTATION, AND USE OF AUTONOMOUS MOBILE ROBOTS IN INTRALOGISTICS APPLICATIONS

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Dissertation Prepared for the Degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF NORTH TEXAS

August 2022

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Maywald, Jacob Daniel. *Exploring Adoption, Implementation, and Use of Autonomous Mobile Robots in Intralogistics Applications*. Doctor of Philosophy (Business), August 2022, 153 pp., 5 tables, 26 figures, chapter references.

Autonomous mobile robots (AMRs) use decentralized, AI-driven decision-making processes to providing material handling capabilities in industrial settings. Essay 1 examines how firms organize and engage to mitigate uncertainty during external technology integration (ETI), using an abductive approach with dyadic customer-supplier data to extend prior ETI models by exploring firm engagement, organizational adaptation, and distinct uncertainty types in AMR ETI projects. Essay 2 applies a grounded theory approach to examine AMR integration, using constant comparison and theoretical sampling to develop core categories explaining how suppliers, customers, and users exchange knowledge impacting AMR integration and project performance. Finally, Essay 3 is a conceptual paper examining the importance of end-user adoption by integrating ETI and technology acceptance model (TAM) frameworks, exploring important relationships between managerial interventions, cognitive constructs, user acceptance, and project success in AMR ETIs. As a whole, these essays contribute to the body of knowledge by extending the breadth and depth of current ETI models, emerging a substantive theory of AMR AIU, and extending TAM by grounding managerial interventions and individual cognitive constructs in an AMR context. Managers can use these frameworks to differentiate AMRs and other autonomous collaborative technology from traditional automation, and develop strategies enabling timely and effective AMR implementation.

ACKNOWLEDGEMENTS

I would like to convey my sincere appreciation for the faculty and staff at the University of North Texas for their support, encouragement, and patience throughout my journey in this program. To my advisor Dr. Ila Manuj, I am incredibly grateful for your mentorship, guidance, and friendship throughout this process. Your persistent professionalism and positive demeanor made this experience tremendously rewarding, and I look forward to continuing our friendship in the future. I would also like to acknowledge the efforts of Dr. Terry Pohlen and Dr. Lou Pelton; whose efforts and counsel were invaluable. I feel truly lucky to have met and worked with each of you.

However blessed I have been with outstanding professional relationships, I know that I would not be here without the six most important people in my life. To my children Easton, Peyton, Lillian, Madison, and Morgan, you bring a light into my life that provides strength during even the most difficult days. It is a privilege and honor to be a part of your lives. To Chris, my wife, know from the bottom of my heart that I view no achievement, including completing this doctoral program, as wholly my own. I am so thankful for the steadfast love and support you provide this family and me. You are this family's rock and I am convinced I would not have arrived here without you. I love you. Finally, I must acknowledge and give all glory to my Lord and Savior Jesus Christ, whom through all things are possible.

The views expressed in this dissertation are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the U.S. Government.

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OVERVIEW

Retail e-commerce and omni-channel distribution continue to experience growth (Batt & Gallino, 2019), challenging warehouses and distribution centers (WDCs) to increase operational efficiency in the midst of acute labor shortages and turnover (Evans, 2021; McCrea, 2019). Dynamic customer demand necessitates low-volume, high-mix orders and narrow delivery windows (Boysen et al., 2019). Innovative firms employ automation to overcome these challenges; however, barriers related to capital expenditure and loss of flexibility prevent many firms from pursuing these solutions (Hackman et al., 2001; Marchet et al., 2015). Autonomous mobile robots (AMRs) are a novel technology which are affordable, flexible, and scalable, and thus well-suited to overcome traditional automation barriers related to warehouse order-picking.

AMRs are industrial robots using decentralized, AI-driven decision-making processes to provide material handling capabilities and other services within a bounded area (Fragapane et al., 2021). Unlike traditional automation, AMRs operate autonomously and are highly interactive and collaborative (Tang et al., 2014). AMRs leverage machine learning, independent decision-making, and collision-free navigation to assist human pickers in executing "hybrid" tasks where control is shared between human and machine (Krüger et al., 2009). Due to physical and active interaction between AMRs and human pickers, greater emphasis of human factors is required when considering AMR adoption, implementation, and use (AIU). Consideration of human factors and the autonomous nature of AMRs makes WDC process integration uniquely challenging relative to traditional automation.

While interest in AMR applications is increasing in practice (McCrea, 2019), academic research remains sparse (Azadeh & Koster, 2019). As AMRs are a new form of collaborative and autonomous technology, existing theory fails to adequately address gaps related to AMR integration and end-user acceptance. This dissertation addresses these gaps using conceptual development and qualitative methods to investigate relevant research questions and obtain a richer understanding of how firms can maximize the potential of warehousing AMRs.

Essay 1, titled “Enhancing Integration of Autonomous Mobile Robots in Warehousing: Mitigating Uncertainty through Inter-Firm Engagement and Organizational Adaptability,” examines how firms organize and engage to mitigate uncertainty during external technology integration (ETI). Current ETI models stress the importance of supplier interaction in mitigating uncertainty during ETI projects(Stock & Tatikonda, 2008); yet, we know little about what types of uncertainty exist and how firms adapt to overcome them. Using an abductive approach, this essay uses dyadic customer-supplier data to extend prior ETI models by exploring firm engagement, organizational adaptation, and distinct uncertainty types in AMR ETI projects.

Essay 2, titled “Integration of Autonomous Mobile Robots in Intralogistics Applications: A Grounded Theory Approach,” applies grounded theory to inductively emerge a substantive theory of AMR integration (Glaser & Strauss, 1967). Extant theory falls short in explaining technology AIU in the unique context of AMRs in intralogistics applications. This essay examines this phenomenon holistically, using constant comparison and theoretical sampling to develop core categories explaining how suppliers, customers, and users exchange knowledge impacting AMR integration and project performance.

Finally, Essay 3 titled “Collaborative Technology Integration: Achieving Organizational Objectives by Influencing End-User Acceptance,” is a conceptual paper examining the importance of end-user adoption by integrating ETI and Technology Acceptance Model (TAM) frameworks. As a collaborative technology, user acceptance is highly relevant to ETI success. Low technology adoption negatively affects the relationship between investment and performance (Venkatesh & Bala, 2008); however, ETI models fail to emphasize an individual perspective. This essay explores important relationships between managerial interventions, cognitive constructs, user acceptance, and project success in AMR ETIs.

As a whole, these essays contribute to the academic body of knowledge by extending the breadth and depth of current ETI models, emerging a substantive theory of AMR AIU, and extending TAM by grounding managerial interventions and individual cognitive constructs in an AMR context. Managers can use these frameworks to differentiate AMRs and other autonomous collaborative technology from traditional automation, and develop strategies enabling timely and effective AMR implementation.

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ESSAY 1

ENHANCING AUTONOMOUS MOBILE ROBOT INTEGRATION IN WAREHOUSING: MITIGATING UNCERTAINTY THROUGH INTER-FIRM ENGAGEMENT AND ORGANIZATIONAL ADAPTABILITY

1.1 Introduction

Retail e-commerce and omni-channel distribution continue to experience volume growth (Batt & Gallino, 2019), challenging warehouses and distribution centers (WDCs) to increase operational efficiency and effectiveness in the midst of an acute labor shortage (Evans, 2021; McCrea, 2019). Dynamic customer demand drives stringent supply chain requirements including small order sizes, high seasonality, and narrow delivery windows (Boysen et al., 2019), forcing WDCs to adapt as order-picking transitions from pallets and cases to individual units, and fulfillment timelines shrink (Boysen et al., 2019; Melacini et al., 2018). Innovative firms employ automation to overcome these challenges; however, a recent survey of warehouse operations managers indicate 49% of respondents still utilize mostly manual processes, 42% had a mix of automated and manual processes, and only 4% had what they described as highly automated operations (McCrea, 2019). Despite the potential of automation to increase warehouse efficiency and effectiveness, barriers related to capital expenditure and loss of long-term flexibility prevent many firms from pursuing these solutions (Hackman et al., 2001; Marchet et al., 2015). Thus, while order-picking, or the process of retrieving product from storage to meet customer demand, is cost- and labor-intensive (de Koster et al., 2007), a majority of WDCs still employ manual order-picking processes (Grosse et al., 2017). In sum, there is a disconnect between the promise of automation and its widespread use in WDC operations.

A novel warehouse technology, which is affordable, flexible, and scalable, and thus well-suited to overcome aforementioned barriers to automating order-picking, is autonomous mobile robots (AMRs). AMRs are "industrial robots using decentralized decision-making processes for collision-free navigation to provide platforms for material handling, collaborative activities, and full services within bounded areas" (Fragapane et al., 2021). On-board computing and advanced sensors enable trackless navigation and obstacle avoidance, allowing AMRs to work seamlessly alongside human order-pickers (Trebilcock, 2020). Leveraging artificial intelligence (AI) to optimize path-finding and workload in real-time, AMRs act as "intelligent assistants" in shared workspaces (Tang et al., 2014), assisting people in the execution of "hybrid" tasks. These hybrid, or collaborative, tasks allow physical strength, efficiency, and precision of machines to be combined with intellect, creativity, and problem-solving of human operators, thereby enhancing task execution (Boysen et al., 2019; Krüger et al., 2009). Unlike traditional automation, AMRs operate autonomously and are designed for robust interaction with humans. This fundamentally changes workplace dynamics; incorporating AMRs into warehouse operations is more akin to introducing a new form of worker rather than a machine to automate a process.

To realize AMRs' full potential, firms must understand how best to integrate them into WDC operations. Automation ventures are challenging, often taking longer than anticipated to generate expected returns or failing altogether (Bell et al., 2014; Cooper & Wolfe, 2005; Fawcett et al., 2011). Technology integrations must cope with issues related to system reliability, compatibility with existing processes, and information system (IS) integration (Tu, 2018). These issues often lead to underwhelming system use and subsequent failure to achieve adequate return-on-investments (ROI) (Devaraj & Kohli, 2003). Moreover, integration of AMRs into WDCs presents unique challenges compared to traditional automation. To ensure safety and efficiency, traditional automation deliberately delineates human and machine activity, distilling interaction to a single place and time (task handoff). However, collaborative technologies (i.e. AMRs) work in shared environments where interaction is not only robust, but necessary to function as designed. Whereas performance of traditional automation is dependent on functional operation and a machine's fit to the applied task, performance of collaborative technology is contingent on ability of operators to effectively collaborate in executing tasks. Thus, integration of AMRs requires increased emphasis on human factors, leading to additional complexity during implementation.

Industry interest and investment in AMR applications are increasing in practice (McCrea, 2019), however academic research remains sparse (Azadeh & Koster, 2019; Boysen et al., 2019). Contemporary research on AMRs in intralogistics is largely technology-focused (Fragapane, de Koster, et al., 2021), relying on analytical approaches exploring areas of planning and control systems, route optimization, dispatching, and order-sequencing (Kousi et al., 2019; Li et al., 2019; Löffler et al., 2021). The practical phenomenon of AMR integration remains unexplored, representing a noteworthy gap as autonomous and collaborative characteristics of AMRs signify a significant departure from the static nature of traditional automation. Therefore, we argue a qualitative investigation challenging existing theory regarding AMR integration is warranted.

The external technology integration (ETI) framework, and its foundation in organizational information processing theory (OIPT) provide the theoretical basis for this research. The purpose of this study is to challenge and extend existing ETI models, using an abductive approach to develop a substantive theory of AMR ETI reconciling the framework's logic with contextual idiosyncrasies (Ketokivi & Choi, 2014). By exploring ETI through the lens of AMR integration, this research contributes to the academic body of knowledge by (i) describing various types of uncertainty which must be confronted during ETI execution, (ii) explaining how joint ETI experience mitigates realized uncertainty, (iii) addressing how bi-directional engagement reduces uncertainty for all stakeholders, and (iv) expressing how firms adapt organizational structures to more efficiently process information. Further, we advance a modified ETI framework based on AMR integration that more fully explains complexity in relationships between ETI constructs in this unique context. Finally, we conclude by offering testable research propositions providing a foundation for future research in the area.

1.2 Literature Review

Our research uses an abductive, theory elaboration approach in studying the phenomenon of AMR ETIs. In doing so, we consult existing theory while maintaining that the context is not well-enough understood to produce detailed premises allowing for deducible hypotheses (Ketokivi & Choi, 2014). This approach provides latitude to use qualitative empirical data to challenge and elaborate existing theory. Thus, a thorough review of OIPT provided researchers initial theoretical sensitivity, directed the initial interview protocol, assisted in developing initial categories, and guided model integration (Glaser & Strauss, 1967).

OIPT is an organizational theory viewing firms as open social systems which must effectively cope with task-related uncertainty and equivocality (ambiguity) to be successful (Daft & Lengel, 1986; Galbraith, 1974). The theory has three foundational theoretical elements: the information processing requirement of tasks, the information processing capacity of organizations, and achieving an appropriate “fit” between the two aforementioned elements via organizational structure of the firm (Tushman & Nadler, 1978). A task’s information processing requirement is a function of complexities intrinsic to the task and an organization’s operating environment. These complexities create uncertainty and equivocality during task execution requiring information processing, or the acquisition, interpretation, synthesis, and dissemination of information (Daft & Lengel, 1986; Tushman & Nadler, 1978). To counteract uncertainty and efficiently process information during task execution, firms must organize effectively, thereby creating information processing capacity (Galbraith, 1974).

From an OIPT perspective, it is important to differentiate between task uncertainty and equivocality. While uncertainty occurs due to lack of necessary information to execute tasks, equivocality results from lack of contextual understanding. In equivocal situations, additional data may not improve information processing. For instance, providing additional data to someone who does not understand the data's context may not improve their ability to analyze the data set, but providing in-depth explanation will. Thus, it is important to understand the role of media richness in OIPT. Media exists in either lean or rich forms. Lean forms of media include company memos, generalized emails, spreadsheets, and databases which provide information to reduce uncertainty, but are ill-suited to reduce task equivocality. It is shared frames of reference that gives meaning to leaner forms of media. Richer media facilitate personalization, the ability to obtain immediate feedback, and provide multiple verbal and non-verbal cues (Cooper & Wolfe, 2005; Daft & Lengel, 1986). Some examples include face-to-face meetings, one-on-one exchanges, telephone conversations, and teleconferences. Rich forms of media, are inefficient at reducing uncertainty, but excellent at combating equivocality (Daft & Lengel, 1986).

As previously mentioned, effective organization results in information processing capacity, which is the outcome of two dimensions of organizational structure: (1) the mechanistic-organic nature of organizational subunits and (2) the presence of coordination and control mechanisms to efficiently exchange information between interdependent subunits (Tushman & Nadler, 1978). Mechanistic models, which are highly centralized, hierarchical, and governed by formalized rules and procedures (Srinivasan & Swink, 2018), are appropriate for low information processing tasks. They are easy to organize, but unable to effectively cope with high levels of uncertainty and equivocality. On the other hand, organic subunits are less formal, governed by fewer rules and procedures, and rely on greater peer involvement in decision-making (Tushman & Nadler, 1978). Organically organized subunits are lateral in nature, facilitating communication networks which increase opportunities for feedback, synthesis of different viewpoints, and use of individuals as problems solvers (Tushman & Nadler, 1978). Organic subunits are better-suited for high-complexity tasks; however, they are expensive to maintain due to increased coordination costs and reduced managerial control.

After determining subunit structure, the design problem transitions to creating mechanisms facilitating coordinated action among interdependent task participants (Galbraith, 1974). While types and means of coordination and control mechanisms vary, their purpose is to facilitate exchange of information between interdependent subunits to increase information processing capacity. Each type of mechanism, whether its purpose is to facilitate volume of data or richness of information, varies in scope and cost. When tasks are highly uncertain and high levels of task interdependence exists, there is increased need for mechanisms facilitating quality and timely information flow among various participants which must coordinate and make mutual adjustments (Tushman & Nadler, 1978).

OIPT views achieving “fit” between information processing requirements and the organization’s capacity to process information as the fundamental managerial challenge. The basic problem of creating either too little or too much information processing capacity results in either task ineffectiveness or inefficiency, respectively. The degree which an adequate fit between these theoretical elements is achieved ultimately affects the quality of task outcomes (see Figure 1.1) (Tushman & Nadler, 1978).

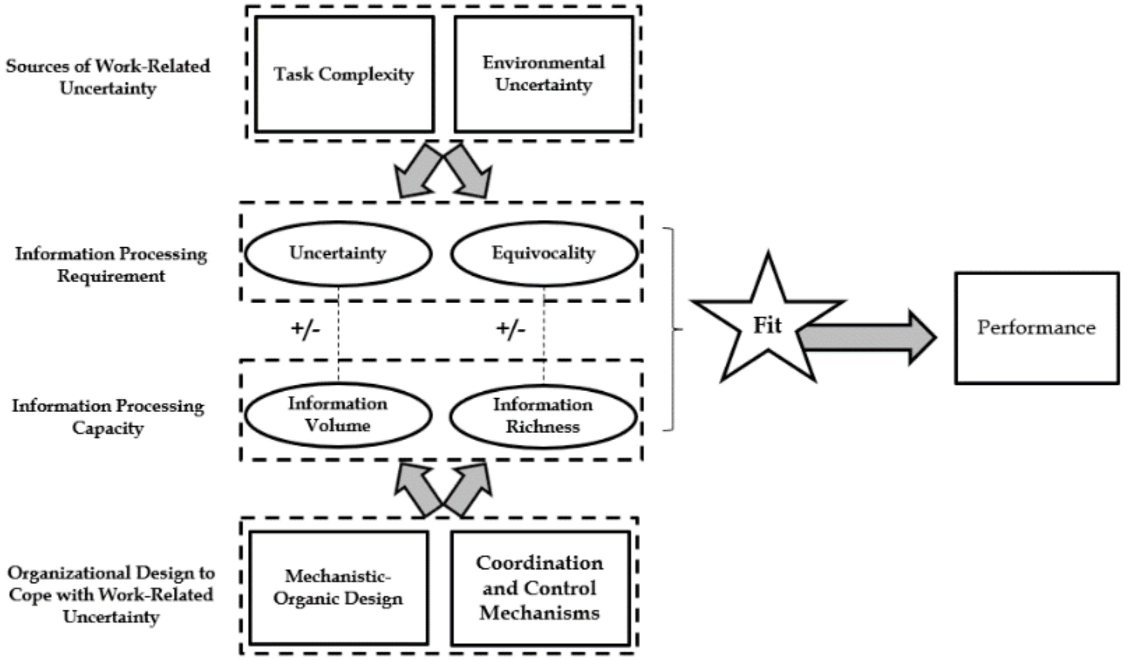

Figure 1.1: Model of organizational information processing theory (adapted from Tushman and Nadler, 1978, p. 622)

1.2.1 External Technology Integration

Similar to approaches taken by Cooper and Wolfe (2005) and Stock and Tatikonda (2008), AMR integrations can be conceptualized as organizational tasks using the theoretical lens of OIPT. Tasks can be described as ETIs, which involves the acquisition and integration of technology from outside a firm into the firm's internal operational processes (Stock & Tatikonda, 2004). Due to AMRs' novelty, complexity, and tacitness (Tatikonda & Stock, 2003), AMR ETIs are characterized as having high levels of technology uncertainty. Technology uncertainty is defined as "the difference between the information needed to obtain and implement the technology, and the information the recipient actually has at the start of the ETI process."(Stock & Tatikonda, 2008, p. 68) Technology uncertainty is analogous to task uncertainty, which leads to rapid change, unpredictable problems, and issues which no standard procedure exists, resulting in trial-and-error learning during task execution (Daft & Lengel, 1986).

In Stock and Tatikonda's (2008) ETI framework, higher technology uncertainty demands greater interorganizational interaction (see Figure 1.2). In characterizing interaction between partnering firms, Walton (1966) recognized three important dimensions: 1) the exchange of information, 2) the structure of inter-unit interaction and decision-making, and 3) attitudes held towards partnering units. Stock and Tatikonda (2008, p. 68) found greater levels of these components of interorganizational interaction result in greater information processing capacity, and refer to these as "communication, coordination, and cooperation in the context of ETI." Accordingly, creating an optimal fit between technology uncertainty and these dimensions of interorganizational interaction result in enhanced project performance. In this view, ETIs are episodic tasks bound by defined beginnings and ends, and project performance is defined by cost, timeliness, and functional performance of the technology (Stock & Tatikonda, 2008).

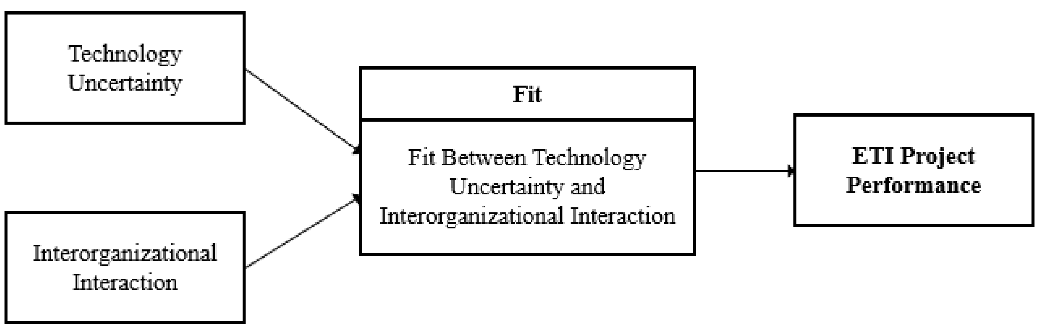

Figure 1.2: Conceptual framework of ETI project performance (Stock and Tatikonda, 2008, p 68)

1.2.2 Research Context: Autonomous Mobile Robots in Warehousing

ETI tasks involving high levels of uncertainty and ambiguity require quality information, as well as subjective experience, judgement, in-depth discussion, and analysis (Daft & Lengel, 1986). Unfortunately, WDCs are typically ill-equipped to confront this type of uncertainty. Basic presuppositions regarding typical warehousing operations' day-to-day tasks include: 1) generally stable and routine environments, 2) well-understood issues and rare exceptional scenarios, and 3) sufficiency of lean forms of media (including schedules, reports, and databases) during normal operations. Typical warehouse tasks (i.e. order-picking) are organized mechanistically emphasizing efficiency, rather than complex problem-solving. While required in volatile environments, maintaining high levels of information processing capacity provides little benefit when environmental conditions are stable and tasks are certain (Srinivasan & Swink, 2018). Instead, simple and cost-effective organizational structures should be employed to the greatest extent possible. (Tushman & Nadler, 1978). Thus, a highly centralized and hierarchical mechanistic subunit structure, governed by formalized rules and procedures, are appropriate for day-to-day, low information processing warehousing tasks (Srinivasan & Swink, 2018). Under normal conditions, no standing need for organic work structures or elaborate coordination and control mechanisms exists, as warehouse tasks are self-contained and executable with little external interdependence.

With this baseline understanding, the challenge is to create “fit” between fundamentally mechanistic subunits (warehouse) and tasks with inherently high information processing requirements (AMR integration) to improve ETI outcomes. When information processing capacity is inadequate, tasks likely take longer, cost more, and will not meet prescribed performance standards. From an OIPT perspective, certainty and stability inherent in warehousing tasks conflict with uncertainty and equivocality during AMR ETIs resulting in poor fit (see Figure 1.3). WDC organizational structures, which face challenges during ETIs that standard rules and operating procedures cannot cope with, are ill-prepared and ill-fit for these tasks. In early stages of technology adoption, the what, how, and why of the technology is less clear (Cooper & Wolfe, 2005). Equivocality generates confusion regarding roles and tasks (Cooper & Wolfe, 2005), which require planning and knowledge exchange through rich media to mitigate. As issues emerge, warehouses are challenged to effectively process ETI task-related information, potentially resulting in less-than-full exploitation of the technology (Srinivasan & Swink, 2018).

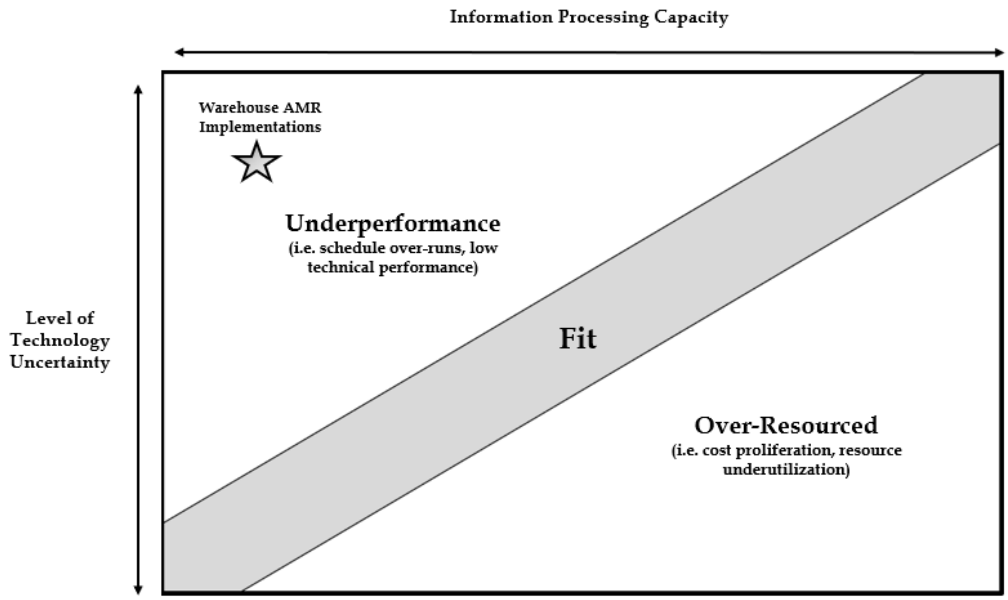

Figure 1.3: OIPT perspective of typical warehouse AMR ETI

1.3 Methodology

AMR ETI involves integrating novel and highly-collaborative technology, therefore we adopted a qualitative approach, leaning on principles of grounded theory (GT) (Corbin & Strauss, 2008; Glaser & Strauss, 1967). However, unlike GT's goal of theory emergence, our aim was theory elaboration using abductive logic, relying on both theory and empirical context to inform the study (Ketokivi & Choi, 2014). We argue ETI frameworks effectively predict integration performance; however, the novelty of collaborative, autonomous technology (like AMRs) in inherently mechanistic WDC environments is a unique context justifying this approach. Thus, our research explores novel contextual conditions of AMR technology integration, making a less-structured approach utilizing expert interviews appropriate (Fisher, 2007). Using OIPT as a theoretical lens, we employed theoretical sampling and constant comparison techniques to guide our study, while simultaneously engaging in data collection and analysis to develop a substantive theory of AMR ETI.

1.3.1 Context and Sampling Criteria

Given ETI frameworks' customer-centric perspective, we initially sought a sample of AMR customer-firms to explain how uncertainty is mitigated during integration. However, after initial interviews we determined a dyadic approach (supplier and customer) provided a more holistic understanding of the phenomenon and strengthened the veracity of findings. Furthermore, we discovered while customers working directly with robotics manufacturers is not uncommon, warehouse technology integrators and consultants often play equally important roles in AMR ETI projects. Thus, we deliberately sought informants from each of these key perspectives.

To develop our sample, we contacted two independent innovation-focused non-profit organizations specializing in industrial robotics. These organizations provided comprehensive lists of leading U.S. AMR manufacturers, which we used to contact participating firms through public websites. In addition, we leveraged standing relationships between a university research center and private industry, and conducted snowball sampling by soliciting potential contacts at the conclusion of each interview (Bhattacherjee, 2012). The final sample consists of 17 key informants from 14 different firms, with varied professional experience ranging from C-level executives to project engineers. Each interviewee had direct responsibility for and experience with some form of AMR ETI project, uniquely qualifying them as knowledgeable agents. The type of firm respondents belonged to were also diverse, consisting of AMR manufacturers, distributors, integrators, consultants, and customers.

Table 1.1: Research participants and firm descriptions

Firm Name (pseudonym)	Firm Type	Firm Description	Informant (pseudonym)	Title of Key Informant(s)
Flash Robotics	AMR Manufacturer	AMR developer that designs, develops, and manufactures fully autonomous robots for manufacturing and warehouse applications	Mary	Director of Marketing
			James	Director of Business Development
Swarm Robotics	AMR Manufacturer	AMR developer producing fully supported autonomous order picking robots with remote access capability for e-commerce applications	Patricia	Chief Marketing Officer
TugCo Robotics	AMR Manufacturer	Robotics start-up developing hardware and software solutions enabling the safe operation and retrofit of warehouse tugging equipment.	Robert	Founder and President
Invictus Robotics	AMR Manufacturer	A medium-sized AMR developer that designs, develops, and manufactures fully autonomous robots for manufacturing and warehouse applications with $30 million in annual sales	John	Chief Revenue Officer
Mechanized Automation Distribution Co.	Material Handling Equipment Vendor	Material handling equipment vendor offering a wide variety of products, services, and consulting.	Michael	Chief Executive Officer
Novel MHE Distribution Co.	Material Handling Equipment Vendor	Large material handling equipment vendor offering a wide variety of products, services, and consulting with nearly $2 billion in annual sales.	Linda	Vice President of Operations
Success Integration Consultants	Warehouse Automation Consultant	Supply chain and distribution experts offering warehouse automation solutions with $30 million in annual sales.	William	Senior Director
Automation Central Consultants	Warehouse Automation Consultant	Supply chain consultants specializing in engineering and labor management with an estimated $1 million in annual sales.	David	Project Lead
Warehouse Solutions Consultants	Warehouse Automation Consultant	An independent consulting firm specializing in optimizing solutions distribution infrastructure with an estimated $10 million in annual sales.	Richard	Project Manager
Et Cetera Solutions Co.	Warehouse Automation Consultant	Warehouse automation and fulfillment solution provider offering software and hardware solutions with an estimated $26 million in annual sales.	Susan	Sales Engineer
ABC Food Co.	Manufacturer/ Automation End-User	Large food manufacturer with over $20 billion in annual North American sales.	Charles	Senior Director of Warehouse Operations
Retail A-Z Inc.	Retailer/Automation End-User	Large retailer operating nearly 1,900 stores throughout the U.S. with over $75 billion in annual sales.	Thomas	Distribution Center Operations Manager

Firm Name (pseudonym)	Firm Type	Firm Description	Informant (pseudonym)	Title of Key Informant(s)
DefenseCo	AMR End-User	Large defense contractor with nearly $60 billion in annual sales.	Chris	Applications Engineer (Site #1)
			Daniel	Applications Engineer (Site #2)
			Elizabeth	Applications Engineer (Site #3)
			Steven	Applications Engineer (Site #4)
Direct-to-Customer Med Co.	AMR End-User	Direct-to-consumer medical supplies company with an estimated $25 million in annual sales.	Anthony	Founder and President

Generally, manufacturers and integrators generally had experience with a wide range of different customers, while customers in our sample represented warehousing in dry goods manufacturing, medical, grocery, and aerospace manufacturing industries. Table 1.1 offers a description of firm type, firm description, and professional title of key informants. The iterative process of collecting, coding, and analyzing qualitative data using constant comparison, and subsequently theoretical sampling, resulted in additional interviews until saturation of categories was achieved.

1.3.2 Data Collection

Data was sourced via semi-structured interview conducted remotely using video conferencing software with at least two (but typically three) members of the research team present. The interviews typically lasted one hour and were recorded in audio and video formats, transcribed, and uploaded into MaxQDA 2020, a software package designed for qualitative research (see Appendix A for the interview protocol). Research team debriefings compared insights immediately following each interview and supplemented weekly research meetings to discuss findings and adjust the protocol as necessary to cover gaps in understanding.

In each instance, we notified informants about the general purpose of the research and provided an early version of the interview protocol ensuring dialogue stayed within the study's scope. Interviews began by describing the study's purpose, a statement ensuring informants understood their rights as research subjects, and informants signing consent forms. While we provided background material, great care was taken to avoid lines of questioning mentioning specific constructs or theoretical frameworks of interest, ensuring informants conveyed actual experiences rather than affirming researchers' theoretical biases. In total, 17 semi-structured interviews were conducted over a seven-month time period resulting in over 500 open codes and 130 theoretical memos.

1.3.3 Data Analysis

Each interview was coded and analyzed by at least two members of the research team. MaxQDA allowed researchers to build “a chain of evidence” to make explicit the links between interview questions, data, and theoretical conclusions drawn from data (Yin, 2003). Data collection and coding occurred simultaneously, with inclusion of new informants and lines of inquiry guided by theoretical sampling procedures (i.e. automation integrators and consultants were sought after supplier-customer dyads produced inconsistent and divergent data). Extensive theoretical memos captured key ideas and connections, while weekly research meetings allowed researchers to compare coding, discuss theoretical findings, and reconcile divergent insights. This process allowed researchers to saturate categories, as well as their various properties and dimensions (Corbin & Strauss, 2008).

Using coding strategies borrowed from a Glaserian approach to GT (Glaser & Strauss, 1967), the team identified first order concepts through a process of open coding, or close examination and classification of textual data. In this early stage of coding, the researchers took great care to assess and code data reflecting respondents’ voices, and to avoid making conceptual leaps (Charmaz, 2006). As codes coalesced, categories emerged and researchers began the process of selective coding to further develop the categories and associated properties and dimensions. Unlike pure GT approaches which emerge theory fully grounded in data, we compared developed categories to existing OIPT and ETI literature, making theoretical connections and elaborating where existing theory lacked explanatory power.

In assessing the rigor of our research and trustworthiness of theoretical findings, we applied the evaluative criteria of fit/credibility, transferability, dependability, confirmability, integrity, understanding, generality, and control (Flint et al., 2002). These criteria, based on interpretive and GT tradition (Strauss & Corbin, 1990), provide standard benchmarks for assessing quality and rigor of qualitative research. Please see Table 1.2 for a description of the criteria and brief discussions of how the research addressed each condition.

Table 1.2: Evaluation of qualitative research trustworthiness

Criteria	Description	How was the criterion addressed in our research?
Fit/Credibility	The extent to which the categories fit the empirical data	The resultant theoretical framework emerged from over 150 pages of expert interview transcripts, 513 open codes, and 130 theoretical memos.
Transferability	The extent to which findings from one study in one context will apply to other contexts	Admittedly, each AMR implementation was unique due to the differences in design and employment, however the theoretical sampling approach allowed us to triangulate and converge on important categories.
Dependability	The extent to which the findings are unique to time and place; the stability or consistency of explanations	The automation integrator and AMR manufacturer key informants provided reflection on multiple instances of implementation in a variety of contexts. The implementation processes described by these participants displayed consistency with customer firms that were interviewed.
Confirmability	The extent to which interpretations are the result of the participants and the phenomenon as opposed to researcher biases	A three-person research team worked in tandem over a twelve-month period, participating in data collection, coding, and interpretation. Findings were discussed during weekly research meetings to minimize individual biases and resolve divergent interpretations.
Integrity	The extent to which interpretations are influenced by misinformation or evasions by participants	Interviews were conducted in a professional, but conversational and non-threatening nature. Participants were presented with consent forms that detailed protections to ensure privacy and anonymity. The researchers are under no impression that participants purposefully misinformed them or evaded questions posed by the interview protocol.
Understanding	Extent to which participants buy into results as possible representations of their worlds.	An executive summary was developed and presented to colleagues. Feedback received was generally positive and validated our framework as an accurate representation of the phenomenon.

Criteria	Description	How was the criterion addressed in our research?
Generality	The extent to which findings discover multiple aspects of the phenomenon	Interviews were of sufficient length, depth, and openness to allow respondents discuss the phenomenon in detail, thereby capturing of multiple facets AMR implementation
Control	The extent to which organizations can influence aspects of the resultant theory	Customers, suppliers, and integrators of AMRs are key actors in the joint team influencing ETI success

1.4 Findings

Analysis and abstraction of coding provided support for Stock and Tatikonda's (2008) model of ETI. However, while Stock and Tatikonda's model explains variability attributable to technology form and interorganizational interaction, it falls short of fully explicating the phenomenon of AMR ETI. For example, previous ETI frameworks (including the Stock and Tatikonda model) are monadic and emphasize technology uncertainty from customer-centric perspectives; however, we found AMR ETIs are best characterized as dyadic, joint tasks where suppliers, customers, and other stakeholders occupy important roles. Figure 1.4 shows an expanded ETI model reflecting complexities and nuances involved in integrating collaborative technology (for example, AMRs) into WDC operations.

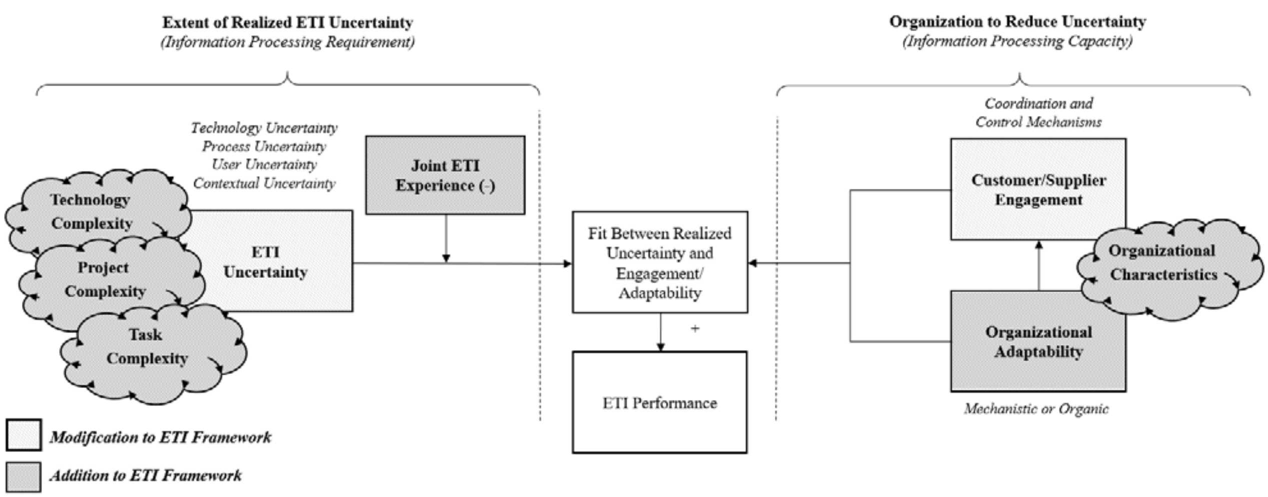

Figure 1.4: ETI framework for warehouse AMR integration

Similar to previous ETI frameworks, as shown in the unshaded boxes above, we found performance an outcome of fit between uncertainty and interaction. However, in addition, we include lighter shaded boxes representing concepts heavily modified from extant ETI models, while darker shaded boxes represent new concepts, or properties and dimensions of existing concepts, uncovered in this research.

Three major findings are discussed in this section. First, joint ETI experience (left side of Figure 1.4) and organizational adaptability (right side of Figure 1.4) play significant roles in decreasing uncertainty and increasing information processing capacity respectively. Second, ETI uncertainty is a conglomeration consisting of elements of technology, process, user, and context uncertainty. Specific characteristics of the technology, project, and task (which influence various types of uncertainty) are identified. Finally, we uncovered customer/supplier engagement (a continuous process benefiting both parties), when fit to the appropriate level of uncertainty, allows joint organizations to effectively process information, leading to exceptional ETI performance.

We found in typical AMR ETI projects, there are at least two, but sometimes three, primary actors involved in project execution. During AMR integrations, customers work directly with manufacturers, with third-party integrators, or with both integrators and manufacturers. In discussing findings, any time a dyadic relationship exists, manufacturers or integrators are referred to as "supplier"; however, distinctions are made between integrators and manufacturers when context dictates relevance. Additionally, since ETIs are viewed as joint tasks accomplished by both customers and suppliers, we refer to the two entities collectively as "joint teams."

1.4.1 Extent of Realized ETI Uncertainty

As mentioned earlier, ETI uncertainty is multifaceted and complex; however, not all organizations experience this uncertainty the same way. Organizations possessing technology or process knowledge, or partnering with other firms that possess this knowledge, experience less uncertainty regardless of ETI conditions. In this section we describe different types of uncertainty, identify their potential sources, and discuss how joint ETI experience moderates the extent organizations realize this uncertainty.

1.4.1.1 Types of ETI Uncertainty

Building upon Tushman and Nadler's (1978) definition of uncertainty in OIPT, we define ETI uncertainty as the difference between the information required to effectively execute ETI projects and the information initially possessed by joint teams. Current ETI models express uncertainty in terms of technological ambiguities (technology uncertainty). However, we view ETI uncertainty as multi-dimensional, as joint teams encountered other types of inherent uncertainty, including process uncertainty, user uncertainty, and context uncertainty. Next, we describe each of type of uncertainty incorporated in ETI uncertainty in detail.

1.4.1.1.1 Technology Uncertainty

We found customer firms typically lack technology-related information required to effectively execute AMR ETI projects. Insufficient experience with AMRs, a novel technology, resulted in deficient understanding of operating conditions AMRs require to optimize their performance. Furthermore, the autonomous behavior of AMRs required firms to seek information to optimize safe and efficient movement in previously unshared environments. We uncovered technology uncertainty - the gap between information required and possessed - occurred at multiple stages in the AMR ETI project.

In initial stages, AMR novelty and complexity impose technological challenges for unexperienced firms. Customers rarely understood warehouse robotics and how to create warehouse environments conducive to maximizing their performance. For example, Anthony at Direct-to-Customer MedCo disclosed they were "coming in blind," making them excessively reliant on their supplier during initial setup and operation. Surprisingly, despite their warehouse automation expertise, integrators also often lacked experience with AMR technology. We found integrators at times struggled to accomplish technology-related tasks such as user training and basic troubleshooting. Moreover, unrealized expectations related to AMRs' capabilities tended to exacerbate technology uncertainty in these early stages. Customers often assumed AMRs were capable of easily dropping into existing workflows without substantive changes. Some companies (somewhat errantly) market AMR flexibility as enabling immediate and seamless integration into current operations with little disruption. Further, sales demonstrations were often conducted on "super-flat floors that are clean and ideal for AMR operation," in stark contrast to most typical WDC environments. This fallacy was often perpetuated as early pilot tests in customer warehouses were typically conducted after floors were cleaned and prepared, masking future potential problems. While most AMRs can technically operate immediately after being "dropped in," they rarely achieve optimal performance without realizing some substantive changes. We found mismatched expectations led to customer neglect regarding adequate engagement with suppliers until after the ETI commences and issues arise.

Next, we found customers begin to discover new technological uncertainties only after AMRs begin operation. Warehouse environments are dynamic, with moving obstacles and disordered layouts, leading to challenging conditions for autonomous navigation. Debris can impede motion, while variable lighting conditions and dust can overload sensors affecting navigation. Chris with DefenseCo noted, even after several weeks of operation issues continued to emerge that "you do not see in online videos or meetings with salespeople." In early stages of their ETI, Chris struggled to operationalize their fleet, stating their AMRs were “maybe working 60% of the time, while the other 40% it was re-routing, thinking, or displaying an error,” leading to work stoppages as engineers engaged in troubleshooting.

Finally, a third critical stage at which technological uncertainty figures prominently is after AMRs are fully operational per the initial scope of the project. Modifications including after-market add-ons (e.g. mobile carts and racks), new hardware (e.g. additional LIDARs), alterations to fleet management software, and process changes add technological uncertainty. For example, Daniel with DefenseCo affixed after-market towing systems to AMRs at their site, which consequently added complexity to path and payload planning. The engineer described the towing system as “terrible” and “very unreliable,” adding it “adds a pretty tremendous amount of complexity.” Further, the engineer explained that the “80/20 rule applied”; it was relatively easy to map warehouses and execute simple missions, but complete integration required substantial additional information and time to execute.

Technology uncertainty can vary from slight to extreme during all the aforementioned stages. As the paper later discusses, the degree to this uncertainty manifests itself is dependent on the characteristics of the technology, project, context, and joint experience. Technology uncertainty combined with lack of experience could lead to failed projects or customers not taking up AMR ETI projects at all. For example, William, an integrator with several decades of automation experience expressed that AMR solutions are currently viable, however inexperience of both integrators and customers convinced him that the “market is not completely ready to go with AMRs across the board.”

1.4.1.1.2 Process Uncertainty

To understand how AMRs best address operationally inefficiency, both supplier and customer must thoroughly understand customer processes. While traditional automation typically operates in isolation, AMRs function in dynamic and collaborative environments with human operators, making it more difficult to define these processes. Understanding customer use cases helps joint teams avoid what John at Invictus Robotics describes as "trying to fit a square peg into a round hole." While seemingly obvious, we uncovered several examples where lack of clarity regarding processes led to less-than-desirable outcomes.

We found process-related uncertainty most salient in initial stages of ETI. Initially, suppliers encounter process uncertainty due to customer idiosyncrasies. Regardless of technology, each instance of ETI is unique because no two customers employ completely identical processes. Even within the same company, we found WDCs exhibited major process variations at different implementation sites. Thus, while supplier experience with multiple customers and contexts can improve outcomes, we found suppliers and integrators engaging to reduce process-related ambiguities during pre-implementation stages were most successful.

Intuitively, customer process ambiguity is inherently a supplier issue; however, we found this not to be exclusively true. Customer firms seemed particularly susceptible to overestimating understanding of their own internal processes, while underestimating the potential for process-related uncertainty during integration. Our respondents suggested firms possessing a firm grasp of their own processes before implementation and understanding process-related uncertainty is unavoidable during project execution were best able to confront process uncertainty. John at Invictus Robotics reinforced this sentiment, stating when customers lack basic understanding of internal processes and expect AMRs "just come into current workflows as-is," it creates "obvious challenges."

Overcoming process-related uncertainty is fundamental to successful AMR ETI.

Unconfronted equivocality concerning target processes firms are bidding to automate can undermine entire projects. For instance, DefenseCo selected AMRs as a target technology before identifying a target process. This technology-centric approach resulted in process-related frustration, and ultimately led to more modest applications of AMRs than originally anticipated. Rather than complete integration, DefenseCo settled on simple point-to-point deliveries, thereby simplifying underlying process uncertainty. In this vein, it is critically important to consider ETIs as process-centric, rather than technology-centric, activities.

1.4.1.1.3 User Uncertainty

In contrast to traditional automation where operational performance is highly dependent on machine performance, AMR performance depends on the ability of human operators to collaborate with AMRs in executing collaborative tasks. Thus, for AMR ETIs the importance of identifying and overcoming user uncertainty is of special importance. We found, unaddressed user uncertainty negatively affected the degree users were willing to adopt and further appropriate AMRs into daily work tasks.

Before integration commenced, users expressed uncertainty regarding their roles in newly created collaborative tasks. Initially, users rarely perceived AMRs as tools increasing efficiency and making their jobs easier, but rather as threats to the status quo. We found respondents characterized users as generally resistant to change, especially among tenured operators who often assumed AMRs would make their job more challenging. One supplier, Robert at TugCo Robotics, frustratingly noted experienced pickers “feel they already know everything” and “they know this is not going to work.” Moreover, some users dealt with feelings of threatened workplace identity. We found several instances of users feeling their employment was in jeopardy or their status in the organization may be compromised.

Subsequently, once integration begins users encounter uncertainty related to functional operation of AMRs. Beyond ordinary learning associated with new technology, AMRs require users to understand behavior of robots working autonomously in their work environments. Efforts by joint teams to enhance ease-of-use in the design phase and engage users during training and education opportunities mitigated some of this uncertainty.

In each stage, engagement and inclusion of users during the ETI process mitigated user uncertainty. However, user uncertainty left unaddressed produced adoption resistance and underwhelming use degrading ETI performance. For example, at Direct-to-Customer MedCo role ambiguity and fear of threatened employment manifested a sense of "resentment towards AMRs" resulting in a "morale issue" leading to multiple reports of active sabotage. The applications engineer, Elizabeth, cited users purposefully positioning obstacles in AMRs' paths, covering sensors, and affixing tape on the robots' wheels, impairing orientation and diminishing machine performance. We found this behavior a product of user uncertainty, and an underlying attempt by users to produce *de facto* evidence indicating the ETI was destined to fail and should be abandoned.

1.4.1.1.4 Context Uncertainty

Outside technology, process, and user uncertainty, other sources of uncertainty exist which complicate ETI execution. We categorize any source outside the aforementioned as context uncertainty. For AMR ETIs, we found sources of contextual uncertainty include IT integration complexity, varying facility conditions, and other circumstantial conditions (for example, our interviews were conducted (remotely) in the midst of the COVID-19 pandemic). However, we found the most important contextual factor is whether ETIs are executed at new ("greenfield") or existing ("brownfield") sites.

Most AMR ETI projects we encountered were brownfield, which produced higher levels of uncertainty during execution phases due to their contingent and idiosyncratic nature. WDCs are by nature designed for existing order picking systems to maximize storage, resulting in narrow aisleways and vertical storage, neither which are ideal environments for AMRs. Uneven floors, inconsistent lighting, and cluttered conditions challenge AMR sensors' ability to autonomously orientate and navigate. Moreover, to optimize AMR performance employees accustomed to manual picking operations must overcome "cultural" impediments in maintaining clean WDC floors. According to Elizabeth at DefenseCo, manual picking operations commonly have "pallets in the aisleways, carts all over the place, (and) other obstructions," which impede AMR movement and degrade performance. Michael at Mechanized Automation Distribution Co. aptly summarized brownfield implementations, stating "you cannot imagine all the different environments that (AMRs) have to be working in."

In contrast, greenfield implementations allow for deliberate warehouse design to accommodate AMR solutions. We found respondents generally preferred greenfield projects, as uncertainty can be accounted and planned for during pre-implementation phases. Greenfield projects reduce uncertainty firms grapple with during project execution, however contextual uncertainty is front-loaded. We found project deadlines, rushed designs, establishing IT infrastructure, regulatory issues, and construction setbacks all resulted in additional uncertainty. Appropriate greenfield planning can mitigate uncertainty in execution phases; however, as Anthony stated, it is "impossible to contemplate every detail" and "some things are outside of (the firm's) control."

Contextual uncertainty, related to internal and external environmental conditions, can permeate all stages of an ETI project, regardless of whether a project is brownfield or greenfield.

We found general sentiment towards brownfield projects consistent with a statement from Chris at DefenseCo who frustratingly expressed an ideal project would "redo the warehouse from the ground up to accommodate AMRs…(warehouses) are not set up for AMRs." However, this sentiment is likely simply a product of brownfield implementations comprising the preponderance of ETIs. Greenfield projects present their own unique challenges; the primary difference is uncertainty is front-loaded in pre-implementation planning phases. Regardless, context is an important driver of uncertainty which must be properly understood and planned for if possible.

1.4.1.2 Sources of ETI Uncertainty

While sources vary, we found three sources chiefly responsible for most perceived ETI uncertainty. First, technology complexity results in challenging and uncertain conditions during AMR integration. Despite recent proliferation, AMRs are relatively new technology and not yet widely deployed in WDCs. Due to their novelty, most customers, and even many integrators, lack required technical expertise to effectively integrate AMRs. Richard at Warehouse Solutions Consultants, a warehouse automation integrator, stated, "it is a problem within the industry that integrators are not accustomed to AMRs...very few of us have experience with them." Second, we encountered a range of project complexity, with some projects taking just a few hours to establish basic operation while others required over a year of heavy involvement from robotics and engineering staffs. This complexity depends on both the extent and breadth of integration (i.e. number of robots, extent of process changes, etc.), and is exacerbated by add-on equipment, assimilating robots from multiple manufactures, or complex IS integration. Lastly, idiosyncratic contexts dictate varying task structures, resulting in various levels of task complexity. According to one integrator, job shop tasks "tend to be more difficult and the robot must be very capable in these environments" while WDCs are "more organized and repetitive process-wise." To illustrate this point, Steven (an applications engineer) executed an ETI of the same model AMR at both his current and previous firms. The first integration was seamless and described as "a perfect scenario," consisting of simple, repetitive deliveries of homogenous material "in a wide-open facility, using identical carts." However, the latter integration moved diverse materials at inconsistent times supporting job shop manufacturing and encountered far more challenges during ETI execution.

1.4.1.3 Joint ETI Experience

We found ETI uncertainty firms experience to be an objective product of technology, project, and task complexity. However, we discovered prior experience, brought to bear by all members of joint teams, influences the degree this uncertainty is realized during AMR ETIs. After considering effects of prior experience, we conceptualize the resulting theoretical element as the extent of realized ETI uncertainty, which is analogous to the task's information processing requirement in OIPT.

Our respondents cited several examples of customers and suppliers leveraging previously obtained ETI knowledge to mitigate or avoid uncertainty in current projects. This phenomenon was clearly demonstrated in short order by an AMR startup, TugCo, which collaborated with an integrator on sequential ETI projects for a customer at multiple sites. The integrator, William at Success Integration Consultants, noted after several implementations the customer and supplier "matured," both becoming more "willing to adapt" after struggling with low levels of user acceptance in early projects. Moreover, during latter integrations familiarity with the customer's processes, systems, and culture improved the supplier and integrator's ability to predict and mitigate issues as they arose.

Additionally, while we found ETIs realize benefits from experience all stakeholders bring to bear, since suppliers generally execute more ETIs than customers, their technology and process expertise is especially critical. We found customers engaging with experienced suppliers were better positioned to mitigate or avoid uncertainty during project execution. However, we note in the context of AMRs, neither integrators nor suppliers are ideally positioned to leverage both technical and process experience. Since AMRs are an emerging technology, integrators lacked experience with AMRs relative to conventional automation, especially in regards to technical aspects of AMRs. On the other hand, we found many AMR manufacturers were startups with limited experience executing ETI projects. In their infancy, these firms generally focus on engineering and technical aspects of designing capable robotics, but lack in-depth awareness of varying contexts their robots would operate in. As they obtained more ETI experience, manufacturers became more assertive in assisting customers in adapting processes to accommodate integration. For example, John at Invictus Robotics noted early ETI experiences led to an evolution in thinking, changing their company's perspective from being "a technology company to a service provider." In another instance, Robert at TugCo suggested customer requests would go unquestioned in early integration projects, but after experiencing multiple ETIs they "no longer hesitate to tell customers what will and will not work." This confidence clearly results from a deeper understanding of interaction between process and technological factors, and is acquired through experience.

1.4.2 Organization to Reduce Uncertainty

According to OIPT, firms organize to efficiently process information in response to uncertainty during task execution. Organization can take place by implementing more organic structures, or by developing coordination and control mechanisms facilitating efficient transfer of knowledge between business units. In Stock and Tatikonda's (2008) ETI framework, coordination mechanisms counteracting technology uncertainty are encompassed in the construct of interorganizational interaction. Our framework extends this conceptualization, examining how joint teams engage during each stage of ETI and adapts organizational structures to offset various sources of uncertainty they encounter. Our findings suggest when realized ETI uncertainty is high, engagement must be bi-directional and robust, with all parties actively engaging to meet their respective information processing needs. The next section discusses how respondents experienced customer/supplier engagement during various stages of ETI and adapted their organizations to facilitate information processing and higher levels of ETI performance.

1.4.2.1 Customer/Supplier engagement

1.4.2.1.1 Pre-ETI Engagement

We found customer engagement with suppliers, in successful implementations, began prior to supplier selection, and sometimes even before committing to AMRs as a solution. Assessing suppliers (or integrators) as appropriate partners early in the relationship reduces serious project disruptions. Further, switching suppliers during an ETI is not feasible. DefenseCo, who overlooked the importance of this partnership, experienced frequent delays and downtime when confronted with issues requiring supplier intervention (e.g., software changes). Steven, a lead applications engineer, characterized communication as "extremely poor," compelling DefenseCo to "become as self-reliant as possible." The AMR manufacturer was not interested in being a long-term participant beyond the initial sale because DefenseCo was a small customer relative to their larger accounts. Chris at DefenseCo stated they were "never approached with any offer to assist with processes or training," requiring DefenseCo to independently confront uncertainty during execution for which they were ill-prepared. We found greater willingness of integrators and manufacturers to engage customers in process improvement early the projects led to less uncertainty in later stages. Without the ability to depend on the technical expertise and process experience wielded by suppliers, as William at Success Integration Consultants argued, customers cannot “realize the full potential of automation without an integrator on board, helping them understand how to maximize it.”

Furthermore, early engagement allows all stakeholders to obtain clear expectations of technological capabilities, required process changes, and ETI goals. We found misaligned customer expectations are commonplace. It was typical for customers to be “oversold on capabilities” and purchase AMRs without properly vetting their application. Regarding unmet expectations, Daniel remarked “manufacturer websites make (AMRs) out to be plug and play, and that is just not true.” Michael at Mechanized Automation Distribution Co. reaffirmed this sentiment, asserting “you have to be really careful that you do not oversell capabilities” because this leads to ETI failure which is “not beneficial for anyone.” We found the most successful firms negotiated, collectively agreed on, and codified performance agreements with suppliers prior to implementation. In addition to facilitating defined expectations and performance criteria, these negotiations guaranteed early supplier involvement in customer processes and ensured good fit before moving into execution phases, resulting in fewer failures attributable to what William called a lack of upfront “due diligence” by one or both parties.

1.4.2.1.2 Engagement during ETI Project Planning

Once joint teams are established and performance expectations are understood, ETI planning commences. During initial planning stages, we found successful joint teams make explicit with whom project accountability primarily resides. Joint teams designating the most experienced firm as the single accountable party for the project enhanced communication and coordination. In most instances, this was the supplier or integrator, especially when customer firms lacked organic engineering capability. In one relevant example, Direct-to-Customer MedCo established a joint team consisting of its own engineering staff, an integrator, and a manufacturer, but empowered the integrator with full control of the project. By outsourcing ETI management, the customer allowed the most qualified entity of their team to direct project execution, ensuring engagement and streamlining communication. In contrast, DefenseCo described the difficulty of working through technical issues without defined roles and responsibilities. During their ETI, DefenseCo encountered a system error related to an after-market cart tugged by their AMR fleet. After engaging the AMR manufacturer, distributor, and cart manufacturer, each party refused responsibility for assisting DefenseCo in fixing the error. The solution, a simple software update, became a multi-week work stoppage where engineers from DefenseCo frustratingly brought together the three firms to "sort out who dropped the ball." We found employing a committed team with a single accountable party facilitates effective communication, coordination, and cooperation.

The planning phase is also where successful companies engaged each other in accomplishing initial assessments and requirement determinations. These assessments were critical for suppliers seeking to understand customer processes in detail, but surprisingly we found initial assessments are perhaps even more beneficial for customers. For example, Steven noted an initial lack of understanding of their own processes, expressing "a key lesson learned is (the importance of) requirements definition prior to deployment, as a couple of times we scrambled after the fact because we did not put enough thought upfront into how material actually gets put on the cart." We found supplier engagement invaluable in this process, as they possess ability to leverage ETI experience from many different contexts, and thus are more adept at collecting data, analyzing processes, and providing insight into customer operations. Michael reasoned suppliers' ability to condense enormous amounts of data, "extrapolate it" to solve problems, and communicate results via "very simple executive summaries" is of prime importance when customers lack analytics capability (which is often the case with smaller firms). For example, David with Automation Central Consultants executed a full engineering study analyzing order and SKU data, documenting each touch point, mapping out sub-processes, and codifying acquired knowledge in a shared "description of operations" document. This document was agreed upon, through a series of a dozen meetings, by all parties (including users) ensuring each stakeholder possessed a shared understanding of current and future processes before AMRs arrived at the facility. Overall, we found detailed assessment and requirements determination in planning phases reduces process uncertainty in latter stages of ETIs.

Lastly, we found engagement of end-users as critical stakeholders in early planning phases led to quicker adoption and long-term use of the AMR technology. As process experts, inclusion of users in ETI project planning was described as "massive" by Elizabeth, who added, "with robotics, you have to go against your natural reaction and throw it into someone's hands you typically would not think is the right person to be doing it." Roboticists and engineers possess the technical expertise required for integration; however, end users are task experts and executors that can enable process optimization at the point of operational use. Furthermore, user engagement provided operators a "sense of ownership" that facilitates long-term acceptance and use. Automation investments often "come from the top," resulting in what David described as "some level of resistance and fear." We found effective and proactive engagement with users mitigates uncertainty, producing instead excitement and enthusiasm.

1.4.2.1.3 Engagement during ETI Project Execution

During the execution phase, introducing AMRs into the operating environment creates technical and process-related challenges. Typically, firms began implementation with small-scale pilots, allowing joint teams to confront and address uncertainty without major disruption. In brownfield implementations, these pilots had to overcome time and space challenges as WDCs rarely completely shut down during the ETI; however, these constraints were less problematic in greenfield projects. Regardless, we found close engagement between customers and suppliers critical during pilots to assess deployment efficacy and efficiently address issues overlooked during pre-implementation and planning phases.

At this critical stage, we found having suppliers physically on-site provided opportunities for collaboration and co-development of solutions to emergent issues. Co-location allowed for knowledge exchange through rich media and enabled common understanding of site layouts and constraints. Reinforcing this idea, James from Flash Robotics, who was initially prohibited from traveling to their customer's warehouse due to the pandemic, stated "I understood the issues after seeing the sizes and shapes of the aisles and pack stations; I get it now and their challenges make so much more sense." David echoed the same sentiment after collaborating with their customer's engineering team for over a year and positioning personnel on-site for the installation, testing, and IT integration efforts. Automation Central Consultant's customer, Direct-to-Customer MedCo, noted the on-site integration team allowed their team to collaboratively "alleviate issues and illuminate opportunities for future improvements."

An innovative concept being offered by some robotics companies providing the highest levels of engagement and integration is robots-as-a-service (RaaS). Similar to "software-as-a-service," RaaS models offer subscriptions where customers pay monthly service fees for a pre-defined level of support. Customers pay for throughput, enabling easy scalability during peak demand seasons by adding or removing robots. The supplier is responsible for integrating AMRs into the customers' operation, and subsequently remotely operates and maintains the robots for the life of the service. Benefits of RaaS include avoiding obsolescence and depreciation, continuous monitoring and support, and eliminating the requirement to develop an organic robotics capability. From an ETI perspective, RaaS allows manufacturers to be "virtually" on-site continuously, resulting in extremely high levels of engagement throughout execution phases and beyond. We found engagement in RaaS models highly reactive, and even proactive a times as suppliers are often cognizant of and engaged in fixing issues before customers are even aware they exist.

Finally, similar to planning phases, successful integrations embraced users as focal members of joint teams throughout the execution phase. Eliminating user uncertainty in this phase typically begins with structured training and on-boarding programs. Susan at Et Cetera Solutions Co. stressed this as "essential," adding "it really helps having people in the warehouse possessing a thorough and technical understanding of how these machines work." Most suppliers employed "train the trainer" approaches, emphasizing understanding of robot behavior and interaction thorough demonstration. According to John, user engagement early in the execution phase helps users develop confidence and "a level of comfort and trust around the behavior of the unit itself." This trust proved essential to increasing user buy-in, appropriation, use, and ultimately ETI project performance.

1.4.2.1.4 Post-ETI Engagement

We found firms realized the most successful improvements when engagement with suppliers continued post-implementation and for an extended period of time for several reasons.

First, long-term commitment to projects reflects the significant investment firms make in AMR technology. Short-term or book-ended ETIs with static completion dates hindered organizations' ability to make required structural and cultural changes necessary to maximize returns-on-investments. For example, Steven frustratedly noted their engineering team desired to "rethink the warehouse design" but was impeded from making long-term physical changes to their warehouse since ETI was considered a short-term, one-off project. Failing to commit to ETIs as long-term projects limits opportunities for long-term structural improvements.

Second, potential process improvements are not immediately apparent until after AMRs are fully operational. For instance, Robert, who routinely conducts post-implementation site-visits a few weeks after implementation, noted his customers "discover a whole bunch of things, things they like and do not like, and we address those things and assist through additional training." One example of successful post-implementation engagement involved Direct-to-Customer MedCo altering item locations due to process changes occurring after employing collaborative AMR picking. Historically, their warehouse placed high velocity products near packing and staging areas to minimize distance traveled. However, since AMRs "eliminated walk time as a factor," the company relocated high velocity items to bulk locations in the rear of the warehouse, opening up enough space to move a wide variety of SKUs near the packing area, increasing batch-picking efficiency. Anthony attributed these process innovations to post-implementation collaboration with their integrator, adding it "completely changed (our) thought process."

Third, successful partnerships employed enduring communication mechanisms that maintained "constant levels of communication" post-implementation. Respondents provided examples ranging from basic remote customer support to more formal supplier "customer success roles" tasked with ensuring customers are informed of important technology or industry changes. RaaS models provide a particularly effective mechanism, as it implies full operation of customer systems, thereby giving suppliers "skin-in-the-game" and incentivizing long-term success. One RaaS supplier, Patricia from Swarm Robotics, opined, "one reason why robotics was not adopted very quickly in the past is because companies would buy these cool robots without understanding how to maximize their use. RaaS allows (the supplier) to be there and, from a development perspective, see every day what is going on, to include the problems we need to fix." RaaS is analogous to having uninterrupted, real-time post-implementation supplier engagement, allowing joint teams to confront contingencies and continuously improve processes.

1.4.2.2 Organizational Adaptability

OIPT maintains firms organize along a mechanistic-organic continuum. Since AMR ETIs are inherently uncertain and equivocal tasks, organic structures designed able to process large amounts of information during ETI execution are best suited to achieve fit. As previously discussed, warehouses are inherently mechanistic, but we found the ability of joint teams to organize and adapt organic capability fit to address ETI uncertainty distinguished successful projects. Developing cross-functional project teams spanning firm boundaries provides customers organic capability to mitigate uncertain and ambiguous situations.

When mechanistic organizations are unable to adapt, ETI execution can be inefficient. This was illustrated by an anecdote provided by James, who recalled his experience working with the automotive industry. Although the industry is considered "pioneers" in field of manufacturing robotics, a sharp divide between engineering and operations emerged as an obstacle to integration. Hierarchical and stove-piped organizational structures resulted in industrial engineers transferring technology to users who "were immediately threatened and willing to do anything in their power to obstruct the robots." These stovepipes limited communication between firm subunits and inhibited engineering's ability to "bring workers into the project to provide input and deliver better solutions." In another example, Steven described confronting implementation issues without certainty of who had authority to approve required changes. He attributed project delays to having to locate and identify responsible individuals, and subsequently "pulling rank" or "reaching out to individuals with more pull" to make changes. The engineer added that "something that I've been attempting to accomplish for two or three months is then suddenly done overnight."

We found when firms were mechanistic, adapting an organic capability by developing cross-functional project or innovation teams enhanced internal coordination and exchange of rich media. In addition, it enhances cross-firm communication with joint team members. According to Michael, "sophisticated customers" with organic, cross-functional capabilities better understood technology, project, and task complexities, and were far more equipped to "communicate their issues" to suppliers. Effective communication improves firm-spanning engagement and facilitates development of joint teams capable of mitigating uncertainty throughout the ETI. Yet, we found adapting an organic capability is challenging for small- and medium-sized firms, which generally lack large engineering staffs and experience with on-boarding automation. In these cases, outsourcing of project execution to qualified suppliers with this capability is critical to achieve AMR ETI success.

1.4.3 Fit Between realized Uncertainty and Organization to Reduce Uncertainty

The concept of fit remains at the heart of our ETI framework, but the model implies a complex relationship between realized ETI uncertainty and efforts to jointly organize and engage. As discussed, AMR ETIs manifest several sources of uncertainty customers, suppliers, and users must overcome. Greater levels uncertainty imposes higher information processing requirements during task execution, requiring teams to adapt and engage to be successful.

The “fit” relationship conveys equal importance to uncertainty and organization. Not all AMR ETIs are equally complex, thus information processing requirements vary. Complexity of the AMR deployment (task) often dictates the effort, engagement, and time required. We found suppliers should be flexible to support simple deployments or intensify engagement during complex integrations or when customers lack capability. From the joint team perspective, successful integration depends on understanding and tailoring intensity of effort to customers’ use cases (thereby achieving “fit”).

1.4.3.1 ETI Performance

The primary aim of ETI is successful integration of technology which increases efficiency and effectiveness of warehousing processes. By the end of the ETI project, AMRs must function as expected and impart anticipated benefits. Furthermore, firms expect to achieve this functionality within planned time and cost constraints (Tatikonda and Stock, 2003). We found firms prioritizing engagement, especially when integrations were complex, tended to perform better in terms of self-reported achievement of time, cost, and functionality performance metrics.

For instance, DefenseCo implemented AMRs at multiple sites, but only engaged their primary supplier on an ad hoc basis. Despite being their “first stab at automating material handling and warehouse operations,” everything was “done in-house,” as the engineering team expressed conviction on wanting to experience “all the hardships and struggles to become system subject matter experts.” However, deficient engagement of their manufacturer, and even their own operations team, produced several setbacks during execution. Shortly after implementation, AMRs experienced “inexplicable errors,” and as Steven noted “we really needed the manufacturer’s help and were not getting the support we needed.” Perceptions of project success were mixed at best, with one engineer, Elizabeth, stating, “while some managers love the technology, others think it could be better. There is hesitation to accept this as the path forward. Is this the future, or is there something better for our application?” Daniel, an engineer at a different site, expressed “management is still excited about AMRs, but it probably did not meet expectations concerning the time to get it up and running.” DefenseCo experienced several months of delays after grappling with software issues and struggling to operationalize their AMRs. However, Daniel added, “they are pleased with the AMRs’ capability when it is up and running.” While technical performance was perceived as adequate, in this case we found high implementation costs and delays directly attributable to insufficient engagement. As Elizabeth conceded, due to their lack of experience with AMRs, “it would have been better to work with an automation integrator,” adding “we would have seen different outcomes.”

In contrast, Direct-to-Customer MedCo closely coordinated with both their integrator and supplier throughout the ETI project, which proved very successful. An example of engagement provided by their integrator, Automation Central Consultants, who explained “through the entire process we have onsite resources” working directly with order pickers to incorporate “tribal knowledge” in developing software-driven process improvements. Moreover, Automation Central Consultants was actively engaged and exchanging knowledge with the manufacturer, Flash Robotics, to tailor software changes and technical adjustments to Direct-to-Customer MedCo ‘s warehouse processes. According to Direct-to-Customer MedCo ‘s CEO, “over time it became a very, very efficient process. We cut down our labor needs and touch points, and improved accuracy. We improved efficiency. We improved safety.”

In summary, we found when uncertainty is high and customers fail to engage members of the joint team or adapt an organic capability, ETI performance suffers. Conversely, thorough engagement between members of joint teams committed to achieving shared time, cost, and functionality goals enables superior performance. We depict the phenomenon of fit in Figure 1.5, depicting how warehousing firms executing AMR ETIs (characterized by a high level of uncertainty) must increase information processing capacity (through engagement and adaptability) to achieve fit, leading to successful project execution.

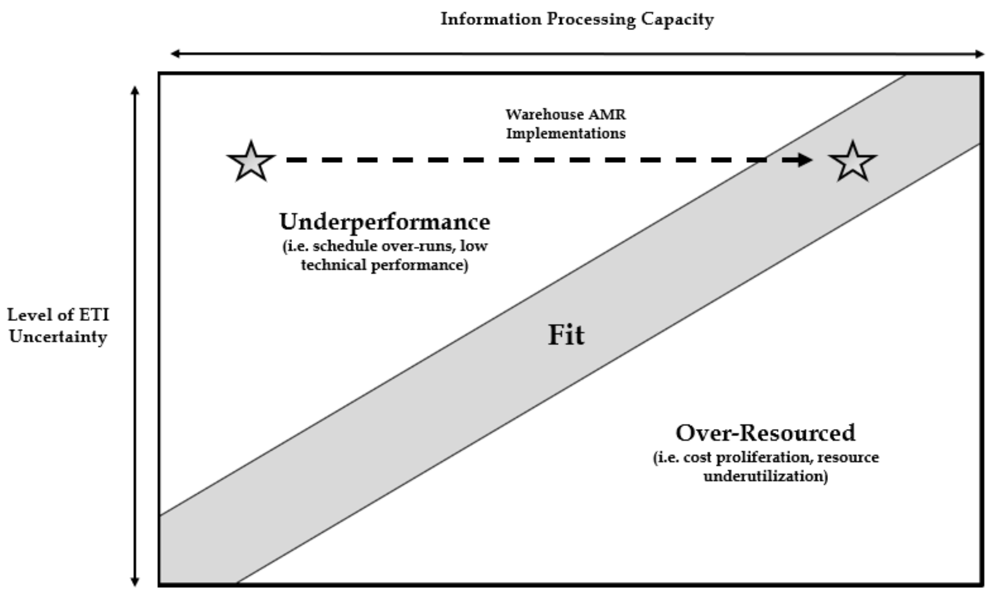

Figure 1.5: Fit between ETI uncertainty and information processing capacity after engagement and adaptation

1.5 Discussion

Market realities are forcing firms to consider ways of creating leaner, more efficient supply chains. In response to increasing warehousing volume and product turnover, firms are seeking automation solutions to replace manual processes. Yet, some firms are reluctant to automate over concerns related to capital expenditure and loss of system flexibility to deal with seasonal variation (Davarzani & Norrman, 2015; Marchet et al., 2015). Autonomous collaborative technologies such as AMRs are well-suited to address these concerns; however, integration of AMRs presents unique and under-studied challenges. Our study shows while traditional ETI frameworks explain how companies should pursue fit between technology uncertainty and interorganizational interaction, they are not comprehensive enough to explain complexities involved in AMR ETIs. Our expanded model reframes ETI from a dyadic perspective, explaining how technology, processes, and context create uncertainty which must be confronted and mitigated by all parties for projects to be successful. Dealing with uncertainty during project execution requires bi-directional engagement in addition to adapting organizational structures able to effectively exchange and process information.

Our study and resultant propositional framework (see Figure 1.6) are meant to not only describe in abstract terms how joint teams achieve ETI project performance, but also provide meaningful and testable propositions for researchers seeking better understanding of how AMRs (and other types of collaborative technology) are best integrated into WDC operations. The following discussion offers research propositions investigators can use as a foundation for future empirical examinations of this phenomenon.

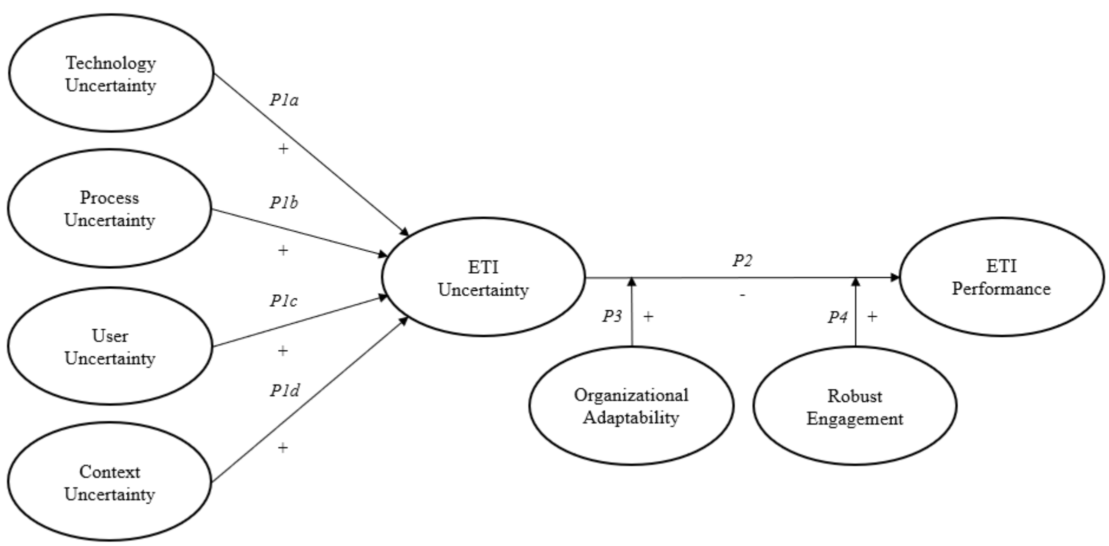

Figure 1.6: Propositional framework

1.5.1 The Nature of ETI Uncertainty

1.5.1.1 Dimensions of ETI Uncertainty

The ETI framework by Stock and Tatikonda's (2008) proposes the primary source of an ETI's information processing requirement is the novelty, complexity, and tacitness of the technology being integrated. However, we found this an oversimplification of the complexity experienced during AMR ETIs. While technology uncertainty contributes to an ETI's information processing requirement, this only addresses a single aspect of a multi-faceted challenge for technology integrators.

As previously discussed, we discovered evidence of technology uncertainty, process uncertainty, user uncertainty, and context uncertainty in AMR ETIs. Customers and suppliers must cope with process uncertainty related to tasks which AMRs are meant to automate. This aligns with our finding that companies enhance ETI project performance when employing a process-centric, rather technology-centric, focus. Furthermore, AMRs, as collaborative technology requiring active and persistent operator interaction, levy user uncertainty on workforces coping with learning new processes and behaviors of robotics operating autonomously in their workspaces. In addition, evidence suggests contextual factors (i.e. complexity of IT integration, facility conditions, COVID-19 pandemic) can introduce uncertainty affecting stakeholders during all phases of an ETI project. We suggest without thorough understanding of these main sources of uncertainty and underlying complexity, joint teams will struggle to achieve ETI performance, regardless of their ability to organize and engage.

Proposition P1a: In AMR ETIs, technology uncertainty is positively related to ETI uncertainty.

Proposition P1b: In AMR ETIs, process uncertainty is positively related to ETI uncertainty.

Proposition P1c: In AMR ETIs, user uncertainty is positively related to ETI uncertainty.

Proposition P1d: In AMR ETIs, context uncertainty is positively related to ETI uncertainty.

1.5.1.2 Joint ETI Experience

Until knowledge and experience of stakeholders are considered, ETI uncertainty can be considered an objective product of technology, project, and task complexity. However, organizations typically possess some technology integration experience which influences the degree uncertainty is realized in current ETI projects. We found organizations, as learning entities, leverage knowledge acquired from earlier ETI efforts. Moreover, our conceptualization of ETI as joint tasks underscores the importance of customer firms leveraging supplier experience. Unlike customer firms which experience infrequent and intermittent ETIs, most suppliers are continuously supporting ETIs in a variety of operational contexts. Since our research proposes information processing is a function of joint teams' ability to organize and exchange information, supplier experience is a critical component of joint teams' information processing capacity. While this study does not include ETI experience in an explicit proposition, we suggest experience transforms how firms perceive uncertainty and organization and it should be considered an important control variable affecting several of the constructs in this framework.

1.5.1.3 ETI Uncertainty and Performance

The negative relationship between uncertainty experienced during the ETI task and ETI performance is fundamental to our framework. Technology, process, user, and context uncertainty inevitably create conditions resulting in the requirement for all stakeholders to obtain and process large amounts of quality information during project execution. Stock and Tatikonda (2008) determined three dimensions of ETI performance: (1) time required to complete the project, (2) financial costs associated with the project, and (3) functional operation/technical performance of the target technology. If firms lack capability to exchange and process information effectively in situations that demand it, detrimental effects to performance are unavoidable. For instance, we found schedule delays attributable to the inability to locate persons responsible for making changes and non-responsive suppliers. Some firms realized financial costs related to additional slack resources to obtain required performance (i.e. the application of engineering man hours dealing with delays and malfunctions attributable to “simple” fixes when suppliers were able to deliver solutions). Functionally, we found user uncertainty in coping with AMR complexity and behavior undermined the degree the technology achieved its anticipated performance. This is consistent with conclusions drawn by Srinivasan and Swink (Srinivasan & Swink, 2018), finding technological features and changes to operational procedures can overwhelm participants, leading to less-than-full exploitation of technology. When ETI uncertainty is high (and information processing capacity is inadequate), ETIs will likely take longer, cost more, and not meet prescribed performance standards.

Proposition P2: In AMR ETIs, ETI uncertainty is negatively related to ETI performance.

1.5.2 The Nature of Organization to Reduce Uncertainty

1.5.2.1 Organizational Adaptability

Our study provides insight on the importance of organizations’ ability to adapt an organic capability during AMR ETIs. According to Tushman and Nadler (1978), effective organizations adapt their structures over time to cope with changing information processing requirements. More organic, or flexible, structures are better-suited during early stages of a project, while mechanistic structures become important during latter stages of implementation (M. L. Tushman & Nadler, 1978). Thus, from an OIPT perspective, it is clear why many technology adoption efforts fail. Warehouses, as mechanistically organized subunits, operate in routine, stable, and predictable environments. Under typical operating conditions, WDCs execute independent and pre-planned tasks, and therefore do not require flexible, organic structures. However, when confronted with ETI uncertainty during a task which formal rules and standard operating procedures do not apply, mechanistic WDCs are unable to cope. Thus, WDCs must adapt organic capabilities to be successful, if only for the temporal task of adoption. We argue successful organizations adapt internal structures via cross-functional and inter-firm teaming to ensure relevant task-oriented information flows freely between interdependent subunits. Further, we found joint teams establishing project or innovation teams across firm boundaries and incorporating multiple levels (i.e. management, industrial engineers, and users) best enabled this concept. We found project teams facilitate constructive engagement, as they are better to understand and communicate challenges and opportunities to other stakeholders. In line with Tushman and Nadler (1978), we suggest firms establish more-permanent and less-costly mechanistic organizational structures only after uncertainty is dealt with early in ETIs.

Proposition P3: In AMR ETIs, organizational adaptability positively moderates the negative relationship between ETI uncertainty and ETI performance.

1.5.2.2 Robust Engagement

As our framework suggests, coordination and control mechanisms spanning firm boundaries facilitate bi-directional flow of information. We found firms interacting on ad hoc bases when uncertain situations arose were less capable at overcoming ETI obstacles. Instead, we suggest robust communication, coordination, and cooperation occurring throughout the ETI, to include pre- and post-implementation phases, allows joint teams to moderate deleterious effects of ETI uncertainty on performance. Engagement should be particularly intense during initial stages of execution, when customers first encounter AMR technology and suppliers first encounter process idiosyncrasy. Moreover, many technology and process uncertainties are discernable only after AMRs are fully integrated and operating. Thus, we suggest mechanisms facilitating long-term engagement between stakeholders, or at least until benefits cease to outweigh costs.

We found three factors particularly important when understanding the effects of stakeholder engagement to performance. First, knowledge exchange through rich forms of media are most effective as ETI is a highly equivocal activity. Bridging differences between distinct, but interdependent, subunits are an issue of equivocality reduction. Often, subunits do not share similar perspectives or coding schema, making communication complex and ambiguous (R. L. Daft & Lengel, 1986). Without exchange of adequately rich information, highly differentiated subunits (i.e. WDCs and robotics developers) find it difficult to understand each other's point of view, leading to misinterpretation and misunderstanding (Cooper & Wolfe, 2005). Values and fundamental beliefs often vary between interdependent subunits. This especially holds true across organizations, as each is composed of individuals with different backgrounds, responsibilities, and interests. Acquiring information can reduce uncertainty, but only rich media allows participants to share subjective experience and intuition to develop shared conceptions and reduce equivocality (R. L. Daft & Lengel, 1986). For technology adopters, equivocality reduction is more important than uncertainty reduction, since the amount of information matters less than team members adopting a shared frame of reference. Therefore, we suggest AMR customers implement coordination and control mechanisms facilitating exchange of rich media with all essential stakeholders.

Second, considering ETIs long-term tasks enhances engagement throughout all phases of the project. ETIs, as described by Stock and Tatikonda (2008), are episodic tasks with defined beginnings and ends; however, we found these boundaries often blurred. The genesis of an ETI is consideration of technologies customer firms intend to integrate to increase operational effectiveness. Processes must be well-defined and well-understood before determining a specific technology's fit for the application. Once AMR and vendor selection is complete, engagement during planning and pre-implementation phases should address potential uncertainty to the greatest extent possible. Yet, while detailed planning benefits the ETI, information processing requirements still exist throughout the entirety of the implementation process and beyond. AMR integration fundamentally changes how tasks are performed, therefore challenges and opportunities may not be obvious until AMRs are fully assimilated into day-to-day operations. We found most successful companies continue to engage to improve operational processes post-implementation. Considering ETI from a process-centric rather than a technology-centric perspective means firms should prepare to make significant, lasting changes and view ETIs as long-term projects rather than episodic tasks.

Lastly, considering AMRs require active, collaborative, and continuous interaction, effective engagement requires stakeholders to predominantly feature users during all phases of ETI. While Stock and Tatikonda (2008) acknowledge user participation as an important contextual factor in ETIs, in the context of AMRs we found it fundamental. Many parts-to-picker warehouse automation systems exploit the strengths of humans and machines discretely, relying on conveyors, cranes, or other smart technology to bring products to human counterparts who are subsequently responsible for sorting, packing, and quality control. Some examples include shelf-moving robots (i.e. Kiva systems, see (Wurman et al., 2008) and Boysen et al., 2017), AS/RS, put-to-light sorting systems, and advanced picking workstations (Boysen et al., 2019). These automation systems operate in isolation from human counterparts (Charalambous et al., 2017), with a single point of interface between machine and human. Thus, most traditional ETIs experience uncertainty at the firm level, but uncertainty is not as salient for individuals. For example, in AS/RS implementations firms must process information related to warehouse modification, IT/data integration, and process redesign; however, user interaction with the technology is limited and consistent, allowing operators to quickly understand newly delineated tasks. With AMRs, the opposite is true. AMRs can operate within existing facilities without making significant infrastructure changes and simply supplement existing processes, reducing firm-level uncertainty during integration. However, the relationship between AMR and user is highly interactive and collaborative (Azadeh & Koster, 2019), requiring higher levels of information processing for users tasked with understanding AMR behavior and cooperation with machines in modified, collaborative tasks. User uncertainty differentiates AMRs from most traditional automation (see Figure 1.7), and requires a different management approach.

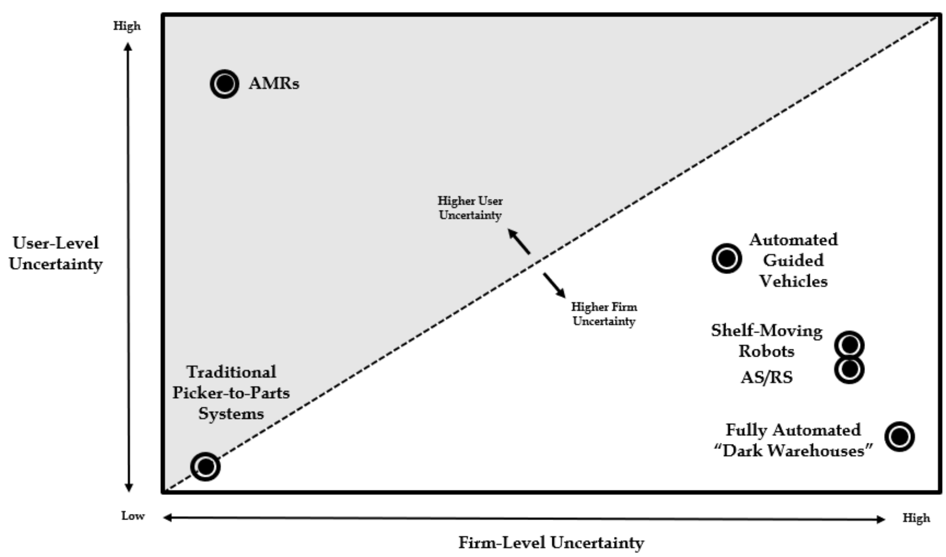

Figure 1.7: Warehouse automation on a dual-spectrum of user-level and firm-level technology uncertainty

This research suggests when integrating collaborative technologies, user engagement is critical for two reasons. First, it allows users to engage subject matter experts, understand AMR capabilities and limitations, and, most importantly, participate in enhanced hands-on training and demonstration prior to implementation. Consistent user engagement produces greater buy-in and self-efficacy, leading to improved acceptance and use (Venkatesh & Bala, 2008). Secondly, user engagement with suppliers allows suppliers deeper understanding of customer use cases and sub-processes. Operators are experts in procedural and process-related aspects of tasks, and thus are well-positioned to provide insight on potential challenges and opportunities during implementation. Beyond the capability of engineering assessments or management engagement, user engagement provides insight into task minutiae, which can prove critical in enhancing supplier understanding of customer operations.

Proposition P4: In AMR ETIs, robust engagement of stakeholders positively moderates the negative relationship between ETI uncertainty and ETI performance.

1.6 Conclusions

As our study indicates, integrating collaborative technology into existing processes is complex. To be successful, firms must engage all stakeholders and organize in a fashion facilitating efficient exchange of information. Likewise, suppliers must engage to understand customer use cases and mitigate process uncertainties. We propose a framework extending prior conceptualizations of ETI which grounds new theoretical elements and addresses unaccounted complexities in the context AMRs. Our findings suggest successful AMR ETIs require joint teams to achieve “fit” between realized uncertainty and organization, and offer real-world examples of firms achieving this fit. These findings lend a new perspective on ETI, offering several novel contributions to both research and practice.

1.6.1 Contributions to Research

As firms pursue improvements in warehouse utilization, picking accuracy, and delivery response times through technology (Marchet et al., 2015), theoretical knowledge of ETI assumes increased importance. Our findings contribute to this understanding in the context of AMRs in the following three ways. First, through the theoretical lens of OIPT, we explain ETIs are best characterized as joint tasks with inherent uncertainties requiring bi-directional engagement during task execution. To maximize opportunities for success, both customers and suppliers must engage to overcome their own uncertainties regarding process the project. Furthermore, our findings suggest considering ETIs episodic tasks can be an impediment to long-term success. Rather, viewing ETIs as long-term projects facilitates meaningful internal changes and lasting cooperation between customers and suppliers.

Second, our study reveals the multi-dimensionality of uncertainty in AMR ETI projects. ETIs are about more than technology; they are about processes, users, and context as well. From an AMR perspective, the centrality of users is especially important. Low technology acceptance and use is a key reason for the oft disconnected relationship between technology investment and firm performance (Devaraj & Kohli, 2003; Venkatesh & Bala, 2008). By mitigating user uncertainty through deliberate communication, training, and inclusion in the ETI process, organizations enhance user ownership and buy-in, resulting in better ETI performance. Additionally, our study reveals levels of objective uncertainty differ from what is actually experienced by joint teams. Our findings suggest information processing requirements realized by joint teams are moderated by ETI experience they possess. This further emphasizes of supplier involvement in ETIs, as suppliers generally execute far greater numbers of ETIs than typical customers.

Lastly, we demonstrate the importance of organizational adaptation and how mechanisms ensuring bi-directional engagement effectively hedge against uncertainty. Organizations are not static, and due to the mechanistic nature of WDCs, it is vitally important to adapt organic capabilities to facilitate problem-solving during ETI execution. Furthermore, since AMR ETIs contain many ambiguous subtasks, coordination and control mechanisms should facilitate exchange of sufficiently rich information to reduce equivocality. Finally, we found assigning responsibility and accountability to a single party to be a critical part of organization. Clearly delineating roles and responsibilities eases communication, enhancing coordination and cooperation.

1.6.2 Contributions to Practice

The depth and richness of our qualitative data provide valuable insights for practitioners seeking to adopt warehousing AMRs. First, explication of various types and examples of uncertainty in AMR ETIs should prove useful for understanding specific challenges joint teams may encounter during project execution. By understanding potential impediments to ETI performance, firms can better prepare contingencies and countermeasures in early planning phases. An important insight for practitioners is the primacy of process in ETIs. Our study reveals process uncertainty must be confronted by joint teams, and provides examples of how this is accomplished (i.e. engineering studies, pilots, codification of processes documents, etc.). We suggest ETIs are best viewed as process-centric, rather than technology-centric, tasks.

Second, our study emphasizes the importance of establishing relationships with willing teams of suppliers and integrators. Suppliers enjoy unique insight into the technical functionality of robots, while integrators provide process and ETI expertise. Ideally, joint teams should contain both knowledge bases, combined with customers willing to provide insight into operational and cultural idiosyncrasies. We advise practitioners co-opt as many perspectives as practical into joint teams, and ensure information can be efficiently exchanged between all stakeholders. Our study demonstrates a necessary duality to engagement; information should not only travel down to customers, but also up to suppliers, increasing overall understanding of customer processes and use cases.

1.6.3 Limitations and Future Research

As is typical with exploratory research, we acknowledge limitations of our results. First, we developed a substantive theory applicable only within the context of AMR ETIs. In this sense, generalizability is limited, even among other types of so-called collaborative technologies. Furthermore, our exploratory qualitative study's inferences are based on a limited sample. We acknowledge without further empirical testing of our framework and propositions, external validity of our findings is limited. Additionally, composition of our sample, despite inclusion of multiple perspectives, could be improved. As a relatively emerging technology, we found it challenging finding customer firms with AMR ETI experience. Despite inclusion of AMR manufacturers and integrators with experience executing multiple ETI projects, customer representation in our sample was limited. Furthermore, inclusion of only U.S. firms in the sample limits our study's external validity in other cultural settings.

As is the purpose of exploratory research, our study illuminates promising lines of future inquiry. Examining additional ETI contexts using our research framework can establish the boundary conditions of our model. For example, future studies can provide greater fidelity on influences of different types of technology (i.e. collaborative or non-collaborative), industrial contexts (i.e. manufacturing or distribution), and types of project (greenfield or brownfield) on ETI uncertainty and performance. Furthermore, we found flexibility, ease of employment, and relatively low startup costs of AMR technology particularly well-suited to the needs of small- and medium-sized enterprises. Additional research could define strategies these sometimes-under-resourced firms use to effectively organize during ETI. Finally, we found highly interactive relationships between users and AMRs distinguish AMR ETIs from other, less collaborative types of automation. Current research investigating warehouse automation is broadly focused on technical and design factors, resulting in a lack of understanding regarding users' roles, and especially the human-machine dyad (Azadeh & Koster, 2019; Mahroof, 2019). Exploring emotional and behavioral changes users experience during an ETI may provide additional insight into how management can mitigate resistance and encourage user adoption.

In conclusion, as a fundamental function of logistics, warehousing must evolve for firms competing in the hyper-competitive retail landscape. Technology is a critical piece of this evolution. However, while future automation may someday eliminate the need for human involvement, independent robot order picking is currently neither efficient nor cost-effective enough in most applications to completely replace human pickers (Azadeh & Koster, 2019). Collaborative technologies enhancing human capabilities offer firms solutions that overcome many of the traditional barriers to automation adoption. Nevertheless, integrating this type of technology comes with unique challenges. Our extended ETI framework based on AMR integration highlights these varied and complex challenges, as well as strategies firms adopt to overcome them. By attaining good fit between organization and uncertainty, firms can achieve excellent ETI performance and reap the rewards of increased operational efficiency and effectiveness.

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ESSAY 2

INTEGRATION OF AUTONOMOUS MOBILE ROBOTS IN INTRALOGISTICS APPLICATIONS: A GROUNDED THEORY APPROACH

2.1 Introduction

Retail supply chains are facing unprecedented challenges in an era of extraordinary growth in e-commerce and omni-channel distribution (Batt & Gallino, 2019; Melacini et al., 2018). Warehouses and distribution centers (WDCs), which provide an essential function as the transitional storage point between two consecutive stages in supply chains, are grappling with increasingly dynamic customer requirements driving higher-velocity operations (McCrea, 2019) during an acute labor shortage (Evans, 2021). To meet this challenge, firms incorporate technology to achieve required speed and efficiency to compete in retail business-to-consumer segments characterized by smaller orders, higher seasonality, and narrower delivery schedules (Boysen et al., 2019). However, while intense supply chain competition continues driving ever-increasing levels of automation sophistication, lower throughput means many small- and medium-sized WDCs cannot justify the considerable capital expenditure required to automate. Thus, most WDCs still employ labor intensive and inefficient picker-to-parts order-picking processes (de Koster et al., 2007; Grosse et al., 2017).

Autonomous mobile robots (AMRs) are a new type of AI-driven, highly-collaborative technology leveraging de-centralized computing and advanced sensors to dynamically optimize routing and assigned tasks (Trebilcock, 2020). AMRs' novel capabilities allow autonomous and seamless operation alongside warehouse operators, sharing control and responsibility for task execution with their human counterparts. In this sense, AMRs function as collaborative robots (or "cobots"), executing hybrid tasks where input from human and machine is necessary.

Employing AMRs in the task of order-picking allows WDCs to exploit strengths of human workers (i.e. creativity, flexibility, problem solving) and machines (i.e. physical strength, endurance, computational power) at a fraction of the cost of traditional automation, making them viable alternatives to fully automated systems.

Yet, attributes making AMRs unique and advantageous are precisely the same catalysts of uncertainty during AMR integration. Traditionally, warehouse automation operates independently in segregated environments, ensuring safety and efficiency by distilling interaction with humans to a single time and place. In contrast, collaborative AMRs work in shared environments where physical interaction is not only intense, but necessary to function as designed. Where performance of traditional automation depends on functional operation of the machine and its fit to the applied task, performance of collaborative technology is contingent on operators' ability to effectively collaborate with machines in executing tasks. AMRs' autonomous and interactive qualities make them akin to integrating a new form of worker, requiring employees to learn to effectively team with AMRs. This fundamentally differentiates AMRs from technologies meant to simply automate a task, and requires a special emphasis on human factors during integration.

Exploring differences in AMR integration into WDC operations and their implications brings us to our two central research questions: (i) *How do AMRs differ from traditional warehouse automation; and (ii) what are the implications of these differences for integrating firms?* This context is novel and relatively unexplored from an academic perspective, as most research examining forward-looking WDC concepts primarily focus on fully-autonomous solutions rather than mixed environments where humans and autonomous systems collaborate (Klumpp et al., 2019). Although technology adoption and integration have rich theoretical traditions to draw upon, little theoretical knowledge exists in this new, unique domain. Thus, we address this gap using a grounded theory (GT) approach to holistically examine WDC AMR integration and use, emphasizing "empirical observation as the driving force" of discovery (Ketokivi & Choi, 2014, p. 234). In areas where little theoretical knowledge exists, GT is an effective inductive method to build mid-range theory grounded in data (Glaser & Strauss, 1967; Suddaby, 2006). It is particularly well-suited to understanding AMR integration, as GT lends itself to both the complexity involved in interactions between firms (suppliers and customers) and between firms and individuals (integrating firms and users) (Mello & Flint, 2009).

Our study's inductive approach reveals an AMR integration process contingent on the effective exchange of knowledge between key stakeholders. Previous research investigating technology integration emphasizes how aspects of technology affect uncertain conditions during the process of integration which integrating firms must overcome (Stock and Tatikonda, 2008). Our findings suggest to maximize AMR integration performance, customers, suppliers, and users must be willing to iteratively exchange knowledge to execute their particular roles during integration by eliminating uncertainty related to technology and process. The study's findings offer important scholarly and practical insights into the phenomenon of AMR adoption, implementation, and use, providing utility to both academics and managers alike.

2.2 Theoretical Scope

Development of our substantive theory occurs within the context of novel, collaborative technology integration within WDCs. Specifically, we examine the process of integrating pick-support AMRs into WDC operations previously employing manual picking procedures. Of all activities involved in warehousing, order-picking, or the process of retrieving products from storage to meet a customer demand, is the most expensive and labor-intensive (de Koster et al., 2007; Drury, 1988). Despite the pace of technological change, most warehouses still rely on manual, picker-to-part strategies where employees walk or drive to various parts of warehouses, retrieve items, and deliver them to central processing locations (Grosse et al., 2017). However, as traditional order-picking requires significant human capital investment, order-picking processes have long been targeted by automation efforts to minimize inefficiency and reduce human-error (Azadeh & Koster, 2019).

Selection of optimal order-picking systems is complex, being contingent on numerous factors including target products (i.e. number of SKUs, size of product, value) and customer order profiles (i.e. order volume, batch sizes, number of lines) (Marchet et al., 2015). Conventionally, WDC automation employs parts-to-picker strategies, essentially exploiting strengths of humans and machines discretely. These advanced systems rely on conveyors, cranes, or some other machine working with WDCs' warehouse management systems (WMS) to deliver products to human counterparts, who then sort, package, and conduct quality control. Examples include shelf-moving robots (i.e. Kiva systems, see (Wurman et al., 2008) and Boysen et al., 2017), automated storage/retrieval systems (AS/RS), put-to-light systems, and advanced picking workstations (Boysen et al., 2019). These systems operate in isolation (Charalambous et al., 2017), with a single point of interface between machine and human. Yet, despite potential benefits including reduced operational costs, optimized warehouse space, increased accuracy, and shortened delivery response times, barriers related to capital expenditure and loss of long-term flexibility prevent many small- and medium-sized firms from pursuing these solutions (Hackman et al., 2001; Marchet et al., 2015).

For firms utilizing manual order-picking systems with low to medium order volume and SKUs, AMRs provide many benefits of higher automation with minimal risk (Marchet et al., 2015). Relatively speaking, AMRs are more affordable, flexible, and scalable than traditional automation, and thus well-suited to overcome the aforementioned barriers to entry. Where other types of automation can require significant infrastructure change and are rigid once installed, AMRs are designed work with and around existing infrastructure. Furthermore, their scalability provides advantages in dealing with seasonal variability and market changes. For example, where highly automated systems (e.g. AS/RS) have unused capacity during low volume periods, WDCs employing AMRs can simply add or park robots based on demand. Some AMR manufactures even offer leasing options and "robots-as-a-service" (RaaS) business models, further lowering entry barriers for smaller firms seeking to enter the automation market.

AMRs provide opportunities for untapped segments of the WDC market to benefit from automation; however, integrating firms must understand fundamental distinctions between AMRs and traditional automation in terms of autonomy and interaction. Typically, automation is employed in segregated environments (Klumpp & Zijm, 2019), resulting in a task hand-off of sorts between machine and operator. In contrast, pick-support AMRs interact robustly and continuously, requiring human operators to "collaborate with robots and execute hybrid tasks." (Askarpour et al., 2019). These "hybrid tasks" involve shared control between humans and AMRs, leveraging complimentary skills to collaborate in mixed environments (Klumpp et al., 2019). Machines excel at repetitively and precisely performing tasks requiring physical strength and efficiency without the performance deteriorating effects of fatigue (Musić & Hirche, 2017; Pichler et al., 2017). Yet, machines struggle replicating human intelligence, creativity, empathy, problem-solving, and even dexterity (Hummel et al., 2015; Zanchettin et al., 2013). By designing hybrid work tasks leveraging complementary competencies, AMR integration emphasizes human-robot collaboration and elevates importance of human factors.

2.3 Literature Review: External Technology Integration

Although the intent of grounded theory is to emerge theory from data, a cursory review of relevant literature is necessary for researchers to attain theoretical sensitivity, develop initial categories, and guide model integration (Glaser & Strauss, 1967). In addition, the literature provides insight into important contextual conditions influencing and directing initial interview protocols. A well-grounded theoretical framework constructed from qualitative research must account for literature, which supports intuitively generated ideas and ensures findings are non-redundant (Mentzer & Kahn, 1995; Suddaby, 2006). As data collection and analysis progressed, two related existing theories, namely the external technology integration (ETI) framework and its foundation in organizational information processing theory (OIPT), assisted us in making theoretical connections based on our comprehension of the data.

As exhibited in approaches taken by Cooper & Wolfe (2005) and Stock and Tatikonda (2008), technology integration can be conceptualized as an episodic organizational task. From this perspective, the task of ETI involves acquisition and integration of technology from outside the firm into internal operational processes (Stock & Tatikonda, 2004). During task execution, integrating firms encounter technology uncertainty, defined as “the difference between the information needed to obtain and implement the technology, and the information the recipient actually has at the start of the ETI process.”(Stock & Tatikonda, 2008) This uncertainty is a product of novelty, complexity, and tacitness of technology (Tatikonda & Stock, 2003), and results in rapid change, unpredictable problems, and issues for which there is no standard procedure and which requires trial-and-error learning (R. L. Daft & Lengel, 1986). To overcome uncertainty during task execution and achieve better ETI performance, Stock and Tatikonda (2008) prescribe engaging in a level of interorganizational interaction commensurate with the degree of uncertainty experienced (i.e. higher uncertainty should be met with a higher degree of interorganizational interaction) (see Figure 2.1).

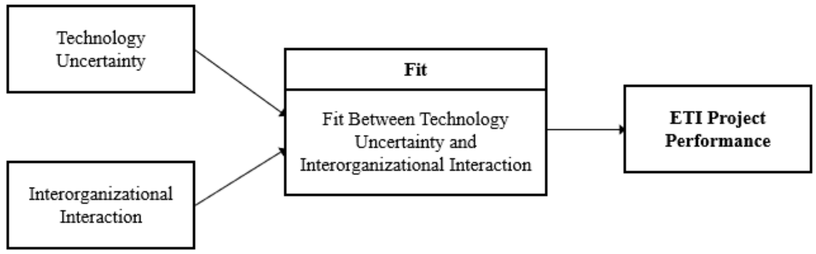

Figure 2.1: Conceptual framework of ETI project performance (Stock and Tatikonda, 2008, p 68)

Stock and Tatikonda's (2008) ETI framework is constructed using the theoretical lens of organizational information processing theory (OIPT), which views firms as open social systems that must effectively cope with work-related uncertainty and equivocality (ambiguity) to be successful (R. L. Daft & Lengel, 1986; Galbraith, 1974; M. L. Tushman & Nadler, 1978). OIPT has three foundational theoretical elements: 1) the information processing requirement of a task, 2) the information processing capacity of the organization, and 3) achieving an appropriate "fit" between the two aforementioned elements during task execution (M. L. Tushman & Nadler, 1978; Zhu et al., 2017). A task's information processing requirement is a function of complexities inherent in the task and an organization's operating environment. These complexities create uncertainty and equivocality during task execution which require information processing, or the acquisition, interpretation, synthesis, and dissemination of information (R. Daft & Lengel, 1986; M. L. Tushman & Nadler, 1978). To counteract uncertainty and efficiently process information, firms must organize effectively (Galbraith, 1974). Information processing capacity is the outcome of two dimensions of organizational structure: (1) the either mechanistic (i.e. vertical, formal, highly regulated, centralized power and control) or organic (i.e. lateral, participative, problem-solving, de-centralized power and control) structure of organizational subunits and (2) the presence of coordination and control mechanisms to efficiently exchange information between interdependent subunits (M. L. Tushman & Nadler, 1978). OIPT views achieving a fit between information processing requirements and an organization's capacity to process information as the fundamental managerial challenge. The basic design problem of creating either too little or too much information processing capacity, given an information processing requirement, results in either task ineffectiveness or task inefficiency, respectively (see Figure 2.2). The degree to which an adequate fit is achieved ultimately affects the quality of task outcomes (M. L. Tushman & Nadler, 1978).

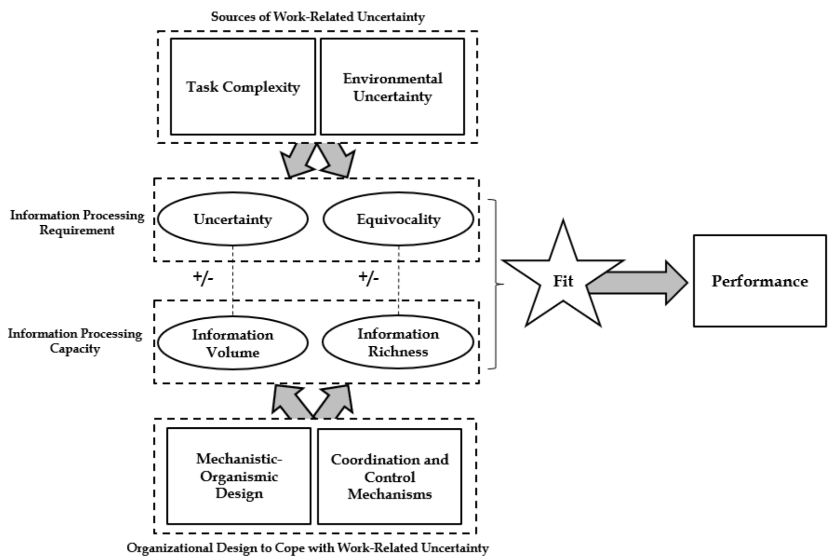

Figure 2.2: Model of organizational information processing theory (adapted from Tushman and Nadler, 1978, p. 622)

While necessary in volatile environments, costly efforts to maintain high levels of information processing capacity provide little benefit when environmental conditions are relatively stable and certain (Srinivasan & Swink, 2018). When this is the case, simple and cost-effective organizational structures should be employed to the greatest extent possible. (M. L. Tushman & Nadler, 1978). Researcher presuppositions regarding WDCs include operation in routine environments with well-understood problems and rare exceptional scenarios. Therefore, highly centralized and hierarchical mechanistic structures, governed by formalized rules and procedures are appropriate for day-to-day warehousing tasks (Srinivasan & Swink, 2018), which typically experience low information processing requirements. Under normal conditions, there is no standing need for organic work structures or elaborate coordination and control mechanisms, as warehouse tasks can be considered self-contained and executable with little outside interdependence. Yet, technological and procedural changes inherent in the "task" of ETI creates uncertainty and equivocality which WDCs are ill-equipped to confront. Due to the novelty, complexity, and the required tacit knowledge to integrate AMR technology, AMR ETIs are characterized as having a high level of technology uncertainty, creating a "mis-fit" between AMR technology uncertainty and WDCs' intrinsic information processing capacity. Unresolved, this mis-fit can potentially lead to adverse outcomes including schedule over-runs, cost proliferation, and low-technical performance (see Figure 2.3) (Tatikonda & Stock, 2003).

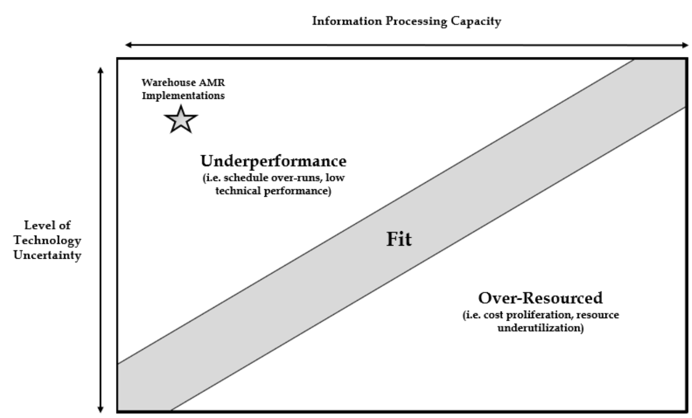

Figure 2.3: OIPT perspective of typical warehouse AMR external technology integration

Thus, from an OIPT lens the challenge is how to best create a "fit" between fundamentally mechanistic subunits (warehouse) and tasks with inherently high information processing requirements (technology adoption) to improve ETI outcomes. When information processing capacity is inadequate to accomplish the task, tasks will likely take longer, cost more, and will not meet prescribed performance standards. Inherent certainty and stability in WDC operations combined with uncertainty and equivocality of AMR ETIs produces a naturally poor fit that must be overcome by increasing information processing capacity.

2.4 Research Methodology

As AMR ETIs, which involve multiple firms collaborating to integrate novel and highly-collaborative technology, represent a unique and under-researched context, we adopted an inductive approach leveraging GT methodology (Corbin & Strauss, 2008; Glaser & Strauss, 1967). GT is appropriate for establishing understanding of phenomenon where little theoretical knowledge exists (Suddaby, 2006). We found GT a suitable approach for our study, as the method allows researchers to investigate events with high degrees of complexity and is especially effective when applied to situations "involving inter-firm integration/collaboration/relationship issues" (Mello & Flint, 2009, p. 114). Moreover, as the collaborative nature of AMRs emphasizes the importance of human experience during integration, GT provides an effective instrument to understand complex interactions between individuals and firms (Mello & Flint, 2009) and how "individuals interact within the whole" (Randall & Mello, 2012).

GT seeks to emerge theory about social phenomena by facilitating theoretical abstraction directly from field data. By grounding theoretical elements in data through constant comparison, GT develops fresh insights and provides empirical foundations for developing new theory. The method facilitates discovery (Fugate et al., 2006) by omitting *a priori* hypotheses, and instead emerges theory composed of integrated hypotheses on a conceptual level (Glaser, 2001). In this way, theory emerges from the experiences of practitioners and "the process by which actors construct meaning (Suddaby, 2006, p. 634)." Our study follows a classical Glaserian approach to

GT emphasizing theory emergence through application of constant comparison (Glaser, 1978; Timonen et al., 2018). This technique is heavily dependent on theoretical sensitivity of researchers to develop insightful theory, rather than following a set of codified procedures. While remaining rigorous, a Glaserian approach avoids potential overemphasis of technique through application of rigid mechanics which may force conceptualizations on data (Mello & Flint, 2009). By identifying "theoretical similarities and differences" through constant comparison and theoretical sampling, this approach to GT allows development of higher order concepts explaining behavior and assists in developing theoretical frameworks explaining complex phenomena (Randall & Mello, 2012, p. 867).

2.4.1 Context and Sample

To understand the phenomenon holistically and strengthen the veracity of findings, we sought data from a dyadic perspective (supplier and customer). Initially, the research team contacted two independent innovation-focused non-profit organizations specializing in industrial robotics. These organizations provided a comprehensive list of leading U.S. AMR developers and manufacturers used to contact participating firms through public websites. In addition, we leveraged several standing relationships between our university's research center and private industry. Furthermore, at the conclusion of each interview we inquired about additional potential contacts in the industry, using a snowball sample technique to find and screen new cases (Bhattacherjee, 2012). The final sample consists of 17 key informants across various firm types participating in AMR implementation including AMR manufacturers, automation integrators and consultants, and AMR customers. Respondents held various titles within their organizations, ranging from C-level executives to industrial engineers and project managers (see Table 2.1 for complete sample description).

2.4.2 Data Collection and Analysis

Our research explores novel contextual conditions of AMR technology integration, thus a less-structured approach utilizing expert interviews was appropriate. Semi-structured interviews typically lasted one hour and were conducted remotely via video conferencing software with at least two (typically three) members of the research team present. Interviews were recorded in both audio and video formats, transcribed, and uploaded into MaxQDA 12, a software package designed for qualitative research (see Appendix A for the interview protocol). Each interview was coded, analyzed, and discussed by at least two members of the research team to ensure consistency in findings. MaxQDA allowed the research team to build “a chain of evidence” to make explicit the links between interview questions, data collected from the respondents, and the theoretical conclusions drawn from the data (Yin, 2003). Data collection and coding occurred simultaneously, with the inclusion of new informants and lines of inquiry guided by theoretical sampling procedures (i.e. automation integrators and consultants were sought after supplier-customer dyads produced inconsistent and divergent data related to ease of integration into existing warehouse systems). Additionally, extensive theoretical memo writing captured key ideas and connections assisting in clarifying relationships between developed categories. These memos, in conjunction with weekly research meetings to compare coding, discuss theoretical findings, and reconcile any divergence of findings, allowed researchers to saturate categories; while further selective coding rounded out relevant properties and dimensions of emerged categories (Corbin & Strauss, 2008). The iterative process of simultaneously collecting, coding, and analyzing qualitative data using constant comparison resulted in additional interviews until theoretical saturation was achieved. In total, 17 semi-structured interviews were conducted over a seven-month time period resulting in over 1,200 open codes and over 100 theoretical memos.

Table 2.1: Research participants and firm descriptions

Firm Name (pseudonym)	Firm Type	Firm Description	Informant (pseudonym)	Title of Key Informant(s)
Flash Robotics	AMR Manufacturer	AMR developer that designs, develops, and manufactures fully autonomous robots for manufacturing and warehouse applications	Mary	Director of Marketing
			James	Director of Business Development
Swarm Robotics	AMR Manufacturer	AMR developer producing fully supported autonomous order picking robots with remote access capability for e-commerce applications	Patricia	Chief Marketing Officer
TugCo Robotics	AMR Manufacturer	Robotics start-up developing hardware and software solutions enabling the safe operation and retrofit of warehouse tugging equipment.	Robert	Founder and President
Invictus Robotics	AMR Manufacturer	A medium-sized AMR developer that designs, develops, and manufactures fully autonomous robots for manufacturing and warehouse applications with $30 million in annual sales	John	Chief Revenue Officer
Mechanized Automation Distribution Co.	Material Handling Equipment Vendor	Material handling equipment vendor offering a wide variety of products, services, and consulting.	Michael	Chief Executive Officer
Novel MHE Distribution Co.	Material Handling Equipment Vendor	Large material handling equipment vendor offering a wide variety of products, services, and consulting with nearly $2 billion in annual sales.	Linda	Vice President of Operations
Success Integration Consultants	Warehouse Automation Consultant	Supply chain and distribution experts offering warehouse automation solutions with $30 million in annual sales.	William	Senior Director
Automation Central Consultants	Warehouse Automation Consultant	Supply chain consultants specializing in engineering and labor management with an estimated $1 million in annual sales.	David	Project Lead
Warehouse Solutions Consultants	Warehouse Automation Consultant	An independent consulting firm specializing in optimizing solutions distribution infrastructure with an estimated $10 million in annual sales.	Richard	Project Manager

Firm Name (pseudonym)	Firm Type	Firm Description	Informant (pseudonym)	Title of Key Informant(s)
Et Cetera Solutions Co.	Warehouse Automation Consultant	Warehouse automation and fulfillment solution provider offering software and hardware solutions with an estimated $26 million in annual sales.	Susan	Sales Engineer
ABC Food Co.	Manufacturer/ Automation End-User	Large food manufacturer with over $20 billion in annual North American sales.	Charles	Senior Director of Warehouse Operations
Retail A-Z Inc.	Retailer/Automation End-User	Large retailer operating nearly 1,900 stores throughout the U.S. with over $75 billion in annual sales.	Thomas	Distribution Center Operations Manager
DefenseCo	AMR End-User	Large defense contractor with nearly $60 billion in annual sales.	Chris	Applications Engineer (Site #1)
			Daniel	Applications Engineer (Site #2)
			Elizabeth	Applications Engineer (Site #3)
			Steven	Applications Engineer (Site #4)
Direct-to-Customer Med Co.	AMR End-User	Direct-to-consumer medical supplies company with an estimated $25 million in annual sales.	Anthony	Founder and President

2.4.3 Methodological Rigor

In assessing the rigor of our research and trustworthiness of the theoretical findings, we applied the evaluative criteria of fit/credibility, transferability, dependability, confirmability, integrity, understanding, generality, and control (Flint et al., 2002). These criteria, based on interpretive (Hirschman, 1986; Wallendorf & Belk, 1989) and GT research approaches (Strauss & Corbin, 1990), provide standard benchmarks for assessing the quality of GT studies. Please see Table 2.2 for a description of the criteria and a brief discussion of how our research addressed each condition.

Table 2.2: Evaluation of qualitative research trustworthiness

Criteria	Description	How was the criterion addressed in our research?
Fit/Credibility	The extent to which the categories fit the empirical data	The resultant theoretical framework, emerged from over 150 pages of expert interview transcripts, 1,200 coded items, and over 100 theoretical memos.
Transferability	The extent to which findings from one study in one context will apply to other contexts	Admittedly, each AMR implementation was unique due to the differences in design and employment, however the theoretical sampling approach allowed us to triangulate and converge on important categories.
Dependability	The extent to which the findings are unique to time and place; the stability or consistency of explanations	The automation integrator and AMR manufacturer key informants provided reflection on multiple instances of implementation in a variety of contexts. The implementation processes described by these participants displayed consistency with customer firms that were interviewed.
Confirmability	The extent to which interpretations are the result of the participants and the phenomenon as opposed to researcher biases	A three-person research team worked in tandem over a twelve-month period, participating in data collection, coding, and interpretation. Findings were discussed during weekly research meetings to minimize individual biases and resolve divergent interpretations.
Integrity	The extent to which interpretations are influenced by misinformation or evasions by participants	Interviews were conducted in a professional, but conversational and non-threatening nature. Participants were presented with consent forms that detailed protections to ensure privacy and anonymity. The researchers are under no impression that participants purposefully misinformed them or evaded questions posed by the interview protocol.

Criteria	Description	How was the criterion addressed in our research?
Understanding	Extent to which participants buy into results as possible representations of their worlds.	An executive summary developed and presented to colleagues. Feedback received was generally positive and validated our framework as an accurate representation of the phenomenon.
Generality	The extent to which findings discover multiple aspects of the phenomenon	Interviews were of sufficient length, depth, and openness to allow respondents discuss the phenomenon in detail, thereby capturing of multiple facets AMR implementation
Control	The extent to which organizations can influence aspects of the resultant theory	Customers, suppliers, and integrators of AMRs are key actors in the joint team influencing ETI success

2.5 Findings

Our work emerged a theoretical framework explaining how AMR integration performance varies based on knowledge exchange (KE) between key stakeholders and contextual conditions in four distinct phases of integration. Figure 2.4 describes the key stakeholders and knowledge they both inherently possess and require to effectively integrate technology, resulting in the need to exchange knowledge with partnering stakeholders. Figure 2.5 depicts the process of KE, consisting of the subprocesses of identifying knowledge deficiencies, facilitating KE, codifying knowledge, and exporting knowledge. Finally, Figure 2.6 depicts demarcated phases of AMR ETI, which influence ways and means KE occurs. The emerged framework extends theoretical understanding of AMR ETI by identifying KE as the core category explaining variation in ETI performance, explicating the process in which KE occurs, and describing how content, direction, primary stakeholders, mechanisms, intensity, and expected outcomes vary based on phase of ETI.

2.5.1 Knowledge Exchange

Our first major finding was KE as the core category explaining the most variation in ETI performance. We found for firms to effectively integrate AMRs into WDC operations, constituent stakeholders must obtain knowledge and share possessed knowledge with other stakeholders (see Figure 2.4).

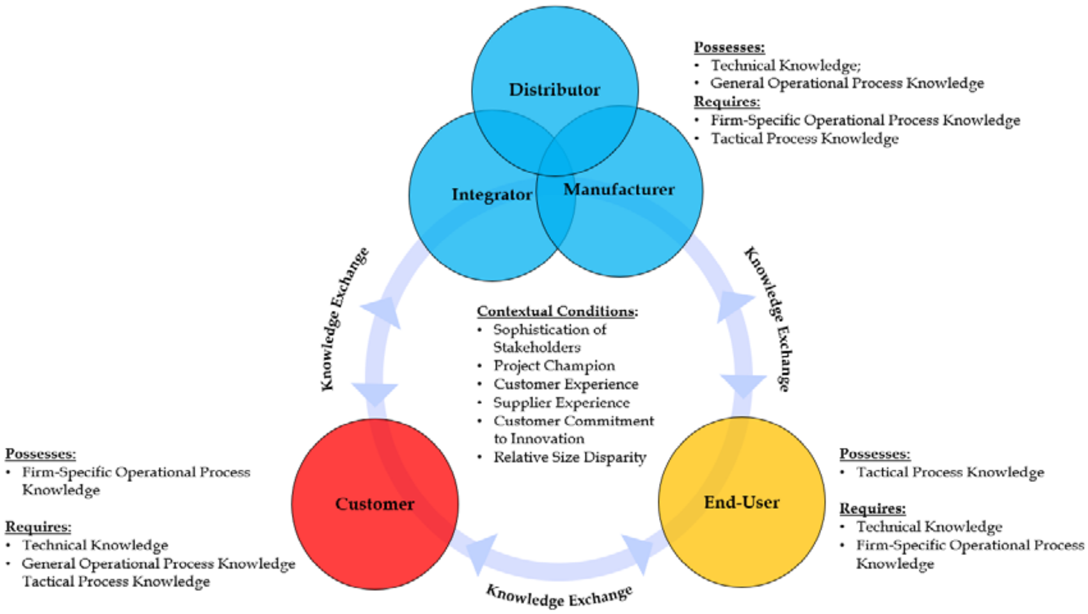

Figure 2.4: Knowledge exchange between key stakeholders

Our work identified both integrating and supplying firms, as well as end-users, as key stakeholders in AMR ETIs. KE effectively allows each stakeholder to better understand how technology and processes interact to improve targeted tasks. Stakeholders inherently possess information valuable to other stakeholders, while simultaneously relying on other stakeholders for knowledge critical to execute their role in the integration effort. For example, customer firms (which we define as anybody above the user level, i.e. management, executives, industrial engineers, etc.) possess firm-specific operational knowledge but lack requisite technical and tactical process knowledge. Suppliers (at times, these could be either technology integrators, distributors, manufacturers, or a combination of the three) possess technical knowledge customers and users require, but lack firm-specific operational knowledge customer firms possess and tactical process knowledge users possess. Users can provide tactical process knowledge enhancing customer and supplier understanding, but require operational direction from customer firms and technical knowledge from supplying firms to effectively appropriate AMRs and execute newly-developed tasks.

2.5.2 Process of Knowledge Exchange

A second major finding was occurrences of KE in four distinct sub-processes. These processes occurred iteratively and continuously throughout ETI projects, reflecting the pervasive nature of KE. We found the most effective ETIs transpired when all stakeholders proactively identified knowledge deficiencies, facilitated KE, codified knowledge, and exported knowledge to mitigate ETI-related uncertainty. Yet, while some stakeholders externally applied learning by codifying and exporting knowledge, others obtained only necessary knowledge to adequately complete a task. For instance, multiple implementation sites at DefenseCo exhibited similar struggles with IT integration and technical performance despite being undertaken subsequently. Although, some information was shared amongst the integrating work sites, the stated "goal" of standardizing integration processes and best practices was never realized. Instead each site individually engaged in KE ad hoc to acquire knowledge they required to solve acute issues, but failed to codify and export this knowledge. In contrast, David with Automation Central Consultants held weekly collaboration calls for a major manufacturer implementing AMRs at several WDCs. These meetings facilitated export of knowledge across sites, as participants pooled resources, collaborated on technical fixes, and recorded best practices in meeting minutes which were subsequently distributed. Essentially, two levels of KE emerged (see Figure 2.5). The first, involving only the first two sub-processes, concerns knowledge acquisition to execute current tasks. The second level, consisting of all four sub-processes, involves knowledge transfer allowing acquired knowledge to further benefit current and parallel projects. Below are short descriptions and examples of each sub-process.

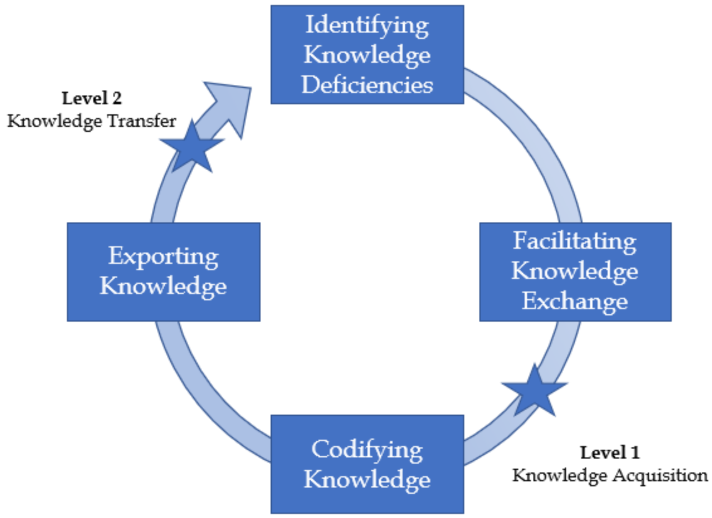

Figure 2.5: Process of knowledge exchange

2.5.2.1 Identifying Knowledge Deficiencies

The first KE sub-process is identification of areas which stakeholders lack sufficient knowledge to complete required tasks. Deficient areas are often obvious, prompting stakeholders to immediately query other stakeholders, but other times result directly from deliberate inquiry. For instance, Michael at Mechanized Automation Distribution Co. explained uncertainty concerning their customers' operations is mitigated through detailed engineering assessments. In-person walk-throughs and focused data collection efforts facilitate understanding of customer workflows, strategy, and processes. Another example is employing small-scale pilots prior to implementation. Pilot results reveal knowledge deficiencies with minimal impact to operations, providing stakeholders information required to engage and fix potential issues before full-scale implementation. In either case, stakeholders take concrete action to illuminate, clarify, and define knowledge deficiencies allowing for efficient KE.

2.5.2.2 Facilitating Knowledge Exchange

Often when stakeholders are cooperating closely, identifying knowledge deficiencies and facilitating knowledge exchange go hand-in-hand. For instance, the previous examples of engineering assessments and pilots are both mechanisms for identifying knowledge deficiencies and facilitating knowledge exchange. However, firms also took deliberate action to ensure the means for KE. Susan at Et Cetera Solutions expressed the importance of a physical, on-site presence during critical phases of integration, while Richard at Warehouse Solutions Consultants depicted their "customer success role" as primary means of understanding new customer requirements and implementing continuous process improvement. Robert and David, representing both AMR manufacturer and integrator respectively, teamed up to conduct weekly calls with their customer's multiple sites, which allowed both user accessibility to technical experts and supplier accessibility to users (who are process experts).

2.5.2.3 Codifying New Knowledge

Once firms obtained required knowledge from partnering stakeholders, they codified knowledge to capture, maintain, and eventually transfer learning. Codification of knowledge manifests itself in new metrics, key performance indicators, internal documentation, and training and implementation guides. For example, Direct-to-Customer Med Company's supplier wrote a jointly developed product with their firm's operations team and users called a description of operations, outlining in detail touch points, product movement, and business rules. After several development meetings, document details were agreed upon and used to baseline future KE between stakeholders. In another example, DefenseCo codified integration milestones, which continued to prove useful after export to several other sites implementing AMRs. Finally, Robert at TugCo Robotics described how co-developed metrics and training guides provided their customer "much clearer direction" during subsequent AMR implementations.

2.5.2.4 Exporting Knowledge

Finally, once firms identify deficiencies, facilitate knowledge exchange, and codify new knowledge, firms exported acquired knowledge to improve performance in current or parallel projects. For example, suppliers obtained knowledge about user processes and preferences, later applying this knowledge to optimize AMR functionality. In one instance, Richard gleaned from an initial assessment that pickers generally picked about seven of a single SKU at a time for up to seven different orders. Using this knowledge post-implementation, he changed the AMR fleet's default maximum of SKUs from five to seven, effectively increasing the workers' batch picking efficiency by forty percent. Moreover, several examples emerged of supplying and customer firms obtaining knowledge at one site and transferring it to others, mitigating potential uncertainty. John at Invictus Robotics summarized this concept, describing his company's "maturation" from a technology company to a service provider. Attributing this maturation to "experience and validation," accumulation of knowledge taught Invictus Robotics "very, very rapidly" to ensure the right application for AMRs, making "adoption as consistent as possible."

2.5.3 Phases of AMR Integration

A third major finding was emergence of demarcated phases during AMR integration which defined the content, direction, primary participants, mechanisms, intensity, and expected outcome of KE. Each phase described in Figure 2.6 varied in length and volume of KE based on integration complexity and stakeholder maturation. We found most integration projects follow the same general pattern, to include sub-processes, in each phase to achieve a goal before progressing to the next phase. When subprocesses were excluded or firms achieved only marginal phase goal success, progression in subsequent phases was inhibited. Although firms differed regarding methods and levels of integration success, in the following section we describe an ideal project approach based on our findings and how KE enhanced performance in each phase of the project.

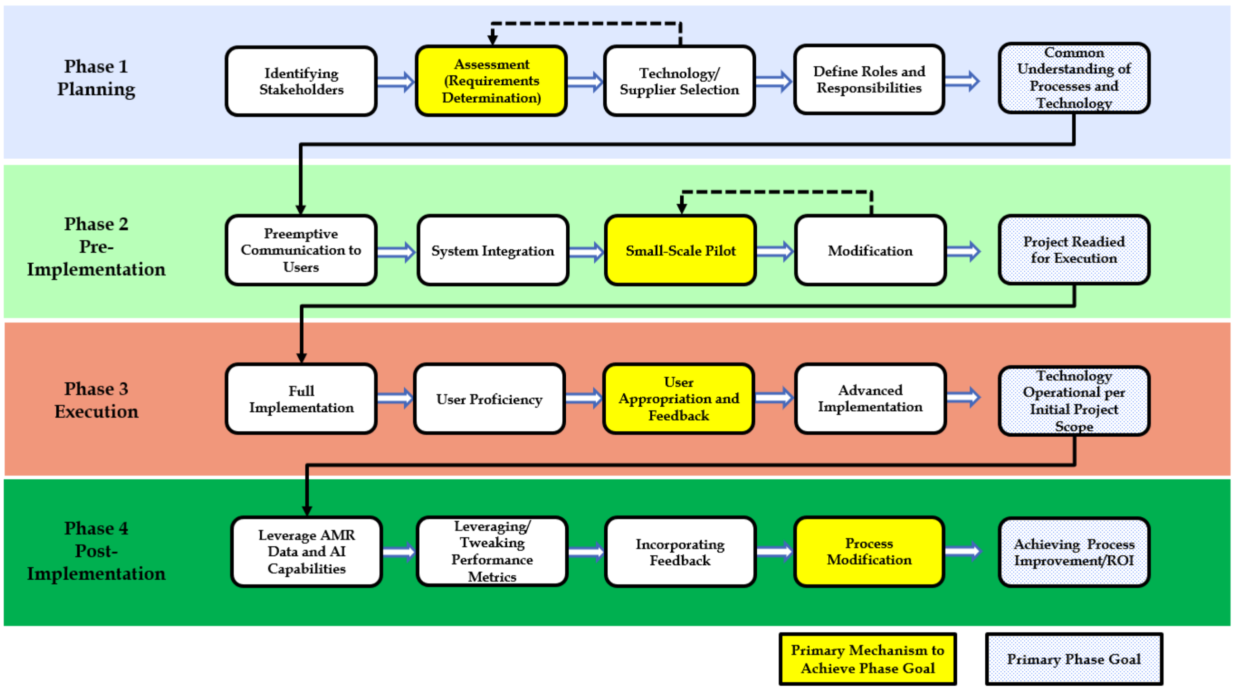

Figure 2.6: Phases of AMR integration

2.5.3.1 Phase 1: Planning

2.5.3.1.1 Description and Goal

The first phase of an AMR ETI is the planning phase. The stakeholders most actively exchanging knowledge during this phase are supplying and customer firms (see Figure 2.7), and both exhibited dominant emotions of excitement and enthusiasm. During this phase, customer firms identify the need to improve an operational task and begin seeking technology solutions. In some cases, customers immediately engaged AMR manufacturers, distributors, or technology integrators to conduct assessments and accomplish requirement determinations. Initial operational assessments evaluated current and future states and identified potential problems or opportunities. After AMRs are selected as preferred solutions and specific manufacturers are chosen, we found suppliers and customers jointly evaluate the AMR capability's fit to the target process. During this process, all relevant stakeholders are brought together to produce and codify planning documents used to baseline future integration phases. Subsequently, roles and responsibilities are determined and stakeholders agree upon performance expectations. The goal of the planning phase is for all stakeholders (suppliers, customers, and users) to possess a common understanding of process and technology fit.

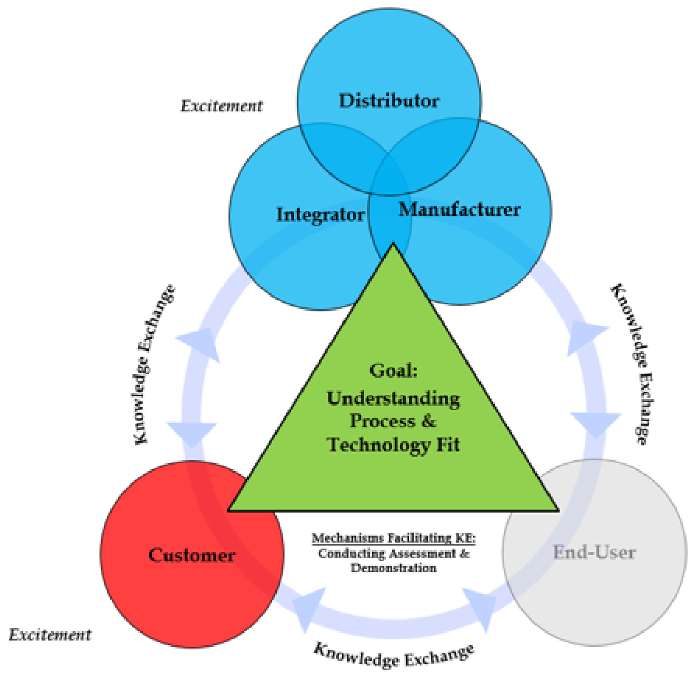

Figure 2.7: Knowledge exchange during ETI planning phase

2.5.3.1.2 Assessments and Demonstration

The most important mechanism facilitating KE to achieve this phase's goal of attaining common understanding of process and technology are operational assessments. Before selecting a manufacturer, or even a technology, customers generally conduct informal self-assessment to identify problem areas or processes considered good candidates for automation. Generally, customers sought highly repetitive, high volume processes to eliminate human effort (i.e.

walking) and improve safety (i.e. reduce forklift traffic, human error). If co-opted, technology integrators are helpful in initial assessment as they leverage both technology- and process-related expertise. Experienced integrators collected operational data, analyzed it, and condensed findings into simple executive summaries, improving customer understanding of internal processes and highlighting specific opportunities or challenges. The outcome of assessment was basic operational requirements definition. Although not always the case, these assessments should drive technology selection and application, not the other way around. Our respondents generally considered other types of automation, but chose AMRs due to their flexibility, scalability, adaptability, perceived ease of implementation, and perceived ability to achieve rapid ROI.

Once AMRs were determined a good fit for the project, suppliers typically conducted joint engineering studies to understand customers' warehousing processes in detail. Suppliers brought a fresh perspective, enhanced by experience obtained from prior integration projects, assisting customers in analyzing processes, understanding strategy, and adjusting workflows to accommodate AMR deployment. During these assessments, suppliers ascertained customer objectives and educated customers on potential constraints. Supplier assessments included in-person site visits, analysis of order and SKU data, and determination of bottlenecks and other pain points. Most assessments included close coordination with end-users, who provided insight into process minutiae allowing for more comprehensive pictures of macro-level processes. Finally, the most effective assessments concluded with written, jointly agreed-upon descriptions of operations and points of interface. These artifacts were inclusive of as many stakeholder points-of-views as possible, and functioned as integration roadmaps during subsequent phases. We found initial assessments critically important, as uncertainties unaddressed in this phase directly impact the efficacy of integration in future phases.

2.5.3.1.3 Identifying Stakeholders and Delineating Roles and Responsibilities

To enable effective KE in this phase, successful firms ensured internal stakeholders were identified and included in planning efforts as early as possible. Early assessments identify critical touch points and areas of integration, and corresponding stakeholders responsible for these areas should be involved in planning. Along with users, IT departments were identified as important stakeholders who must understand AMRs' data exchange requirements. However, users, as process experts and executors, were universally cited as critical stakeholders to include in planning, developing, and defining projects' end-states. By incorporating users' vision into solutions early, customer firms instilled a sense of user ownership, where users shared in perceived successes or failures of integration.

After suppliers are brought into the project, successful firms defined stakeholder roles and responsibilities to avoid ambiguity. Some customers preferred holding suppliers or integrators completely accountable to deliver project outcomes, as these entities typically possessed superior ETI experience and capabilities relative to integrating customer firms. This was especially true in cases where customers lacked internal engineering or technical capabilities. Having the most experienced and capable stakeholder in charge enhanced communication and coordination between stakeholders throughout projects. Companies failing to thoroughly define roles and responsibilities often confronted miscommunication and misunderstandings when resolving problems in latter phases. This had the propensity to hinder further KE as customers subsequently attempt to become "self-reliant."

2.5.3.1.4 Defining Performance Expectations

One important outcome of effective KE in during planning is clear and shared expectations of AMR capabilities. To this end, stakeholders found it beneficial to codify agreed-upon understanding of the projects' current- and end-states. Making jointly-agreed-upon performance agreements explicit ensured stakeholders understood what project success looked like. When firms failed to develop a common understanding of processes, technology capabilities, or goals, unmet expectations were common. Respondents cited "overselling" of AMR capabilities is common, thus it is critical to ensure AMR performance expectations are clear. Deliberate, straightforward customer-supplier engagement discussing requirements, objectives, constraints, and goals prior to moving forward into subsequent phases made it enhanced expectation management and minimized misunderstandings.

2.5.3.2 Phase 2: Pre-Implementation

2.5.3.2.1 Description and Goal

During pre-implementation phase, all stakeholders engage in intense KE to ready the WDC operation for project execution. Based on work accomplished in planning phases, firms closely coordinate to execute required infrastructure and IT modifications accommodating incoming AMRs. Users begin to take a focal position in the implementation, as both supplying and customer firms communicate impending changes altering new, AMR-integrated picking tasks. As this was the first phase users predominately participated in KE, they exhibited several dominant emotions including excitement, resentment, intimidation, fear, and nervousness (see Figure 2.8). Customer firms convey AMR benefits to end-users, ensuring fundamental understanding of their new roles in picking tasks; while suppliers provide training and demonstration, assisting users in grasping technical aspects of operating AMRs in their work environments. In return, users provide customer and supplying firms insight into tactical-level integration processes, offering feedback to work through technical glitches and improve end-user experience. The pre-implementation phase culminates in limited scale pilots, where operational concepts are tested, potential problems are identified, and solutions are validated. After modifications to incorporate changes resulting from pilots, this phase culminates in readying the project for full-scale execution.

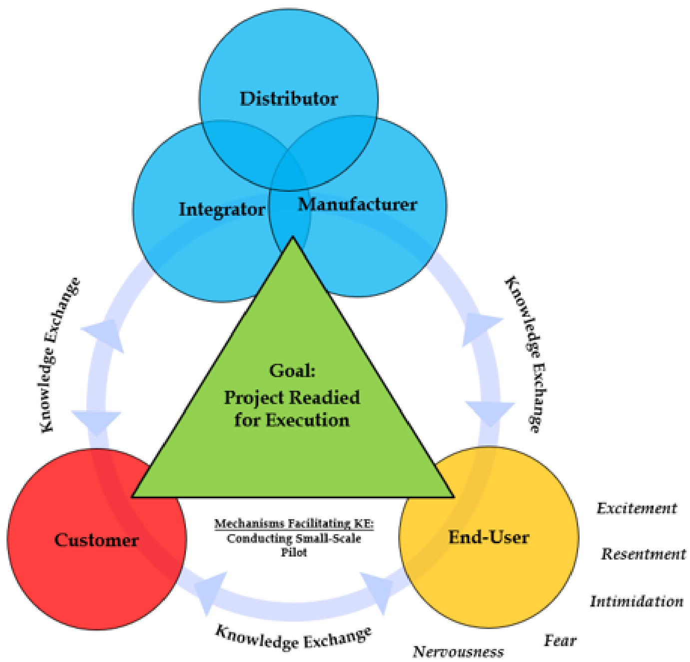

Figure 2.8: Knowledge exchange during ETI pre-implementation phase

2.5.3.2.2 Proactive Communication with Users

We found fear and uncertainty among users practically ubiquitous during pre-implementation phases. Nearly every respondent described users as apprehensive about job security and learning new technology and tasks. However, the extent of early firm KE with users was extraordinarily effective at mitigating this uncertainty. Proactively communicating methods, user roles, and goals for the implementation limited resistance and instead engendered excitement. However, when firms executed ETI without clear communication, users' fear eventually manifested into resentment, resistance, and even active sabotage.

Much of the cited user resistance was directly attributable to employment concerns. Generally, management understood people perform tasks robots cannot replicate, and were not looking to downsize (especially in an environment of intense hiring competition). Transparency and messaging about how AMRs make tasks easier or how people can better utilize their time and skills are important. DefenseCo published a company-wide article communicating their goal of not replacing operators, but freeing them up to focus on more challenging, critical tasks. Successful firms convinced users they are still responsible for the task, but that AMRs make tasks less strenuous, increase output, and decrease wasted time. Early user involvement in ETIs signaled employment was not threatened, but instead that management cared enough to make strenuous and ergonomically demanding tasks of order-picking easier for their employees.

Moreover, to overcome resistance and enhance acceptance, we found KE engendering user buy-in or "ownership" critical. Suppliers and customer firms actively listening and incorporating feedback gave users a stake in success or failure of the implementation. William at Success Integration Consultants described a strategy used by several integrating firms to improve buy-in. These firms take a handful of top performing order-pickers and involve them in planning meetings and one-on-one demonstrations. By valuing their input, these "influencers" were able to "bring the rest of the workers along," generating "genuine excitement." Alternatively, if communication was poor users felt like AMRs were "ordained from above." Without obtaining buy-in, William explained "the chances of people wanting to use the system correctly is questionable at best."

2.5.3.2.3 Working through Technical Issues

During pre-implementation phases, all stakeholders are actively involved solving issues related to AMR and system integration. Suppliers assisted customers with technical aspects regarding mapping, setting up cameras and sensors, conducting stress tests on transactional and navigational data, and IT integration. Most suppliers spent portions of this phase on-site with customers, acting as consultants communicating technological limitations and ensuring AMRs can safely execute required tasks. While suppliers contributed technical knowledge, users, as process experts, were often part of defining the ultimate solution. Users enlightened both customer firms and suppliers on process idiosyncrasies, ergonomic limitations, and user preferences facilitating changes enhancing efficacy and user acceptance.

Of significant importance in this phase is IT and infrastructure integration. Although not required for basic operation, most AMRs are integrated into shop floor control systems or warehouse execution/management systems (WES/WMS). In certain instances, a significant amount of system engineering was required to integrate AMR fleet software with customers' internal WESs. Susan at Et Cetera Solutions emphasized the importance of IT, stating "we are no longer talking to the chief executive officer, but rather the chief information officer to help them understand requirements for AMR adoption." Customers and suppliers must be honest partners who are willing to share knowledge and data, and work through security protocol challenges. If not addressed during pre-implementation, IT complexity and security became major hindrances in latter phases of integration.

2.5.3.2.4 User Training and Demonstration

During pre-implementation phases, training and demonstration are key mechanisms of KE. Users must obtain operational guidance, but also knowledge related to new roles and responsibilities, AMR behavior, interaction and cooperation with AMRs, and basic maintenance support. As such, we found firms deployed basic training for employees "casually" encountering AMRs and more in-depth training for users utilizing AMRs in primary job duties. Train-the-trainer strategies were prevalent, with some training the customers' "all-star pickers" as subject-matter-experts and conduits to influence less experienced users. This approach effectively transfers responsibility for tactical-level integration from suppliers or industrial engineers to users. As Chris from DefenseCo asserted, if users can troubleshoot and overcome their own issues, they feel a "sense of pride in shaping how their team uses and expands use."

An interesting aspect of training included getting users "culturally on-board" with making AMRs a critical aspect of how users execute job tasks. AMRs can be optimally programmed, but if users leave pallets in aisles or deviate from standard operating procedures, efficacy diminishes. As Steven at DefenseCo put it, "there are a lot of little things people must understand" to maximize AMR capability, and this entails changing of attitudes and habits. In-person demonstration emerged as an effective mechanism providing basic understanding of AMR behavior and interaction. Live demonstrations gave users an opportunity to observe experts executing picking tasks, generating excitement and mitigating apprehension. Demonstrators, in turn, solicited immediate feedback from users who "know intimately what the challenges are" and instructed on expectations beyond basic operation (i.e. decluttered warehouse floors, ways not to impede AMRs when passing, etc.). Suppliers suggested demonstrating AMRs functionality and physically picking items led to clearer expectations, greater understanding, and improved buy-in and adoption.

2.5.3.2.5 Limited Scale Pilot Implementation

Pilots are mechanisms allowing all stakeholders to test whether their conception of technology and process fit is congruent with reality, and subsequently to engage in constructive dialogue to remedy surfacing issues. Pilots provide an opportunity to identify deficiencies, exchange knowledge to level-set understanding, and expand KE to overcome problems and enhance full-implementation. Typically, small, simple applications were selected for pilots before ramping up to broader deployments. If stakeholders had unaddressed misalignment in expectations, pilots provide opportunity to reconcile these issues prior to full-implementation.

For users, pilots provide an opportunity to become more comfortable with AMRs, partially eliminating the “intimidation” experienced by users in full roll-outs. For most users, this acts as a first experience with AMRs in actual operational scenarios, leaving them either overwhelmed and unsettled or excited and optimistic. Regardless of their actual experience in the pilot, open dialogue with customer and supplying firms allows users to clarify ambiguities and enhance their overall experience post-implementation.

2.5.3.3 Phase 3: Execution

2.5.3.3.1 Description and Goal

After pre-implementation, firms begin ETI execution as AMRs and new operational processes are fully deployed. During this phase, users are principal actors ensuring projects adequately address operational tasks, and most KE occurs between customer firms and users (see Figure 2.9). Customer firms sometimes experienced frustration and disappointment at a perceived lack of progress, while users were often impressed, felt supported by management, and were excited about using AMRs. As users developed proficiency, a process of appropriation occurred where users take ownership of AMRs and begin to adapt use to meet their purposes. As firms collected data and assessed efficacy of new, AMR-enhanced processes, open dialogue between users and management facilitated incorporation of improvements to meet or exceed the project’s initial scope and achieve an adequate ROI. After a period of acclimation, the technology is considered fully integrated into internal operations, and we found the intensity of KE lower than planning and pre-implementation phases. Expected outcomes in this phase include achieving user proficiency and meeting or exceeding the initial AMR project’s scope.

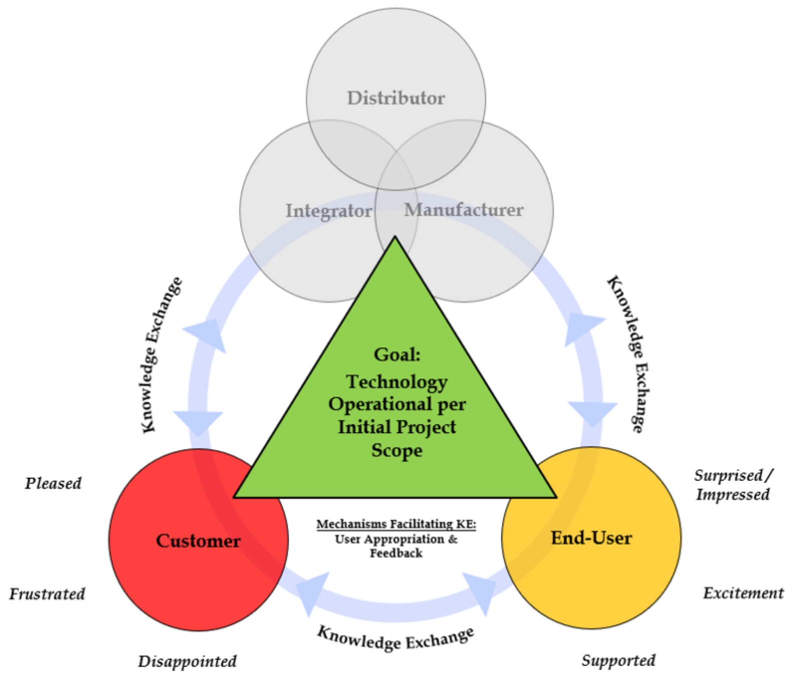

Figure 2.9: Knowledge exchange during ETI execution phase

2.5.3.3.2 User Appropriation and Feedback

The primary catalyst of KE in execution phases of ETI is knowledge acquisition via user appropriation. Appropriation is defined as "the way users 'take possession' of a technological innovation over time" by selecting, exploring, and modifying aspects of the technology (Carroll, 2004, p. 2). Each operational context is different, therefore users are active participants in determining technology design in its final form, as they take idiosyncratic approaches to AMR deployment within their organizations. Appropriation puts users at the center of knowledge development, as they optimize their processes and make improvements during ETI execution.

Yet, while users can make modifications optimizing use at tactical levels, many changes require management or industrial engineering to make operational changes, while still others require supplier involvement to make technical improvements. Open dialogue facilitating KE in terms of user feedback requires customers and suppliers willing to listen and allow user feedback to influence changes, as well as users feeling comfortable enough to provide constructive feedback. When firms access what Susan at Et Cetera Solutions called “tribal knowledge,” they were able to make operational, software, and even hardware changes to maximize efficiency based on local rules-based operations. We found firms encouraging feedback and allowing users to influence ETI end-states increased user buy-in, excitement, and ETI success.

Appropriation and KE are contingent on open dialogue, but are not possible at all unless knowledge is acquired through use. Firms continued facing user resistance to AMR integration during execution phases, encountering users who desired “instant gratification” and grew frustrated when encountering problems seemingly slowing their work. One approach cited to overcome this resistance was presenting data showing tangible benefits of AMRs which may not be obvious. For instance, Robert from TugCo Robotics conducted time and motion studies to show workers they were walking less and picking more, which earned him “converts” among users. Other firms employ incentives if users met performance metrics while employing AMRs.

2.5.3.3.3 Continued Supplier Support

Despite the preponderance of KE in execution phases being chiefly internal, in most cases suppliers still played a consultative role, providing technical and material support to throughout the project. Frequency and intensity of KE varied greatly between firms, with quality of relationships framing continued interaction. When these relationships were strong, stakeholders felt comfortable sharing data and committing resources to continuously improve the application; however, when relationships were poor, supplier KE was almost non-existent during execution phases as customers were resigned to working technical and sustainment issues in-house, which not-surprisingly resulted in delays and cost-overruns.

For ETI projects with stakeholders enjoying positive relationships, supplier KE continued to be productive. As projects moved towards advanced implementations, stakeholders exchanged knowledge focused on technical fixes, training, efficiency, and ease of use. Some suppliers emphasized accessibility by holding weekly calls between customers, integrators, and manufacturers ensuring the team was reactive to problems. Robert explained returning in-person after a couple of weeks is “useful” because “they have discovered a bunch of things that they like and do not like, and after we address them things flow smoothly.” Essentially, as customer firms and operators continue to obtain knowledge during execution, having mechanisms to exchange this knowledge with suppliers facilitates better outcomes.

Finally, some business models deliberately fostered continued, robust KE between suppliers and customers. Many respondents described allowing suppliers access to IT networks, enabling suppliers to continually monitor AMR performance remotely and be more reactive to customer needs. Patricia at Swarm Robotics described in detail her company’s offering called Robotics-as-a-Service (RaaS). In RaaS models, suppliers actually run the operation remotely, focusing on delivering throughput rather than a discrete number of AMRs. This allows suppliers to tailor and scale support to their customers’ needs, treating AMRs almost like an autonomous, scalable labor force. Concepts like RaaS facilitate the highest levels of KE during project execution by allowing suppliers to be virtually on-site continuously. Patricia stressed operating the fleet for customers allows them to “see every day what’s going-on” which “really helps from a development perspective.” Using RaaS to monitoring operations and identify problems, suppliers and customers work together to jointly develop solutions in real-time.

2.5.3.4 Phase 4: Post-Implementation

2.5.3.4.1 Description and Goal

Finally, after a project meets its initial scope, a post-implementation stage begins where stakeholders pursue process improvement and increased ROI. Interestingly, not all companies experienced a fourth phase, but for those who did, excitement was the dominant emotion experienced by all stakeholders (see Figure 2.10). During post-implementation, data is captured and leveraged, performance metrics tweaked, and processes re-engineered reflecting new operational realities. Through continued KE, firms achieved the goal of continued process improvement and higher ROI generation.

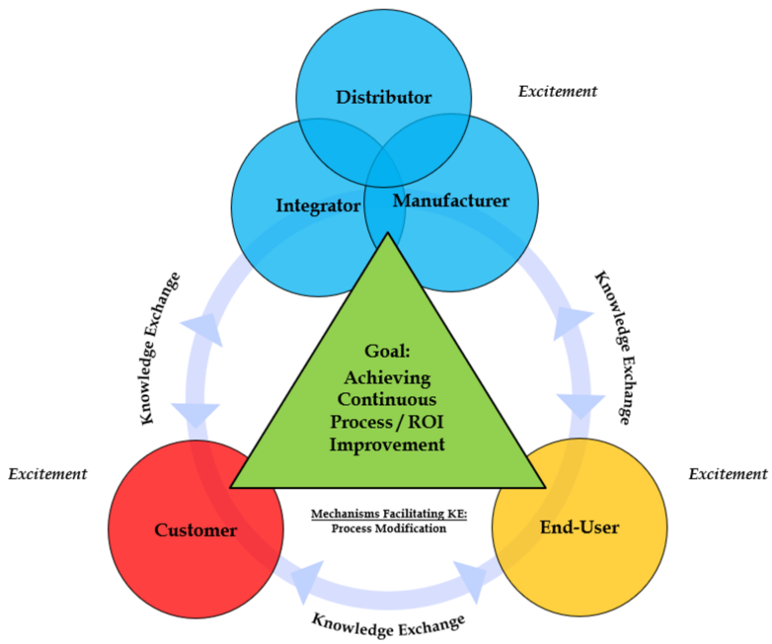

Figure 2.10: Knowledge exchange during ETI post-implementation phase

2.5.3.4.2 Suppliers Providing Long-Term Support

Post-implementation supplier-customer KE ranged from very basic communication regarding parts or technical support to very strong partnerships where stakeholders continued to learn and improve integration efforts. This range was most influenced by customer firms' view of the ETI. If ETI was deemed a short-term, book-ended project with a definitive beginning and end, firms considered the execution phase of the project terminal and subsequent engagement only occurred as "abnormal" problems developed. However, if AMR ETIs were considered long-term projects, stakeholders continued to engage, holding recurring meetings discussing industry, technological, or requirements changes. An important characteristic of AMRs is the ability to adapt and scale to changing product mixes or throughput requirements. Employing mechanisms ensuring continued KE ensured suppliers were in lock-step with customers to improve existing processes, but also to help customers "adapt relatively quickly" when needs changed. As Richard stated, to identify and solve emerging problems "a constant level of communication is key."

2.5.3.4.3 Incorporating User Feedback

We found it vital to continue keeping users heavily-involved in process improvement efforts post-implementation. Users are best-positioned to understand how AMR operate in their work environments, which when shared allows supplying and customer firms to develop hardware and software changes, incorporate add-ons, or explore new value-adding AMR applications. Moreover, by codifying and incorporating knowledge obtained during previous integration phases and developing training guides, firms provide clearer direction to new users, and potentially new sites adopting AMRs. By tapping users for feedback, firms reinforce user "ownership" and ensure knowledge utilized to create new processes or changes originate from validated sources.

2.5.3.4.4 Process Modification and Improvement

As post-implementation AMR-driven processes solidify, opportunities exist for firms to re-examine efficacy of these processes. Two sources of knowledge primarily catalyzed re-assessment. The first is knowledge acquired by users via experience and proficiency. As previously discussed, appropriation and familiarity allowed users to acquire first-hand knowledge over time. Second, as customer firms collected data post-implementation, they obtained knowledge by developing and tracking metrics and key performance indicators. This can be shared with users by providing operational direction, or with suppliers to leverage technological improvements.

In one example of post-implementation process improvement, Direct-to-Customer Med Co. relocated their warehouse's high velocity items, traditionally placed near staging areas to minimize distance traveled, to bulk locations in the rear of the warehouse since AMRs "eliminated walk time as a factor." This allowed the firm to open up space near staging areas for a wider variety of SKUs, increasing batch-picking efficiency. Anthony, the company's CEO, attributed this innovation to post-implementation collaboration with integrator and users, asserting "re-examining processes post-AMR implementation completely changed (our) thought process."

Many potential improvements are not apparent until after AMRs are fully operational. As new processes are put in place, bottlenecks begin to emerge. In one instance, Swarm Robotics identified a bottleneck caused by variability in human behavior (i.e. breaks, fatigue). In this case, they implemented a put wall, essentially creating a break in the process and providing greater working inventory for human pickers. In another example, Flash Robotics working in conjunction with Warehouse Solutions Consultants, determined their customer's huge efficiency gains in order-picking lead to a buildup of inventory at staging areas. This led them to re-examine their trucking schedule, include more frequent pick-up times, and ultimately reduce customer lead-time for orders.

2.5.4 Contextual Conditions

Each ETI is unique and consummated under a set of rich contextual conditions affecting the degree effective KE is achieved. Although context changes over time, we suggest sets of contextual conditions stakeholders encounter in each unique ETI is beyond their immediate control to influence. Yet, these conditions impact experiences and perceptions of stakeholders, shaping how they relate to one another.

For instance, inherent sophistication of customer firms enhances their ability to self-assess operations and potential technology solutions, as well as communicate with solutions providers. Additionally, customers determining their organization possessed adequate engineering and analytical expertise were apt to decline co-opting technology integrators, preferring instead to work directly with suppliers. By executing ETIs without the assistance of an integrator, KE was actually hindered, as integrators ease communication and coordination between customers and manufacturers.

Another example of a contextual condition affecting is the relative size disparity between a customer's AMR fleet and the fleets of their suppliers' other customers. We found when customer fleets were small, and their supplier worked with other customers with relatively large fleets, service diminished and KE suffered. Alternatively, when customers represent a large proportion of a supplier's business, service and KE is tailored and deliberate. As Daniel from DefenseCo explained, "We have a less than stellar relationship with the manufacturer, to be perfectly honest with you. They are not always responsive, because, I'll be blunt, we are not very meaningful to them as a company. Their largest customer buys thousands of AMRs while our company buys only dozens. From my perspective, they truly do not actually care about my business."

For a complete set of contextual conditions affecting KE during AMR ETIs, please see Table 2.3.

Table 2.3: Contextual factors

Factor	Impact	Representative Quote(s)
Sophistication of Stakeholders	• If customers are “sophisticated” by means of adequate engineering and analytical expertise, they are better equipped to assess their own business processes and communicate issues to suppliers (or other stakeholders). • Larger companies are more sophisticated at executing change management, more accustomed to continuous improvement and innovation, and more clear-eyed in terms of expectations compared to smaller, less-resourced firms.	• “A lot of this is based on how sophisticated the customer is you’re dealing with. If they’ve got an experienced and educated analytical department, they will be much more prepared and equipped to communicate the issues to us. That’s a very big piece when working jointly with their project team to do an analysis of the project.” • “Big companies are used to continuous improvement and innovation. But when you get past the large corporations and drop down to that next layer, they don’t have the sophistication in project management, change management, and data management.”
Stakeholder Experience	ETIs realize benefits from experience all stakeholders bring to bear, but since suppliers generally execute more ETIs than customers, their technology and process expertise is especially critical. Several suppliers described a maturation process after being involved in several projects where they felt more comfortable assisting customers with self-assessment and process-engineering, rather than just saying yes to customer demands (a transition from a technology company to a service provider). Customers engaging with experienced suppliers were better positioned to mitigate or avoid uncertainty during project execution. When stakeholders have experience, inherently they possess greater knowledge. When this experience (or knowledge) is pooled through KE during an ETI, integration is enhanced.	• “We did everything in-house. Looking back, I think co-opting an integrator would have probably been the better way. We learned from this, as this is our first stab at automating material handling and warehouse operations. Looking back, I would rather have gone to more of an expert in warehouse automation and technology and say, ‘hey, where have you seen these things be really successful’ versus us just saying, ‘hey, we think this would be successful here. Let’s just go try it’. I think we would have seen different outcomes.” • “Once you do a few (integration projects), you get better. And then you do a few more, and you do better and better. “ • “So as with most startups, most small companies in the early days when you’re dealing with customers the answer is always ‘yes’. But as we’ve gained more experience and more validation, we’re more comfortable with telling a customer ‘well actually, this isn’t the right application’. But if you either adjust your workflow or we look at another application, we are invariably able to add value.”
Project Complexity	AMR ETI projects ranged from very basic implementation of only a few robots to more complex projects with dozens of robots and a high-level of information system integration. When projects included add-on hardware to increase AMR capability (i.e. racks, tow carts, etc.) or attempted to integrate hardware from different manufacturers, this added a tremendous amount of complexity. Additionally, firms encountering issues regarding network security or integration with homegrown warehouse management systems dealt with extra project complexity. Some firms overcame this complexity by codifying software interfaces and data transactions in ETI planning phases. Additional project complexity required more robust KE.	• “We will bring robots up on site for testing and validation, at which point they’re pretty much ready to go. So that can happen very quickly, or it may take more time depending on the complexity of the deployment. We’ve had deployments up and running from contract signing to AMRs operating within two weeks. In other instances, bigger fleets and more complex deployments obviously take longer.” • “The robot out of the box is pretty good. We did not initially have any issues, but the towing hook adds a pretty tremendous deal of complexity. You’re now towing a payload making path planning much more complicated. “ • “Usually we come out to sites when there’s higher-level software integration as opposed to manually directed operations. So, we may be involved with doing some integration and communication testing between software.”

Factor	Impact	Representative Quote(s)
Relative Size Disparity	When customer fleets were small, and their supplier worked with other customers with relatively large fleets, service diminished and KE suffered. Alternatively, when customers represent a large proportion of a supplier's business, service and KE is tailored and deliberate.	• "We have a less than stellar relationship with the manufacturer, to be perfectly honest with you. They are not always responsive, because, I'll be blunt, we are not very meaningful to them as a company. Their largest customer buys thousands of AMRs while our company buys only dozens. From my perspective, they truly do not actually care about my business" • "We had five or six (AMRs) at the time. We are just too small of fish for them to really care about, like, I know at the time when I was working on the hook fleet they had customers that had bought like 50 or 100 of these things. And I actually remember one of them came to help us with something finally after weeks of saying, can you please come and just spend a day or two. And after the first day, they were like, 'I have to go to the (our other customer's) plant and they left."
View of ETI as Short- versus Long-Term Projects	Customer firms that viewed ETI as a short-term automation project to automate a specific task or function struggled to make institutional changes necessary to optimize and continually improve AMR performance. When firms showed a commitment to innovation more broadly, rather than commitment to a limited-scale project, they were more willing to share knowledge and forge deeper partnerships with other stakeholders. Moreover, suppliers were generally keener to obligate additional resources with customers committed to long-span management and achieving a more sustainable (rather than quicker) ROI. Firms committed to AMR integration as long-term projects forged relationships allowing them to expand their capabilities and adapt to changing market environments over the long-term.	• "I would say I can tell you what I wish that AMR rollouts were thought of as long-term projects and not 'this one delivery is a good idea'...I wish, in general, the projects were bigger picture, like let's rethink the way that we warehouse a little bit." • "And (integration) is a typically a long span management. So, it makes the ROI a little longer. We do not want to do business with companies that aren't serious about really innovating their companies." • "So there's all these things can kind of eventually play together as our needs change and our business grows. We don't really feel like there's a high risk that we will have to abandon this technology a few years down the road as our needs change. You know (Flash Robotics) is expanding their capabilities, improving their algorithms and looking for new applications that could benefit us down the road. And (Warehouse Solution Consultants) being our solution provider is doing homework and legwork to be aware of all the different technologies, working with (Flash Robotics) and other companies. So really you know that that's kind of the value added that they provide to us."
Project Champion/ Project Manager	• Firms enjoying leadership championing the implementation affected the energy, effort, and resources necessary to succeed at lower levels. When it was not apparent that leadership was behind the project 100%, lower-level management and users were less enthusiastic to acquire and share knowledge. • One tangible outcome of having leadership champion a project is the appointment of a full-time project manager. Project managers serve as a single, central hub allowing for smooth communication between the firm and other firm-level stakeholders. However,	• "Then there are sites that have just very poor leadership or leadership just has not bought into it. Users feel like they have been given this it and it was ordained from above that they have to do this. And they just know it is not going to work. The AMRs seem to break most often at these sites and overall AMRs just might not be successful there" • "If the company is not 100% behind it, it's hard for the associates to get 100% behind it, especially when they think it is going to take their job." • "If you don't have management that understands the process and they're not pushing change management down, and the people at the ground don't have buy in, you know, the chances of them wanting to use the system and to use it correctly is questionable at best."

Factor	Impact	Representative Quote(s)
	when project managers are assigned while simultaneously retaining other responsibilities, their effectiveness wanes.	• "And most people do not adequately, allocate resources to project management. I've only been with one client that actually had a full-time project manager assigned to the project and it was probably the smoothest implementation."
Meaningful Relationships with Stakeholders	• When relationships are strong and protracted, KE is enhanced. Ideally, these relationships would exist between each identified stakeholder (customer, supplier, and users). If customer-supplier relationships are poor or dysfunctional, KE is stifled as customers deal with unresponsive suppliers and struggle through technical problems. • Additionally, having a consultant or integrator fully on-board can be important, as integrators act as a link between customers and manufacturers, easing communication and coordination. Maintaining strong relationships helps projects evolve from basic implementation into something more meaningful that continues to improve over the long-term.	• "Our partnership is strong, they provide a tremendous amount of value to our organization. I have all of their cell phone numbers from both the engineering and sales side. I am able to call them, and they call me, and we solve problems and work together. It is a true partnership." • "And some companies want to dab their toe in it, not use it to its full potential and unless an integrator is really on them and help them understand the full potential and get the full use out of it. It's not as simple as 'here's your P.O., here's your robot, have fun'. It's more of a relationship you build in order to get them to use the machine to its full potential."
AMRs Designed for Ease-of-Use	When AMRs are easy to use and intuitive by design, users require less training (KE) from suppliers. Deliberately designing AMRs with users in mind (for example, incorporating operating systems users were already familiar with, i.e. wrist-mounted touch screen interface using Android or iPhone iOS) eased adoption. AMRs with simple and intuitive controls reduced feelings of being "overwhelmed."	• "Our whole company is founded on that premise of the easier and more intuitive it is to work with the more. It acts as you'd expect the faster it is going to be for workers to adopt because it's designed really for them to use." • "Part of the strategy we had beginning was, look, this unit is incredible. It's super robust, very flexible, and includes all these commands users can apply. But what we found was users are just overwhelmed. And so that's when we encountered a lot of people digging their feet in thinking 'I just want to come in and just pull my cart around and pick my cases, so let's just keep it simple'. So, what we found worked was keeping all the flexibility there, but training them to operate the AMR with just these two buttons, the entire time. That's all you need."

2.6 Discussion and Implications

AMRs are emerging as important alternatives to traditional warehousing automation as AI enables real, physical, and practical human-machine collaboration for the first time. AMRs are potential game-changers for small- and medium-sized WDCs, who until now faced barriers to automating, relegating them to competing with conventional manual order-picking systems. However, as we have discussed, autonomous and collaborative characteristics fundamentally differentiate AMRs from traditional automation and should change the way firms approach adoption, implementation, and use. In response, our research examined the phenomena of technology integration to develop a substantive theory explaining how firms best assimilate AMRs into WDC operations.

Though previous research examining ETI asserts interorganizational interaction is a key mechanism mitigating deleterious effects of technology uncertainty (Stock and Tatikonda, 2008), our study provides a much clearer and more comprehensive understanding of how AMR integration occurs in the context of intralogistics. The specific context is important because it describes what Stock and Tatikonda (2008) would characterize as the extremes of technology integration. AMRs are novel, complex, and require tacit knowledge to integrate effectively, distinguishing AMR integration as possessing high levels of technology uncertainty, yet WDCs possess inherently low information processing capacity. We believe our study exploring how firms overcome this “mis-fit” through an iterative process of KE between stakeholders (including end-users) yields considerable insight generating both research and managerial relevance.

2.6.1 Research Implications

The proliferation of technological innovation has pushed the field into exploring implications of fully autonomous systems undergirding the supply chain of the future. As a result, the preponderance contemporary research centers on future logistics concepts, but fails to address contemporary, mixed-environments where machines and humans collaborate (Klumpp, 2019). Our study addresses this critical gap by examining how firms integrate AMRs into WDC picking operations, ascertaining KE's pivotal role in uniting supplying firms, customer firms, and users towards improving ETI performance. By explicating the process of KE, how it varies based on phase, and how it affects ETI performance, we contribute a framework that can act as a foundation for future AMR research, or collaborative technologies more broadly.

Our study's qualitative, GT approach, produced a rich set of findings resulting in a substantive theory of AMR ETI explaining this specific phenomenon, but also generated a myriad of important implications related to ETI more generally. Firstly, contrary to prior conceptions of ETI emphasizing the primacy of technology in affecting integration outcomes (Stock and Tatikonda, 2008) we determined the ways, means, and applications in which technology is integrated and how firms adapt work tasks to accommodate technology is non-trivial. Customers and users must obtain technological knowledge to effectively integrate AMRs, but cannot do so without suppliers, who possess technological knowledge but require process-related knowledge from their customers. ETIs are more complex than the technology being integrated; relationships, experience, stakeholder sophistication, firm culture, and complexity of application are just a few factors affecting ETI performance. To understand and overcome ETI challenges, stakeholders require knowledge; however, no single stakeholder has perfect information at the outset of an ETI. We found if stakeholders are able to effectively exchange knowledge they do possess, integration outcomes are enhanced. Alternatively, when KE was ineffective firms failed suffered setbacks and diminished performance.

Second, we found the "level" uncertainty manifests itself during AMR integration differentiated AMRs from other types of automation. As traditional automation physically separates machines from human operators, repetitive interaction occurs in a single place and time. Thus, users deal with little uncertainty, since basic processes may change but little learning or adaptation is required to become proficient. More uncertainty is realized at the firm-level, as infrastructure changes, process re-engineering, and integrating elements internal and external to their WDC challenges managers and industrial engineers. In contrast, AMRs can be theoretically deployed with few changes to warehouse-level operational processes and sometimes with little to no infrastructure change. AMR integration is seemingly less problematic for firm-level entities; however, users must now cope with uncertainty regarding robot behavior, appropriation, and new roles in AMR-integrated tasks. With AMR ETIs, less uncertainty is leveraged upon firms and more uncertainty is leveraged upon users (see Figure 2.11). Rather than the effectiveness of technological integration, AMR ETI performance is based on the operator's ability to effectively collaborate with AMRs during task execution. Future ETI research should explore the consequences of this shift, and seek to integrate theory explaining individual technology acceptance.

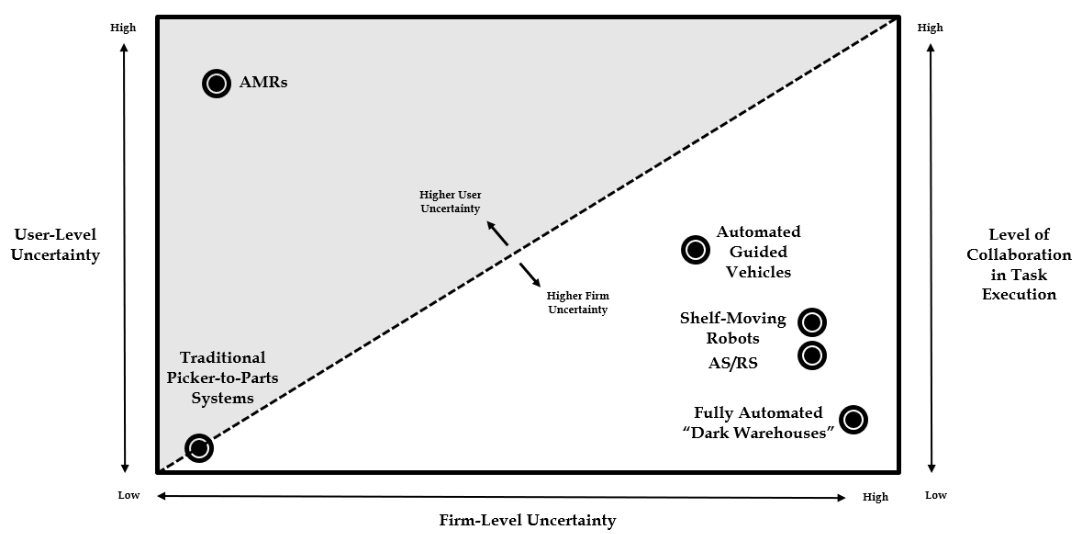

Figure 2.11: User- versus firm-level uncertainty during ETI

Finally, although we found KE important during each phase of integration, KE was most predominant during planning and pre-implementation phases, and less so during execution and post-implementation phases (see Figure 2.12). We found two reasons explaining this. First, some firms were seemingly satisfied achieving a basic level of operation. This was especially true among integrating firms lacking leadership commitment to innovation or firms with weak or shallow relationships with suppliers. For these firms, ETI effectively ended in Phase 3 Execution. Fewer firms committed to ETIs as long-term, rather than short-term episodic, tasks. However, these firms, empowered by strong stakeholder relationships, enjoyed continued improvements in Phase 4 and superior returns-on-investments. When firms viewed AMR ETI as long-term projects, they were more inclined to make physical and institutional changes to accommodate them. Future studies examining ETI should assess customer outlook regarding the perceived role of technology in future operations and whether AMRs support long-term strategies or are viewed as "one-off" projects to improve efficiency.

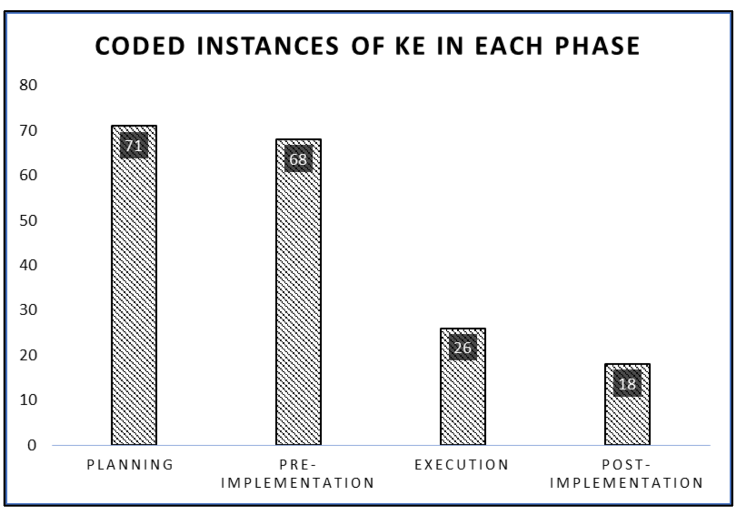

Figure 2.12: Coded instances of knowledge exchange during each phase of AMR ETI

2.6.2 Managerial Implications

Beyond theoretical implications, our findings suggest important implications for managers seeking to implement AMRs in WDCs. Our process model can act as a guide for both customers and suppliers planning integration projects, providing insight into how firms navigate common sub-processes in each phase of AMR ETI. By identifying KE as the core category explaining variation in performance, our process model gives detailed guidance on how firms execute KE in each phase in pursuit of achieving “phase goals” facilitating further progression. Moreover, our findings make the iterative process of KE explicit, meaning managers can use our process model to decide if knowledge must simply be acquired to solve acute issues, or if knowledge should be transferred internally or externally. Overall, managers can leverage these frameworks to better understand how AMRs differ from traditional automation and develop strategies to better enable timely and effective AMR integrations, leading to better operational performance.

Moreover, we found KE possessed utility to help stakeholders solve problems, but also ensured stakeholders constructed shared conceptions of both technology, process, and the intersection of the two. Mis-matched expectations between supplying and customer firms resulted in major issues if left unresolved. When customers had clear expectations of AMR capability and performance outcomes, and suppliers clearly understood customer processes and goals, both parties were better able to comprehend knowledge they and their partnering stakeholders required. Managers should facilitate level-setting of expectations, through KE, by ensuring execution of in-depth assessments, demonstrations, written performance agreements, small-scale pilots, and in-person exchanges.

Finally, our study illuminated the importance of user centrality when integrating autonomous, collaborative technologies like AMRs. Because performance ultimately depends on how well users collaborate with AMRs in executing picking tasks, their perspective should be valued in every stage of integration. We found by including users in planning and soliciting feedback to make substantive changes before, during, and after implementation, managers can positively influence buy-in and user feelings of ownership. As Steven put it, firms “have to go against their natural inclination when it comes to (collaborative) robotics” by minimizing the role of industrial engineering and emphasizing user participation. By elevating users as central stakeholders, managers can overcome user anxiety, improve user acceptance, enhance appropriation, and lay the groundwork for long-term process improvement.

2.7 Conclusion

AMRs have the potential to broadly transform intralogistics as we know it, breaking dichotomous notions of WDCs employing all-or-none approaches to technology. Mixed WDC environments of the future will feature humans and robots sharing spaces and responsibilities, and their effectiveness very-well could hinge on how well humans collaborate with machines in the execution of hybrid picking tasks. Rather than the typical automation approach of replacing humans, AMRs augment workers, helping them to pick more efficiently and effectively. We determined AMR integration, as in use, is a human challenge as much as it is a technology challenge. When stakeholders partner to meet the challenge of effectively exchanging knowledge, reduced uncertainty eases the integration of AMRs into WDCs and ultimately increases operational performance.

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ESSAY 3

COLLABORATIVE TECHNOLOGY INTEGRATION: ACHIEVING ORGANIZATIONAL OBJECTIVES BY INFLUENCING END-USER ACCEPTANCE

3.1 Introduction

In an era of supply chain competition, warehouses and distribution centers (WDCs) are increasingly critical links ensuring firms can compete in an environment of dynamic customer demand, smaller order sizes, and narrower delivery windows (Batt & Gallino, 2019; Boysen et al., 2019). E-commerce and omni-channel distribution increases order-picking volume considerably, pressing WDCs transitioning from traditional to direct-to-customer distribution models to become more efficient in the midst of an acute labor shortage (Evans, 2021; McCrea, 2019). Despite the ability of automation to increase output and minimize unproductive work, warehouses still overwhelmingly employ manual order-picking processes (de Koster et al., 2007; McCrea, 2019). Barriers relating to capital expenditure and loss of long-term flexibility prohibit many firms from adopting automation (Hackman et al., 2001; Marchet et al., 2015); however a new generation of smart robotics, driven by artificial intelligence (AI), offer WDCs the affordability, flexibility, and scalability to overcome these traditional barriers.

The task of order-picking is not only the fastest growing warehouse (Nieves & Sharma, 2021), but also the most expensive and labor-intensive warehousing task (de Koster et al., 2007; Drury, 1988). As traditional order-picking requires significant human capital investment, order-picking processes have long been targeted in automations efforts aimed at minimizing inefficiency and reducing human error (Azadeh et al., 2019). Recently, widespread access to AI-driven, scalable technologies, such as autonomous mobile robots (AMRs), is allowing order-picking tasks to be economically automated using existing warehouse infrastructure. AMRs are industrial robots using decentralized decision-making processes to optimize workload and provide a platform for collision-free material handling within a bounded area (Fragapane et al., 2021). On-board computing and advanced sensors enable trackless navigation and obstacle avoidance in WDCs, allowing AMRs to work seamlessly alongside human order-pickers (Trebilcock, 2020). Leveraging AI to optimize path-finding and workload in real-time, AMRs act as “intelligent assistants” in shared workspaces (Tang et al., 2014), assisting people in the execution of order-picking tasks. Order-picking requires flexibility and problem-solving, but also physical strength and endurance. The ability of AMRs to actively collaborate with human counterparts allows the strength, efficiency, and precision of the machine to compliment the intellect, creativity, and problem-solving of its human operator, creating a synergistic effect in task execution (Boysen et al., 2019; Krüger et al., 2009).

AMRs provide a capable solution to increase warehouse productivity; however, firms must understand how to effectively integrate them into their WDC operations to realize AMRs’ full potential. Automation ventures are challenging, often taking longer than anticipated to generate expected returns or failing altogether (Bell et al., 2014; Cooper & Wolfe, 2005; Fawcett et al., 2011). Moreover, integration of AMRs presents unique challenges. Traditional automation deliberately delineates human and machine activity, distilling interaction to a single place and time (task handoff); however, collaborative technologies (i.e. AMRs) work in shared environments where human interaction is not only robust, but necessary for the technology to function as designed. Operational performance of traditional automation is dependent on functional performance of the machine and its fit to the applied task. In contrast, AMR performance depends on abilities of human operators to collaborate and effectively partner with AMRs in executing order-picking tasks. Thus, AMR integration requires increased emphasis on human factors, resulting in increased complexity during implementation.

The firm-level process of acquiring and integrating technology from an external source is known as external technology integration (ETI) (Bell et al., 2014; Stock & Tatikonda, 2004). A series of studies by Stock and Tatikonda (2000, 2004, 2008) indicate customer-supplier interaction is a key factor mitigating uncertainty firms encounter during ETI execution, ultimately leading to higher rates of integration success. However, their framework overlooks users' central role in adoption and implementation processes, which due to AMRs' collaborative nature is presumed to be fundamental in this context. Despite the pace of technological change, low-levels of individual acceptance and use within adopting organizations remains a central concern. When new technology is introduced, individual resistance is a common response, with reactions ranging from avoidance and creating workarounds to explicit sabotage (Venkatesh & Bala, 2008). Under-whelming use of new systems continues to plague organizations, often resulting in failure to achieve adequate ROI from technology investments (Devaraj & Kohli, 2003). Thus, during technology integration projects it is critical firms take active steps to mitigate user resistance and ensure widespread acceptance and employment.

Therefore, to understand AMR ETI holistically, our paper takes a conceptual development approach to integrate a user perspective in ETI using the technology acceptance model (TAM) as a theoretical lens. Developed by Davis (1989) to predict intention of users to adopt a new IT system, TAM is widely considered the most influential and commonly employed theory explaining the acceptance or rejection a new system (Lai, 2017; Venkatesh & Bala, 2008). The purpose of this paper is to explicate the relationships between actions available to management and individual cognitive constructs positively influencing TAM constructs, leading to increased technology acceptance and, ultimately, more successful technology integrations.

First, organizational information process theory (OIPT), ETI, and TAM are introduced as theoretical bases of our new framework. Then, interorganizational interaction, a central determinant of ETI success at the firm-level, and user participation are explored as important activities promoting cognitive determinants of individual acceptance. Next, theoretical links between psychological ownership, technology trust, self-efficacy, and TAM constructs are developed. Finally, the logical relationship between greater individual technology acceptance and firm-level ETI performance is inferred and developed. Our work provides theoretical evidence that, in the context of highly collaborative technologies (i.e. AMRs), management-level interventions influencing individual-level acceptance of technology can improve firm-level outcomes regarding ETI project performance.

3.2 Literature Review

3.2.1 Organizational Information Processing Theory

AMR ETIs, which involve the acquisition and integration of AMRs into a firm's internal operational processes, can be understood as firm-level, episodic tasks through the lens of OIPT (Stock & Tatikonda, 2008). OIPT is an organizational theory viewing firms as open social systems that must organize effectively to cope with task-related uncertainty and equivocality (ambiguity) (R. Daft & Lengel, 1986; Galbraith, 1974; M. Tushman & Nadler, 1978). According to OIPT, tasks differ in their level of predictability as a result of task complexity, task environments, and degree of interdependency between business units, resulting in varying levels of information which must be processed during task execution. To deal with information processing requirements, firms organize subunits in either mechanistic (i.e. vertical, formal, highly regulated, centralized power and control) or organic (i.e. lateral, participative, problem-solving, de-centralized power and control) fashion and implement coordination and control mechanisms to ascertain requisite information processing capacity for target tasks (M. Tushman & Nadler, 1978). OIPT views achieving "fit" between tasks' information processing requirement and an organizations' information processing capacity as the fundamental managerial challenge. The basic problem of creating either too little or too much information processing capacity, results in either task ineffectiveness or task inefficiency, respectively. The degree to which adequate fit is achieved ultimately affects quality of task outcomes (see Figure 3.1).

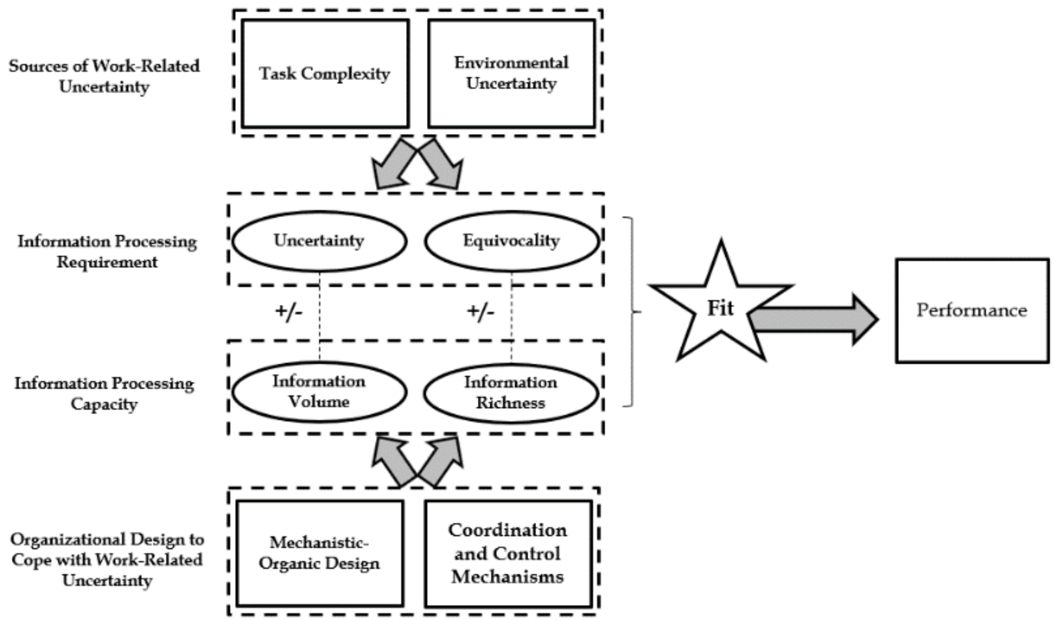

Figure 3.1: Model of organizational information processing theory (adapted from Tushman and Nadler, 1978, p. 622)

During the task of ETI, Stock and Tatikonda (2008) propose organizations mitigate technology uncertainty by ensuring appropriate levels of interorganizational interaction (IOI) with suppliers, thereby increasing recipient information processing capacity during project execution (see Figure 3.2). Technology uncertainty, defined by Stock and Tatikonda (2008) as "the difference between the information needed to obtain and implement the technology, and the information the recipient actually has at the start of the ETI process," is a product of technology's novelty, complexity, and required tacit knowledge. IOI captures the extent of dyadic interaction between recipients and suppliers of technology among dimensions of communication, coordination, and cooperation (Tatikonda & Stock, 2003). Therefore, at an organizational level, managers should pursue "fit" between the level of IOI among these dimensions and the level of manifest technology uncertainty during ETI execution to ensure successful outcomes.

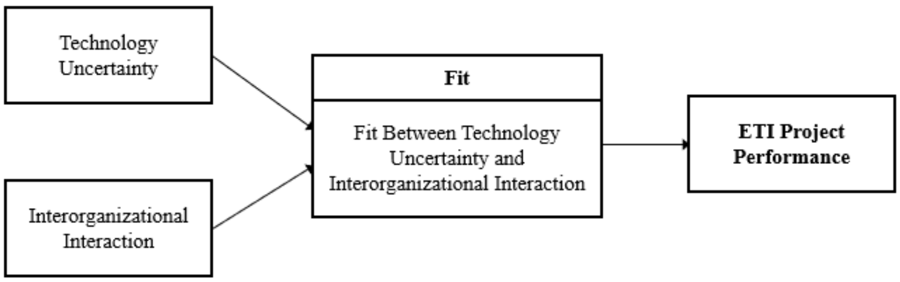

Figure 3.2: Conceptual framework of ETI project performance (Stock and Tatikonda, 2008, p 68)

Typically, WDCs are characterized as having low information processing requirements during normal, day-to-day operations. Most warehousing environments are stable, with well-understood issues and rare exceptional scenarios. Thus, highly-centralized and hierarchical mechanistic structures, governed by formalized procedures and designed for efficiency are appropriate for routine, low information processing tasks typical of most warehouses (Srinivasan & Swink, 2018). Yet, technological and procedural changes inherent in the "task" of ETI creates temporal uncertainty and equivocality which WDCs are ill-equipped to confront. Due to the technology's novelty, complexity, and required tacit knowledge to integrate, AMR ETIs are characterized as having high levels of technology uncertainty, creating a "mis-fit" between AMR technology uncertainty and warehouses' intrinsic information processing capacity. Unresolved, this mis-fit can potentially lead to adverse outcomes including schedule over-runs, cost proliferation, and low-technical performance (see Figure 3.3) (Tatikonda & Stock, 2003).

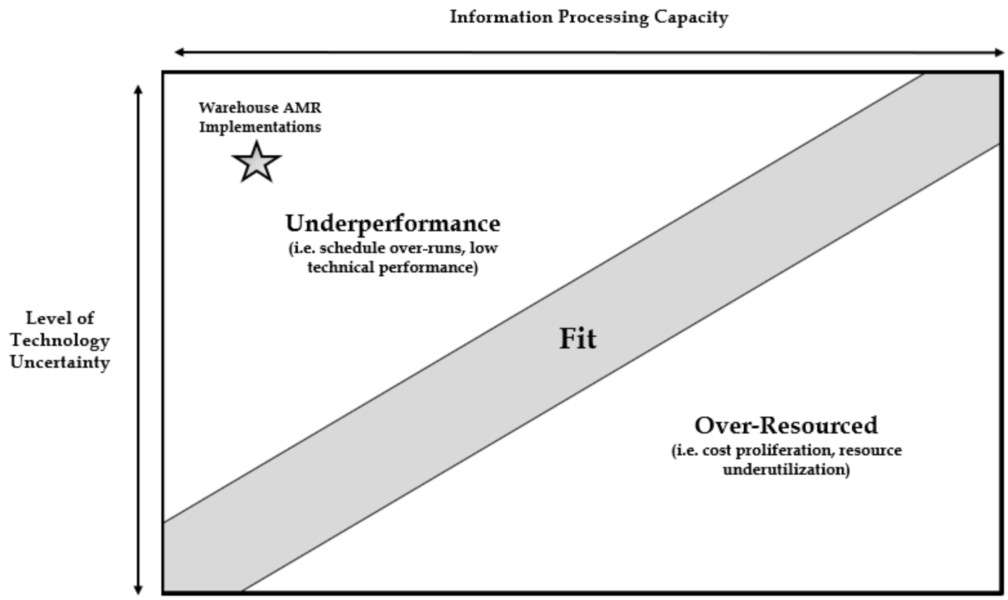

Figure 3.3: OIPT perspective of warehouse AMR ETI

While OIPT is foundational to current ETI frameworks, some aspects of OIPT remain unaddressed in current ETI models. For example, previous ETI models focus singularly on coordination and control mechanisms encompassed in IOI. This view understates the importance of organizational structure, and requirements for mechanistic organizations to adapt an organic capability to achieve "fit" when uncertainty and equivocality are high. In addition, the nature of coordination, communication, and cooperation involved in IOI matter. In this sense, it is essential to understand the role of media richness in OIPT. Media exists in either lean or rich forms. Lean forms of media such as company memos, generalized emails, spreadsheets, and databases provide information to reduce uncertainty, but are ill-suited to reduce task equivocality (R. L. Daft & Lengel, 1986). It is a shared frame of reference that gives meaning to leaner forms of media. Richer forms of communication facilitate personalization, the ability to obtain immediate feedback, and provide multiple verbal and non-verbal cues (Cooper & Wolfe, 2005; Daft & Lengel, 1986). Some examples of rich media include face-to-face meetings, one-on-one exchanges, telephone conversations, and teleconferences. Rich forms of media, are inefficient at reducing uncertainty, but excellent at combating high levels equivocality (Daft & Lengel, 1986). Firms undertaking AMR ETIs likely experience deficiency of information (uncertainty), but also ambiguity concerning what that information means (equivocality), which is best counteracted with IOI involving sufficiently rich information.

3.2.2 Technology Acceptance Model (TAM)

Successful ETIs are important for organizations to realize expected benefits commensurate with their technology investments, but are impossible without ensuring users accept and use technology as intended. Ostensibly, organizations can coerce technology acceptance by making its use mandatory; however research suggests this approach can result in reluctant or deviant behavior producing dissatisfaction, low morale, and decreased productivity (Bhattacherjee et al., 2018). Despite the pervasiveness of technology in the workplace, resistance to new technology due to fear, lack of confidence, perceived difficulty of use, and lack of motivation is commonplace and remains a central concern for adopting organizations (Igbaria & Iivari, 1995). From a firm perspective, it is important to understand available and suitable management interventions to persuade voluntary user adoption based on inherent system benefits. To this end, TAM is an important addition to our conceptual framework.

In the field of information systems (IS), a stream of research using TAM (and numerous variants and extensions) has made incremental progress in understanding cognitive factors predicting intention of end-users to adopt new IT systems (Davis, 1989; Venkatesh et al., 2003; Venkatesh & Bala, 2008; Venkatesh & Davis, 2000). By extending the theory of reasoned action (Fishbein & Ajzen, 1975) to IS, TAM concludes two primary constructs, namely perceived ease of use (PEOU) and perceived usefulness (PU), are responsible for individual behavioral intention to use a system (Davis, 1989) (see Figure 3.4). Thus, when new technologies are introduced, individual beliefs about the extent that using a system will enhance an individual's job performance (PU) and be free of effort (PEOU) are important in predicting system use (Venkatesh & Davis, 2000).

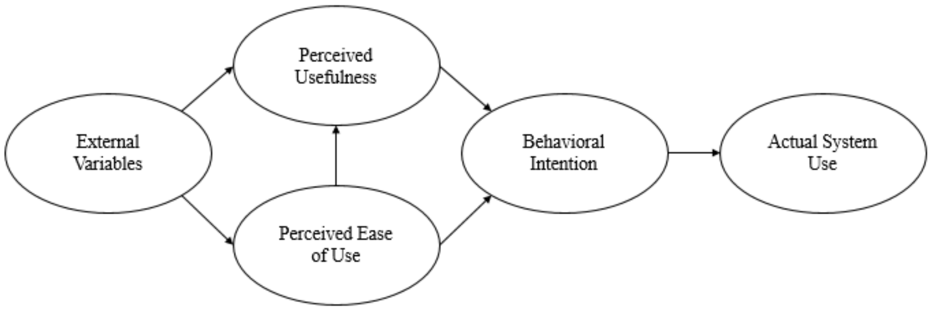

Figure 3.4: Technology acceptance model (Venkatesh and Davis, 1996)

TAM hypothesizes the central constructs of PEOU and PU mediate a host of external variables influencing behavioral intention. Due to interpretation of PEOU and PU as associative cognitive constructs, external variables are the focus of numerous extensions of TAM. For example, the TAM2 framework (Venkatesh & Davis, 2000) explores several determinants of PU, including both social influence and cognitive instrumental processes in their model. Venkatesh & Bala (2008) developed TAM3 by integrating additional determinants of PEOU and focusing on interventions designed to aid managers in increasing user acceptance. Among these interventions are organizational support, training, and increasing user participation during implementation. The unified theory of acceptance and use of technology (UTAUT) attempted to integrate elements of eight competing user acceptance models (including TAM), concluding the four constructs of performance expectancy, effort expectancy, social influence, and facilitating conditions capture the essence of most existing frameworks (Venkatesh et al., 2003). Finally, a further extension of UTAUT applied within a consumer context produced UTAUT2, which explored three additional constructs, namely hedonic motivation, price value, and habit (Venkatesh et al., 2012). It is important to note while these various TAM-related models address external variables and their relationships with core TAM constructs of PEOU and PU, few studies include firm-level, managerial interventions designed to influence these variables (Venkatesh & Bala, 2008).

Regarding the type of technology under examination, the relationships in TAM are considered robust and fairly invariant (Burton-Jones & Hubona, 2006; Chircu et al., 2000), therefore propositions regarding these relationships are not examined explicitly in this paper. As AMRs are behaviorally dependent on complex suites of AI software, we expect TAM relationships to hold in the context of AMR acceptance and use. Rather, management interventions, context-dependent determinants of TAM, and integration with the ETI framework is our paper's focus. We expect the outcome of TAM, the degree in which AMRs are accepted and employed by users, will directly affect overall ETI project success.

3.3 Conceptual Development and Research Framework

The simplicity and predictive power of TAM make it an ideal framework to explore user acceptance of technology adoption in a multitude of settings, however TAM's parsimony is also cited as a major limitation (Ha & Stoel, 2009; Venkatesh, 2000). Our conceptual framework (see Figure 3.5) makes theoretical arguments proposing the most salient determinants of PEOU and PU in the context of user-centric, collaborative technologies like AMRs. Moreover, our framework emphasizes practical managerial relevance by underscoring management interventions hypothesized to positively influence these TAM determinants. In the following sections, we investigate two important managerial interventions to improve technology acceptance, develop causal relationships between individual cognitive determinants and the constructs of PEOU and PU, and integrate TAM and ETI frameworks to hypothesize how firm-level intervention can result in greater individual acceptance and, ultimately, enhanced ETI performance.

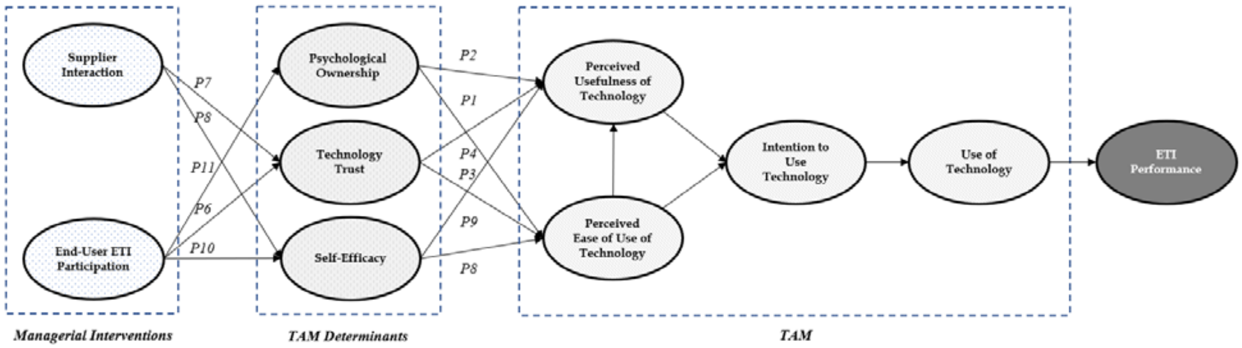

Figure 3.5: Proposed TAM model for AMRs

3.3.1 Managerial Interventions

Exploring cognitive determinants of primary TAM constructs provides practitioners little utility without understanding how managers can influence these determinants. Interestingly, most previous studies of TAM overlook the importance of managerial intervention. To promote long-term effective use and acceptance of AMRs, firms must positively influence user perceptions of AMR ease of use and usefulness (Igbaria & Iivari, 1995). Our study posits two managerial interventions of importance in AMR ETIs: 1) encouraging supplier interaction with users and 2) allowing user participation to influence implementation. In these ways, managers can realize tangible effects on user acceptance, leading to improved ETI outcomes.

3.3.1.1 Supplier Interaction with Users

From a firm-level ETI perspective, Stock and Tatikonda (2008) explain how IOI results in information processing capacity necessary to mitigate technology uncertainty during ETI execution. When considering collaborative technologies (i.e. AMRs), we propose the means by which IOI is executed should include supplier engagement at the tactical (user) level. We suggest frequency and intensity of supplier-user communication, coordination, and cooperation during ETI execution are critical factors affecting user technology trust and self-efficacy. Thus, if possible, managers should encourage, or even mandate, robust supplier interaction with users to mitigate the effects of uncertainty and equivocality during ETI projects.

During an ETI, relationships between suppliers and end-users built on open communication and interaction are key to facilitating productive and collaborative integration efforts (Mckeen et al., 1994), and mutually benefit both parties. When organizations execute ETIs, rapid change and unpredictable problems create issues for which there is no standard procedure. These issues create equivocal conditions, requiring rich information exchange and trial-and-error learning to overcome (R. L. Daft & Lengel, 1986). Media richness, as described by Daft and Lengel (1986, pg. 10), pertains to “the learning capacity of communication.” To reduce equivocality, rich forms of information exchange (such as face-to-face exchange and open dialogue) allow participants to effectively share subjective experience and intuition to develop shared conceptions of problems (R. L. Daft & Lengel, 1986). Since warehouse order pickers and AMR suppliers have highly divergent backgrounds, interests, and beliefs, richer forms of supplier-user interaction help to develop congruent frames of reference resulting in fewer misinterpretations and misunderstandings (Cooper & Wolfe, 2005).

The personalization, immediate feedback, and multiple communicative cues (both verbal and non-verbal, including body language and tone of voice) of rich media (Cooper & Wolfe, 2005; R. L. Daft & Lengel, 1986) benefits the ETI in two ways. First, it allows users to clarify ambiguities with suppliers regarding functional behavior of AMRs and their operational application. Rich media exchange, especially when supplemented by supplier-led hands-on-training and demonstration, allows end-users to learn by accessing knowledge directly from technical experts, effectively reducing ambiguity. Second, since rich information exchange is reciprocal, this type of interaction allows suppliers to obtain deeper understandings of users' operational requirements, beyond the ability of stand-alone assessments or management engagement. As experts in procedural and process-related aspects of tasks, operators are well-positioned to provide suppliers insight into potential problems or challenges, as well as opportunities, during implementation.

3.3.1.2 User Participation

While Stock and Tatikonda (2008) acknowledge user participation in ETI projects as an important contextual factor influencing performance, from a perspective of individual acceptance, it is fundamental. User participation is defined as the observable behavior of end-users in system development and implementation activities (Barki et al., 1989; Kappelman & McLean, 1991). User participation in the IS field examines contributions of users in both the system planning and design phase and the implementation phase. Our focus is on implementation, while taking the position that implementation and user appropriation are part of the actual design process (Carroll, 2004).

Ives and Olson (1984) found user participation to be especially important when projects are unstructured or user acceptance is important, both of which aptly characterize AMR implementations. In a meta-analysis of the role of user participation in IS development, He and King (2008) found if system acceptance is the goal, user participation should be designed to induce psychological involvement. Lynch and Gregor (2004) focus on the degree of user influence in design of technology, finding actual influence must reflect more than just a "token" level of user participation to affect performance. Furthermore, evidence points to latter-phase user participation positively influencing user satisfaction and system success (Kappelman &

McLean, 1991), and is strengthened further when system and task complexity is high (Mckeen et al., 1994). This aligns with Deci and Ryan’s (1985) work on autonomy and intrinsic motivation, and their assertion that when management promotes autonomy and self-determination, employee satisfaction and quality of work life improves (Deci et al., 1989). User participation in the project likely increases their assessment of control over the situation, leading to improved coping, adaptation, and outcomes (Beaudry & Pinsonneault, 2005). Thus, in the context of warehouse AMR ETIs where technology uncertainty is presumed high, we argue active user participation will promote individual acceptance and use.

3.3.2 Mediating Cognitive Constructs

As previously mentioned, external variables affecting core TAM constructs of PEOU and PU are the focus of many extensions and applications of the theory. There have been consistent calls for greater emphasis to examine both direct and indirect effects of external variables in understanding system acceptance (Burton-Jones & Hubona, 2006; P. Y. K. Chau, 2001). In addition, the context-specificity of these variables to individual systems and organizational settings suggests more systematic and contingent applications of TAM are best-suited to increase predictive capacity (Legris et al., 2003). In our framework, we emphasize three constructs that are both salient in the context of AI-driven, collaborative technologies, and highly influenced by supplier interaction and end-user participation: 1) psychological ownership (PO), 2) technology trust (TT), and 3) user self-efficacy (SE).

3.3.2.1 Psychological Ownership

PO, defined as “the state in which individuals feel as though the target of ownership or a piece of that target is theirs,” concerns an individual’s feelings of possession towards a target object (Pierce et al., 2003, p. 86). The literature cites two interesting reasons individuals are motivated to own possessions. The first is to obtain the ability to "affect desired outcomes in (their) environment" (Furby, 1978, p. 60), which is related to the need for autonomy and control (Deci & Ryan, 1985). A second motivator of individual possession is a psychological need for security (Furby, 1978). Initially, users often perceive new technology as a threat (Bhattacherjee et al., 2018). During an AMR ETI, users will likely feel anxiety and lack of control over processes and outcomes (Beaudry & Pinsonneault, 2005). PO of AMRs provides both perceived control over ETI outcomes and a sense of security as developed skills and experience make users' employment more valuable. Thus, adequate motivation exists for end-users to develop PO.

An important concept closely related to PO is technology appropriation. In the IS literature, appropriation is defined as "the way users 'take possession' of a technological innovation over time" by selecting, exploring, and modifying aspects of the technology (Carroll, 2004, p. 2). Appropriation is comparable to Rice and Rogers' (1980) concept of reinvention, or the degree technology is changed by users during adoption, and the process through which technology's design is completed through use (Fidock & Carroll, 2006). We conceptualize technology appropriation as the extent users take ownership of new technology through application and development of idiosyncratic approaches to its use in specific organizational contexts. Gaskin and Lyytinen (2010) claim PO and technology appropriation are theoretically equivalent at the individual level. We argue that, while not equivalent, technology appropriation is the process through which PO occurs. As users appropriate technology, they take responsibility for how technology is used in their organization, leading to an effective transfer of responsibility from designer to user (Gaskin & Lyytinen, 2010). The design of technology in its final form is completed by users, who take effective ownership of the technology by incorporating it into day-to-day work functions. As appropriation occurs, users become intimately familiar with functional aspects of the technology and learn how best to exploit its features, increasing confidence regarding its ease of use and utility. Users appropriating technology and enjoying a sense of PO feel more familiar with and competent in technology use (Gaskin & Lyytinen, 2010). By the same logic, PU increases naturally; as users appropriate AMRs, they deliberately decide which aspects of the AMR are useful and how best to use them.

Proposition 1: Psychological ownership is positively related to perceived ease of use of technology.

Proposition 2: Psychological ownership is positively related to perceived usefulness of technology.

3.3.2.1.1 Managerial Intervention and Psychological Ownership

Warehouse order-picking is quite simple in description, but optimizing picking operations depend on a host of variables including warehouse design, type of product (size, shape, perishability, etc.), variability of product (number of stock keeping units), and desired throughput rate (Marchet et al., 2015). Thus, it can be presumed user adoption and application of warehouse order-picking technology will be non-standard. During implementation, users undergo two distinct paths of learning. First, users systematically learn to functionally operate technology as developers intended. Secondly, users learn to apply technology and develop proficiency within their individual use case (appropriation). In this second way, users "can and do circumvent inscribed ways of using the technologies – either ignoring certain properties of technology, working around them, or inventing new ones that may go beyond or even contradict designers' expectations and inscriptions" (Orlikowski, 2000, p. 407). This supports the presupposition that users do not employ technology in a pre-defined manner (Poole & DeSanctis, 1989), but instead make technology their own by deciding which features to use and how to use them. When users participate in AMR ETIs, PO increases as users appropriate AMRs and expand their influence and stake in ETI outcomes.

Proposition 3: End-user ETI participation is positively related to psychological ownership.

3.3.2.2 Technology Trust

Traditionally, due to safety and efficiency considerations, robots and human operators operated in segregated environments, inhibiting all but necessary interaction. However, recent advances in AI allow interaction between humans and machines to be much more intimate, reinforcing the importance of TT as a predictor of acceptance and use (Yagoda & Gillan, 2012). From a relational perspective, trust is defined as “the willingness of a party to be vulnerable to actions of another party based on the expectation the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party.” (Mayer et al., 1995, p. 712) Research shows humans respond to technology socially, exhibiting similar attitudes towards technology and making judgements about interactions in a similar fashion as human-to-human interaction (Lee & See, 2004; Nass et al., 1997). Between human actors, factors influencing perceived trustworthiness include a partner’s ability, benevolence, and integrity (Mayer et al., 1995). However, regarding human-machine interaction, we modify this conceptualization as technology lacks intentionality. Thus, we assume operators disregard benevolence and integrity in assessments of TT, instead focusing on perceptions of the machine’s ability to execute tasks in a safe and consistent manner (Chen et al., 2018). Trust is built as counterparts act in a reliable manner, but damaged as individuals experience unexpected and inconsistent behavior (Muir, 1987). Thus, in the context of AMR implementation, TT is expressed as the extent an individual believes technology will reliably behave as expected.

In social and economic contexts, trust is a pre-condition for effective interaction when uncertainty is present (Pavlou, 2003). Therefore, it can be argued the importance of trust in the presence of ETI-driven technology uncertainty is elevated, especially when expertise is low and task complexity is high (Chircu et al., 2000). During initial stages of ETI when uncertainty is most prevalent, individual perceptions of TT are likely to be low. As an emerging technology, it is probable that AI-driven machines operating autonomously in shared environments engender inherent fear and skepticism. Developing trust when conditions are uncertain reduces doubt and generates a greater sense of safety (Ha & Stoel, 2009; Suh & Han, 2002).

When users cannot trust technology to behave reliably, they can be expected to expend additional time and effort understanding, monitoring, and controlling AMR behavior (Chircu et al., 2000). When trust is present, transaction costs are lower and cooperation is enhanced (Pavlou, 2003). Thus, we suggest TT positively influences PEOU. Furthermore, if trust is not established is early phases of adoption, employees may only utilize AMRs for a brief period before reverting to habitual behavior and processes (Klumpp et al., 2019). When AMRs demonstrate the ability to deliver benefits as expected, trust increases and the PU of the technology is reinforced (Gefen et al., 2003). When trust is absent, users may prefer to execute tasks without the assistance AMRs, as they perceive potential costs to be greater than expected future unguaranteed rewards (Gefen et al., 2003; Pavlou, 2003). If users cannot trust AMRs to reliably produce expected benefits, the value associated with its use is diminished (Chircu et al., 2000; Tu, 2018). Thus, we also suggest a direct link between TT and PU of a technology.

Proposition 4: Technology trust is positively related to perceived ease of use of technology.

Proposition 5: Technology trust is positively related to perceived usefulness of technology.

3.3.2.2.1 Managerial Intervention and Technology Trust

AMR technology can engender a level of objective trust through design by ensuring performance, consistency, and reliability. However, as trust is highly dependent on individual differences, behavior is influenced by the perception of trustworthiness, not the actual objective trustworthiness of systems (Sheridan & Hennessy, 1984). Even if technology is objectively trustworthy based on reliability of action, users must still perceive this to be true.

Increasing reliability and ease of operation strengthens perceptions of trustworthiness and individual anticipation that benefits are likely to be realized (Tu, 2018). Feedback mechanisms and user experience are two ways to reduce uncertainty and bridge the gap between potentially biased perceptions of trustworthiness and the objective ability of AMRs to reliably perform tasks (Ososky et al., 2013; Tang et al., 2014). Feedback mechanisms, which include gestures or signaling of movement or action, increase operator trust when action is signaled and subsequently executed. Of course, similar to humans with divergent backgrounds and languages, the success of this approach depends on users' ability to recognize and understand signals or gestures AMRs provide. A major benefit of supplier interaction with users is enhanced experiential learning and training with the machine (Sheridan & Hennessy, 1984). As technological change accelerates, human technological knowledge and competence has lagged resulting in a knowledge gap (Klumpp, 2018). In light of this gap, supplier interaction with users enables rich knowledge exchange, eliminating some user-level uncertainty before full implementation begins. Moreover, supplier-enhanced training and demonstration facilitates enriched personal learning experiences critical to developing user competence and trust in system reliability (Klumpp & Zijm, 2019).

Proposition 6: End-user ETI participation is positively related to technology trust.

Proposition 7: Supplier interaction with end-users is positively related to technology trust.

3.3.2.3 User Self-Efficacy

SE theory explains that strength of an individual's beliefs about personal task effectiveness influences both initiation of and amount of effort exerted when coping with challenging tasks (Bandura, 1977). Gist (1987, p. 472) defines SE as "one's belief in one's capability to perform a specific task" which "arises from the gradual acquisition of complex cognitive, social linguistics, and/or physical skills through experience." Likewise, Compeau and Higgins (1995, p. 189) state SE is "the belief that one has the capability to perform a particular behavior." Simply put, technology SE is an individual's judgement of their own capacity to use a target technology. This is important because if users believe they lack capacity to use a system, they will likely resist system adoption and use (Beaudry & Pinsonneault, 2005). Accordingly, it is no surprise SE is an oft included antecedent in extant TAM models (K. W. Chau et al., 2002; Igbaria & Iivari, 1995; Venkatesh & Davis, 1996).

Venkatesh and Davis (1996) suggest both an intuitive and theoretical basis relating SE to PEOU. SE is concerned with confidence and self-belief; thus, it naturally follows that technology SE is closely related to PEOU of technology. PEOU is defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 320), which is definitionally similar to SE. Furthermore, since technology is virtually pervasive in modern workplaces, users have a relatively well-formed conception of their SE relating to a technological domain (Compeau & Higgins, 1995). Therefore, user SE can be expected to influence PEOU, regardless of prior hands-on experience (although such experience is shown to increase SE and PEOU) (Venkatesh & Davis, 1996). In essence, a user's perceived ability to successfully use an AMR influences their evaluative and behavioral response to AMRs (Ellen et al., 1991).

In regards to SE and PU, beyond the implicit indirect relationship of SE to PU through PEOU (Venkatesh & Davis, 1996), evidence suggests a direct relationship between the two constructs. According to Bandura (1978), SE judgements impact how individuals perceive expected outcomes because those expected outcomes are highly related to how well the individual thinks they can complete the relevant task. Compeau and Higgins (1995) found SE was positively linked to both outcome expectations and system use. Thus, users who are confident in their ability to effectively use AMRs are more likely to perceive expected outcomes as positive, and are furthermore motivated to seek these expected outcomes through AMR use. Therefore, we propose there a positive relationship between SE and both PEOU and PU.

> *Proposition 8: User self-efficacy is positively related to perceived ease of use of technology.*

> *Proposition 9: User self-efficacy is positively related to perceived usefulness of technology.*

3.3.2.3.1 Managerial Intervention and Self-Efficacy

The enactive mastery of skills developed through user experience is a particularly impactful determinant of SE (Bandura, 1977). As users employ and achieve perceived successes with AMRs, SE is enhanced (Igbaria & Iivari, 1995). However, if users lack direct experience with AMRs prior to an ETI, user participation in pre-implementation phases can assist in developing accurate perceptions of system characteristics and benefits (Hartwick & Barki, 1994), thereby enhancing users' ability to ascertain accurate outcome expectations. Additionally, Bandura (1982) suggests SE can increase not only though direct prior experience, but also through vicarious experience. Thus, rich supplier-user interaction that includes hands-on training and expert demonstration likely results in increased individual confidence in technology use. Moreover, as the opinion, support, and encouragement of others influence an individual's judgement in their own abilities (Igbaria & Iivari, 1995), verbally persuasive supplier engagement may further positively affect SE (Bandura, 1977). In effect, suppliers that connect with users in an encouraging and supportive fashion may raise efficacy expectations.

Lastly, supplier interaction and user participation are evidence the recipient firm is willing to provide organizational support and resources to adopting users. Igbaria and Iivari (1995) found organizational support positively related to higher judgements of SE, since additional resources facilitate user proficiency. This aligns with Compeau and Higgins's (1995) findings that, when required, availability of organizational support increases user ability and therefore judgements of SE. We view encouraging direct supplier interaction with users as a form of organizational support, reflecting the dyadic nature of ETI (involving both supplying and recipient firms) (Stock & Tatikonda, 2008), which similarly influences SE. Robust supplier-user engagement can mitigate end-user ambiguity, while providing a mechanism for targeted training in areas of deficiency (Gist, 1987). Additionally, permitting supplier-user engagement reflects a formal stance from organizations towards AMR usage, resulting in organizational norms positively affecting outcome expectations (Igbaria & Iivari, 1995). Thus, we propose both user participation and supplier interaction with users positively affect SE.

Proposition 10: End-user ETI participation is positively related to end-user self-efficacy.

Proposition 11: Supplier interaction with end-users is positively related to end-user self-efficacy.

3.3.3 TAM and ETI Performance

In the development of Stock and Tatikonda's (2000, 2004, 2008) ETI framework, task effectiveness is measured by key elements of project effectiveness, namely timeliness, cost-effectiveness, and functional performance (Meredith & Mantel, 1995). This firm-level conceptualization's central argument emphasizes supplier-recipient IOI as the focal counterbalance to technology uncertainty leading to superior tactical-level project outcomes. However, it is precisely at the tactical-level where we argue the inclusion of a user perspective is critical. Individual resistance to technological change is virtually ubiquitous (Bhattacherjee et al., 2018; Venkatesh & Bala, 2008), and can ultimately result in system under-utilization and poor returns-on-investment, or even implementation failure (Devaraj & Kohli, 2003). Regardless of the fit achieved between technology uncertainty and firm-level IOI, widespread user resistance can undermine ETI performance. Thus, we argue greater levels of user acceptance, particularly when management action reinforces individual PO, TT, and SE, result in higher levels of ETI performance among dimensions of timeliness, cost-effectiveness, and especially functional performance.

Proposition 12: End-user acceptance and use of technology is positively related to ETI performance.

3.4 Implications

Our expanded TAM framework is developed with managerial interventions and TAM determinants theorized to be salient in our AMR-specific context. This is in line with Legris et al.'s (2013) contention that technological, organizational, and social factors must be considered to maximize TAM's effectiveness in predicting acceptance and use. Moreover, we link individual and organizational perspectives to show how ETI performance (an organizational-level outcome) is logically related to user acceptance and employment of technology. We make conceptual arguments indicating managerial action has profound effects on individual cognition influencing greater user acceptance, and ultimately positive AMR ETI outcomes. The major implications of these arguments are described in detail in the following section.

3.4.1 Firm-Level ETI Outcomes as a Consequence of Individual-Level User Acceptance

When considering integration of autonomous, intelligent, and highly interactive technology that users are expected to collaborate with to perform essential tasks, we found traditional ETI models neglecting the central role of users inadequate. From an organizational ETI perspective, the degree which customer and supplier firm interaction are tailored to technology uncertainty explains variation in ETI project performance. However, we argue the "fit" between these two constructs is trivial if users refuse to use or appropriate the technology.

By modifying IOI to include direct supplier interaction with end-users, we show how higher levels of IOI can engender higher levels of TT and SE. Furthermore, when managers include users as participants and central stakeholders early in ETI projects, not only are TT and SE positively influenced, but PO increases. We argue TT, SE, and PO are important determinants of TAM in our AMR-centric framework, and that managerial action can directly influence these determinants. Therefore, we forward an integrated ETI-TAM framework, emphasizing the importance of user acceptance to ETI performance while acknowledging managerial influence on the cognitive determinants of TAM (see Figure 3.6).

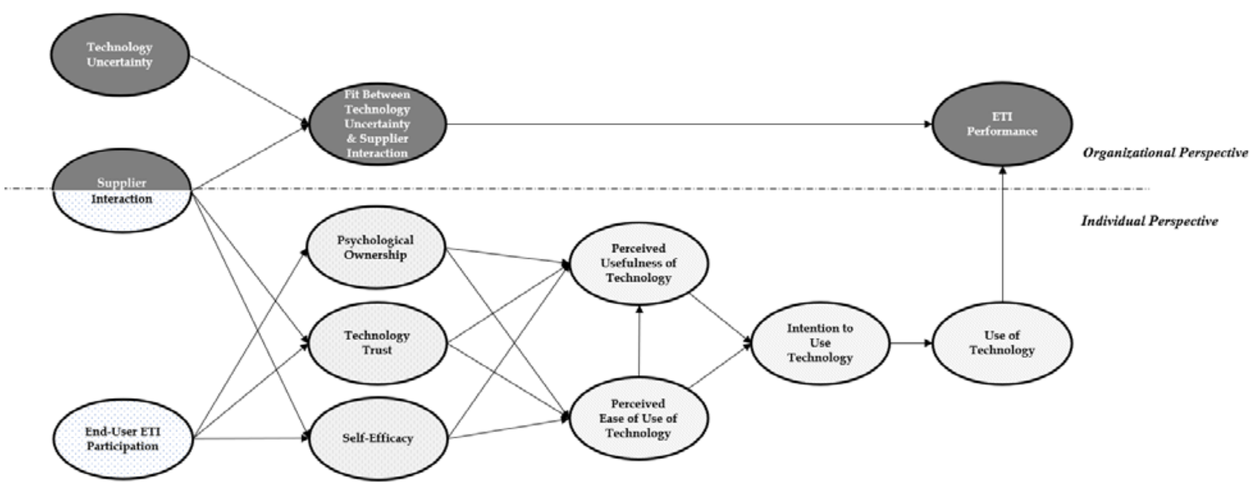

Figure 3.6: Integrated ETI/TAM framework

3.4.2 Central Role of Users in AMR External Technology Integration Projects

From an ETI perspective, recognizing sources of technology uncertainty and how they manifest themselves during ETI execution is critical in understanding how to mitigate uncertainty. Yet, it is not just the source, but also the destination of uncertainty that can be important. We argue, as a new class of AI-enabled, autonomous technology, AMRs catalyze more uncertainty among users, and less among firm-level entities (i.e. management or industrial engineering). This represents a fundamentally different challenge for integrating firms compared to traditional warehouse automation.

Traditionally, automation and human operators functioned in segregated environments, typically resulting in a single point of interface where items or tasks are handed-off. In this sense, uncertainty during traditional integration projects is most salient at the organizational-level, as firms are responsible for a host of integration tasks including process re-engineering, infrastructure modification, and IT integration. In contrast, uncertainty at the user-level is low as interaction is limited and simple. AMR integration differs significantly from this conventional process. AMRs are designed to be flexible and scalable, which minimizes the need for organizations to make extensive infrastructure and process modifications. AMRs' ability to adapt and operate within existing warehousing structures minimizes uncertainty inherent in firm-level design and planning phases. However, AMRs leverage additional uncertainty on users. Frequent and intense interaction introduces role ambiguity in newly created collaborative tasks and the requirement to understand and cope with behavior of autonomous robots functioning in shared workspaces. Thus, AMRs diverge from traditional warehouse automation as uncertainty is more salient for end-users and less so at the organizational-level (see Figure 3.7).

Considering this divergence, our framework emphasizes user acceptance's impact on ETI performance. Supplier interaction with users and user participation in ETIs likely produces user information processing capacity, enhancing organizations' overall ability to deal with uncertainty during ETI project execution. Prior ETI frameworks emphasize technology uncertainty, but we suggest ETI is a process-centric, rather than technology-centric, task. As process experts, users should retain a central role in ETI, as their contributions will have an outsized impact on the project's success during integration and beyond.

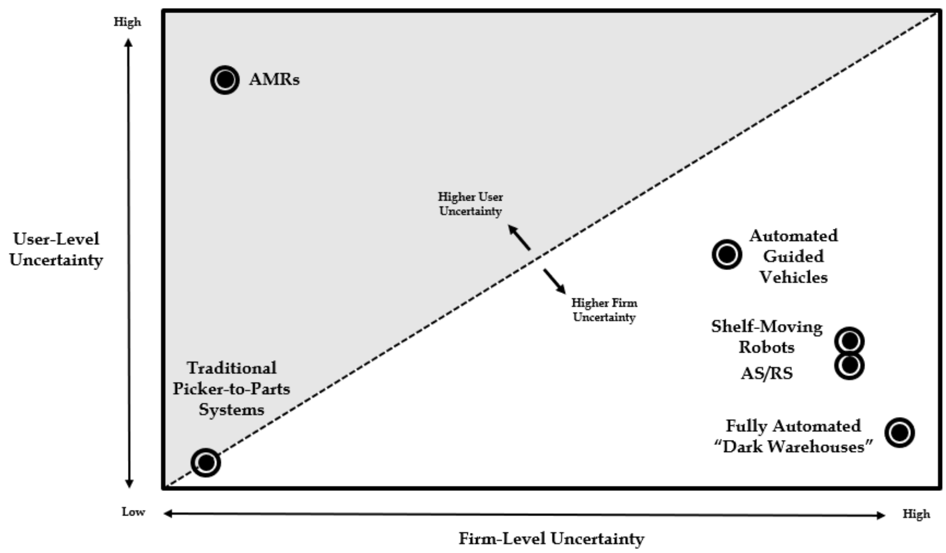

Figure 3.7: Warehouse automation on a dual-spectrum of user-level and firm-level technology uncertainty

3.4.3 Management's Role in Influencing User Acceptance

We establish supplier interaction directly with users may increase TT and SE, but these interactions do not happen organically without permission and facilitation from recipient firm management. These exchanges provide the technical knowledge users require, and the tactical process knowledge suppliers require, to maximize the potential of AMR deployments. By establishing formal coordination and control mechanisms facilitating rich knowledge exchange, management allows users and suppliers to cultivate shared conceptions of problems and co-develop solutions enhancing user PEOU and PU.

In addition, management inclusion of users as early participants in ETI planning and execution enables users to shape future tasks and interactions with AMRs, giving them a stake in the success or failure of projects. By sharing control and allowing users to influence project outcomes, management effectively shares ownership in the project. As users appropriate AMRs and develop a sense of PO, perceived competence and confidence in use increases, resulting in increased acceptance, use, and ETI performance.

3.5 Conclusion

Firms seeking competitive advantage would be wise to pursue technology as a means to increase operational efficiency and effectiveness, however they must also understand the process of integration is non-trivial and can be impactful in determining the long-term efficacy of a technological solution. ETI frameworks firmly establish IOI as an effective counterbalance when confronting technology uncertainty during ETI projects; however, we argue in the case of collaborative, interactive technology like AMRs, users must feature prominently in the ETI process if ETI success is to be achieved. If firms wish to achieve operational-level ETI performance, management must understand how tactical-level intervention can positively influence individual acceptance and use behavior. Integrating firm- and individual-perspectives of AMR integration through the lenses of ETI and TAM frameworks explains how firms pursuing positive individual adoption outcomes increases the likelihood of achieving positive organizational outcomes when adopting technology.

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FINAL CONCLUSION

AMRs can be a transformative intralogistics technology, but only if firms can effectively integrate them into their operations. Dissimilar to many traditional forms of automation, AMR performance is mostly contingent on operators' ability to collaborate in task execution. AMRs provide a possible glimpse into the future of WDC operations, characterized by mixed environments optimizing capabilities of humans and robots as they cooperatively operate in dynamic, shared environments. For firms to achieve integration success, they must understand inevitable uncertainty they encounter in the ETI process, and develop strategies to overcome both human and technological challenges.

In Essay 1, we sought to understand these challenges and solutions through an abductive approach extending logic founded in the theories of OIPT and ETI. In this essay, a new framework of ETI was developed based on the novel and complex context of AMR ETI in WDC operations. An explication of several types of uncertainty, coordination and control mechanisms, and organizational adaptation during AMR ETIs shed light on how firms cope with uncertainty by tailoring information processing capacity to "fit" uncertain situations, and achieve superior ETI performance.

The richness of qualitative findings in Essay 1 uncovered AMR integration as a multifaceted phenomenon, with technology, project, and task complexity producing variability in uncertainty and ETI outcomes. In lieu of this complexity, Essay 2 builds upon Essay 1 by employing GT methodology to emerge important concepts explaining this variability, and how exchange of knowledge between key stakeholders in various phases of ETI is critical to overcoming uncertainty. One of these key stakeholders, AMR end-users, emerged as central to ensuring ETI success. The study found AMRs requiring active and physical human collaboration emphasizes ensuring user buy-in and ownership through open KE when integrating AMRs.

Finally, building on findings in Essay 1 and Essay 2, Essay 3 develops an integrated ETI-TAM framework conceptually developing relationships between managerial interventions, cognitive determinants of TAM, and TAM constructs' influence on AMR ETI performance. The emphasis on user acceptance is reinforced by the notion that "fit" in an ETI context is irrelevant to performance if users resist use or refuse to appropriate AMRs. By considering technological, organizational, and social factors relevant in AMR warehouse integration, Essay 3 illuminates managerial actions and TAM determinates specifically salient in an AMR ETI context, giving managers the tools to positively influence user acceptance, and ultimately enhance ETI outcomes.

Collectively, the three essays in this dissertation provide a foundation for future research examining the impact of collaborative technologies in intralogistics applications and strategies for maximizing their effectiveness. In particular, this dissertation provides empirical evidence the process of integrating AMRs into warehousing operations is non-trivial and can be impactful in determining long-term efficacy. Moreover, these essays emphasize unique challenges users encounter when integrating collaborative, autonomous technology, underscoring AMR integration as a phenomenon rife with both technological and human challenges. Together, these essays contribute by offering insight into AMR ETI uncertainty, organizational strategies for overcoming uncertainty, and managerial interventions increasing user acceptance and ETI performance. As technology and artificial intelligence continue to increase in sophistication and application, understanding autonomous, collaborative technology's (i.e. AMRs) ground-breaking approach to enhancing human potential will take on increased importance, as these technologies enable new opportunities to develop more effective and efficient intralogistics processes, enhancing firms' supply chain competitiveness.